CHALMERS
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Development and Implementation of Robotics in Construction

A Case Study of a Contractor Firm

Master's thesis in Architecture and Civil Engineering

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Master's Thesis ACEX30-18-51
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ABSTRACT

The construction industry lacks behind other industries in applying advanced technologies like robotics. There is a growing demand on implementing robots in the construction activities which are described as time and cost consuming, and hard for the human being to handle, but there are obstacles that hinder this implementation and push back towards using conventional methods in constructing. The purpose of this research is to investigate the barriers that prevent the robotics from being used widely in the construction activities, and provide relevant proposals that helps facilitating robots on construction sites. Since information management and change management are the two main facilitators that the construction industry lacks comparing to other industries, a further attention is given to these aspects in order to make the construction organisations more open for robotisation. Semi-structured interviews are used to derive qualitative data that help understand, analyse and enhance this research. BIM and The robot oriented design are found to play essential roles when employing robotics. This study answers questions regarding what to improve and how to improve it in order to serve the mentioned purpose of this research. Further studies are needed to establish a full understanding of other relevant subjects like the change in the supply chain, the business model and logistics which will be needed for robotics implementation.

Key words:
Construction robots, Information management, Change management, Robotisation, Robot oriented design.

Utveckling och implementering av robotter i byggande

Examensarbete inom masterprogrammet Master' Internationellt projekt ledning & design och byggnads projekt ledning

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I should admit that I owe my family a lot for all the love and support they have showed. Belonging to this family keeps me warm in the cold and dark of the Nordic area and all over the world.

My fiancé, the princess of my life and my lovely future wife, who has been very supportive and patient regarding my absence and being busy with my work and study, thank you and I promise to compensate all of the missed time with a much more magnificent and marvelous time.

Unfortunately, at the time I am writing my words, Al-Yarmouk camp for the Palestinian refugees in Damascus Syria, where I born and grew up, is being plundered, after it has been destroyed and turned into ruins and ashes. I hope I will be able to use the experience and knowledge I have got out of my study to help building it again.

The main inspiration and motivation behind doing my master has been my lovely country Palestine, unfortunately, we are still under occupation. However, one day this occupation will be terminated and blown with the wind, no doubts, when that time comes, we will build it to be the most beautiful, developed and advanced country in the world, we will be equipped with the knowledge, faith and willingness. That is what I have learned from the great Palestinian engineers, who has formed my conscious and ambition, especially the Palestinian president Yasser Arafat, the Founders of the Consolidated Contractors International Company (CCIC) Mr. Haseeb Al-Sabbagh and Mr. Saed Khoury, may their souls all rest in peace, I promise them to continue their journey and make their dream comes true. Palestine will be a free independent state with its capital Jerusalem and all Palestinian refugees back to their original homes and lands.

From the bottom of my heart thanks to Sweden, that has hosted me as a refugee and given me all the chances and opportunities to build a new life and better future. Today I am a Swedish citizen and hold this country and its people in my heart as my homeland Palestine and Syria where I lived most of my life.

Issa Balchi
25th May 2018 Stockholm Sweden

Contents

Preface

This study investigates the utilization of robotics in the construction activities with the use of a case study of a contractor company. The company is developing a rebar-cages-robot project and studying how to employ it in its construction sites. The study has been carried out from January to June 2018 as a 30-credits master thesis for Construction Project Management Programme. The master thesis is conducted in the Department of Architecture and Civil Engineering at Chalmers University of Technology.

As the authors of this work we would like to thank our supervisor Petra Bosch for her valuable time and effort dedicated for this research. We would like to thank also the interviewees in The Contractor Firm and the Development Centre, which assisted us with valuable input that help enhancing this study.

1- Introduction

The construction industry is a massive prevalent industry (Kamaruddin et al., 2016), and can be one of the domestic economy pillars (Egan, 1998) that contributes to about 7% of the GDP in the industrialised countries (Balaguer & Abderrahim, 2008). Clough et al. (2000) see that thriving in construction is usually associated to national prosperity. Many features of the construction industry are identified by Abdul-Aziz & Mohmad (2010) and include the involvement of a huge number of stakeholders with different interests and backgrounds, distributed over different processes and phases. All of that makes the industry very complex. Moreover, the construction, unlike most of other industries, has a one-time product focus, as projects differ by nature, location, risks, budget, design, and stakeholders. All of that leads to temporary organisations being dismantled after project completion. The project organisation, with a few exceptions, still performs with the traditional over-the-wall syndrome (Evbuomwan & Anumba, 1998), where each discipline works in a professional silo and the output of the previous discipline forms an input for the next discipline that interprets the inputs according to its own understanding away from the creator of this input. All of that makes the construction efficiency a questionable topic (Latham, 1994. Egan, 1998. Fairclough, 2002).
With the rapid growth of the population worldwide and the dramatic increase of the demand for resources, the efficiency in any industry becomes an obligatory aspect, that does not only provide an environmental value but a competitive advantage as well (Reinhardt, 1999), where the final products are delivered with the minimum amount of energy and material. Achieving this type of process efficiency can be done through the use of advanced technologies that have been used in the recent years (Bock, 2015).
Automation and robotisation are two relevant subjects when studying the utilization of advanced technologies in construction. A general definition of automation is the replacement of human labour by machinery that is automatically or remotely controlled. The term *construction automation* refers to both the automation of physical aspects of construction processes like robotics, and the information processing in construction like using computers for estimating, scheduling and computer-aided design activities (Demsetz, 1990). The robot institute of America has defined a robot as *"reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialized devices, through variable programmed motions for the performance of a variety of tasks"* (Barfield, et al., 1995, p.480). This definition of a robot categorizes it under the physical applications of automation which is the focus of this study.
However, the construction seems to lag behind other industries in taking advantage of automation and robotisation and its productivity declines over the time. Japan Federation of Construction Contractors (2012) finds that the construction industry was more productive than the manufacturing industry before 1992. After 1992, the manufacturing industry has employed the robotics and automation solutions to enhance its productivity, increase the efficiency and move towards mass production, while the construction industry has kept performing in the same conventional and expensive way. This way has resulted in the decline in the construction productivity over the time (Pachon, 2012).
The need for an innovative construction method that reduces the cost and time of the projects and increases the quality and safety, is the inspiration for this research, and employing robots could be the tool to achieve the stated objectives. Using robots helps the automated execution of the basic and essential part of the activities without the need for human interaction.
The technology is available and it works well for the other industries, but it has not been really employed in the construction industry. Previous studies about employing the robotic solution in the construction industry have focused on the technical aspects, while the managerial field, which is essential to make strategic decision and implement this technology, has not been studied deeply so far (Bock, 2015). This paper focuses on the information management, as acquiring, creating, controlling and sharing the information are the cornerstone for creating the knowledge required to operate and use this technology effectively. Additionally, the paper examines if information type and structure for executing the work by robots is different from those required to execute the work in a conventional way.

Furthermore, it is relevant to manage the change in the processes and the people's behaviour in order to reduce resistance, increase acceptance and organise the processes to fit with the new technology and produce the information required by the robot to do the job.

1.1 Aim of the study

Automation and robotics have proven their efficiency and capability to move any industry to a new level and minimizing its waste while maximizing its productivity. In addition, the adaption of these technologies improves the safety in the construction industry (Pachon, 2012). Although construction employs some of the automation and robotic technologies in the prefabrication yards mostly, it is still facing obstacles to take advantage of this technology and adapt it to the full scale in the on-site construction projects. In this paper, we are studying robotics in construction from a managerial perspective. Since implementation of robotic solutions will require intense information and change management to get the expected benefits out of them, we focus our research in this direction.

The main research question this paper is trying to answer is the following:

- How could Robotisation improve the construction industry on-site through information and change management?

In order to answer the main question, further sub-questions are provided to break down the scope and direct the research.

RQ1- What are the impacts of adapting robotics on the construction site?

RQ2- What are the main hinders for the adoption of robotics technology in the construction industry?

RQ3-What is the role of information management in employing robotics in construction?

RQ4-How to implement the robotisation required changes in a contractor firm?

For this purpose, a wide-range literature review has been conducted from different disciplines, with paying attention to the special properties of the on-site construction.

1.2 Delimitation

Robotics is a new topic in the construction. Although it is very interesting to study extensively, due to the time and resource limitation, the research is not aiming to draw a path for a full automated construction site. Instead, it revolves around facilitating the adoption of a Single Task Construction Robot (STCR) and spread robotic solutions within a contractor firm. For this purpose, one construction company that is trying to introduce robots to its sites has been investigated.

Moreover, one single activity is going to be studied and analysed, namely the fabrication of the reinforcement cages. The change in the supply chain and the material is out of the scope of this study, although it is essential and could help in overcoming some of the obstacles that hinder the full adoption of the proposed technology on site.

1.3 Structure of the thesis

This study is organised and structured in different chapters. Chapter two is talking about the construction industry and its need for a technology, like the robots technology with the benefits that this technology provides and the hindrance for its adoption in the construction. Chapter three describes the managing of the information that is required to execute the job using the robots. Chapter four focuses on how to manage the change that is caused by implementing such a technology in order to get the expected results. The description of the methodological parts and how this research is conducted exists in the chapter five, while the case study is in chapter six. Chapter seven and eight are assigned for the empirical finding and the discussion part to analyse the empirical findings in the light of the theoretical framework in the early chapters. Finally, the recommendations out of this study and the final conclusion are listed in chapters nine and ten respectively.

2- Introducing robots technology to construction

Key indicators regarding productivity, quality, safety, and defects prove that the conventional construction method has reached its limit and highlight the need for new construction methods that can open new doors (Bock, 2015). In the recent years, construction has imitated the lean concept from the automotive industry after noticing the efficiency that the automotive industry could reach from implementing the lean philosophy in their process. Minimizing waste and creating value for customers in the automotive industry has not been achieved only by analysing the manufacturing processes and removing the waste, but through the adoption of the automation solution and robots, which helps in opening the mass production door for this industry (Karabegović, 2016). The International Federation of Robotics has reported the automotive industry as the major employer of the robotic technology by consuming 35% of the total supply of this technology during 2016 followed by the electric/ electronic industry by 31% (IFR, 2017). The *Figure 1.1* shows the supplied industrial robots between 2014 and 2016 segmented by the industry.

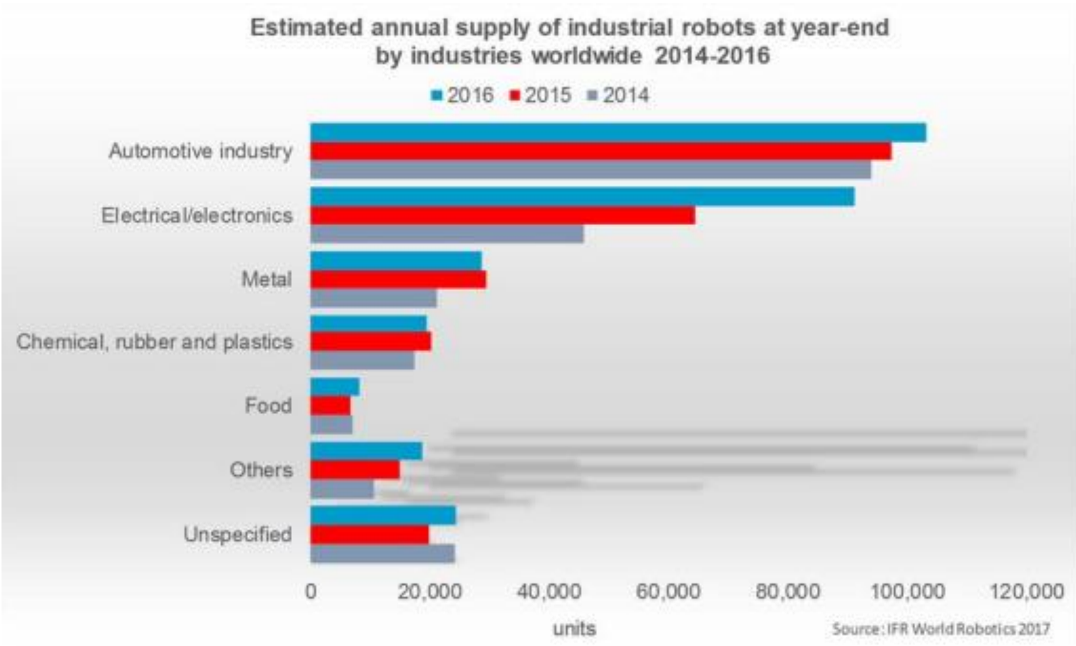

Figure 1.1 Robotic technology in various industries years 2014, 2015 & 2016. (IFR, 2017, p19).

The previous figure shows the absence of the construction industry due to the small and non-recognizable amount of robotisation. The Japanese Obayashi Corporation, one of the leader organisations in adapting and developing the robotized site construction solutions, has found that *" 82% of the all high-rise structures authorised by the Building Centre of Japan over the period from 1986 to 1995 could be constructed using the BIG Canopy automated solution"* (Pachon, 2012, p.4), which is a high automated construction system that uses advanced cranes and a material management system to manage the flow of materials and components (Wakisaka et al. 2000). The technology of automation and robotics, which can be called the fourth industrial revolution (Manzo et al., 2018), can present a lot of the chances to the construction sector. However, implementing such a technology will result in organisational and functional changes. Without understanding these changes it is impossible to get the potential results of adopting such technology and we will end up executing in the same conventional way using fancy machines, and not getting the ultimate benefits out of them. (Moniz & Krings, 2016).

Moreover, identifying the benefits and barriers can help in unifying the vision about the robotisation, its future, expected results and potential targets, which is essential for creating a shared vision that is crucial for the success of any project (Roberts, 2012), It will also promote the importance of implementing such technology on site.

2.1 Benefits of using robots in construction

The technical development of automation proved itself as a major driver for success in most industries. But since automation is costly and has a lot of barriers when introducing it to the construction industry, researchers tried to balance its benefits against its cost, which requires further investigation of the prospective benefits of implementing such a change. Löfgren (2006) focused on the financial and tangible aspects of technology in construction since it is approached as an investment that needs to be analysed. So, he proposed measures of the benefits acquired from technology as following (based on Grembergen, 2000):

• Operational excellence, which measures to what extent the technology is able to improve the existing internal processes in the organisation, and how much this improvement will reduce the time and cost needed to deliver tasks in the construction industry (efficiency perspective).

• User orientation, which measures the value achieved by technology for the end users. This measure focuses on the utility and usability of the end product (effectiveness perspective).

• Business contribution, which is increasing the financial value of business activities and management (effectiveness perspective).

• Future orientation, where the attention is brought to the technological innovation and learning, enabling development of business and organisation (performance perspective).

Those tangible benefits of technology in the construction industry could measure the direct benefits of introducing robotics to the construction sites. From the efficiency perspective, the replacement of labour with robotics on construction sites could be costly, especially in the initiating phase, but the right use of robotics on-site help to reduce the labour cost, which is one of the major costs in the construction industry (Kim et al., 2010). The cost of the human resources is between 30-50% of the total project cost of any construction project (Dabirian et al., 2016). Additionally, robots could work under a wider range of circumstances than humans can do (Balaguer, 2000), this attribute of continuity and stability in the fluctuated construction environment helps to save time, which reflects positively on the cost saving. On the effectiveness perspective, automating the construction sites helps to reduce the human errors and provide a manufacturing type of controlled industry where the focus is placed on developing the quality of the end product (Kim et al., 2010). Performance-wise, automating the industry helps having an ongoing record of the construction process, problems and solutions, which eases the decision making for the management and enhances the continuous development of the industry (Henderson & Ruikar, 2010).

Nonetheless, Löfgren's approach of measuring the technological benefits in construction was described by Henderson & Ruikar (2010) as "direct" financially oriented and "hard" tangibly focused. On the other hand, the industry showed more attention to a wider range of benefits, which are "Identified for each technological proposal, including financial, efficiency, functional, informational, direct, indirect, short-term, long-term, internal and in some instances, inter-organisational, cultural and even potential benefits." (Henderson & Ruikar, 2010, p.12). Those aspects bring the attention to other unquantifiable benefits, which might be more important for organisations than the financially based evaluations like return on investment.

The construction industry is one of the most dangerous industries, the risk for the workers' death in the construction industry is about three times higher than the average of all industries(Sorock et al., 1993; Tallberg et al., 1993). Using robotics in such a hard work environment will decrease the need for human interaction in high-risk activities, which decreases the rate of injuries on-sites and provides higher safety standards (Demsetz, L., 1990). Additionally, having programmed robotics on-site decreases human errors, which leaves us with a more controlled work environment (Kitahara & Takashi, 2006). Demsetz (1990) believes that the major benefit of automation in construction could be the improvement of safety. Additionally, to the help of reducing labour in hazardous environment activities, the use of machines in tasks that need repetitive motion could reduce the incidence of cumulative trauma disorder, which is increasingly a frequent cause for workman's compensation claim. This increase in safety will reflect positively on the cost of the projects since six percent of the total project cost is due to construction accidents (Tucker, 1988).

2.2 Barriers

Implementing technologies in the construction industry has faced some obstacles. In order to achieve the full potential of the technology in this field, researchers strive to identify and analyse those obstacles and propose recommendations to overcome them. Henderson & Ruikar (2010) state that there has been a tendency to blame the technology itself when desired results were not achieved, this could be combined with the high degree of fragmentation that the industry has. Anumba &Ruikar (2002) and Skibniewski & Nitithamyong (2004) highlight the barrier of fragmentation as an important obstacle that hinders the uptake of new technologies in construction, this lack of unity and multidisciplinary character makes it too complicated to automate the construction processes.

Stewart et al. (2004) tried to analyse and systemize the barriers of implementing technology in construction. In order to do so, they collected those barriers from a wide range of literature and listed the most relevant barriers, and then categorized them into three discrete levels: industry, organisation, and project, see *Figure 2.1*. The literature pointed out that the barriers on the industry level are more linked to the competitive and fragmented nature of the industry. Where the project level's barriers are linked to the lack of planning and the aiding of technologies in the project, together with focusing on high return on investment from the first project, which creates resistance and fear of change caused by the uncertainty and fear to achieve the potential results of the project and the investment in new technology.

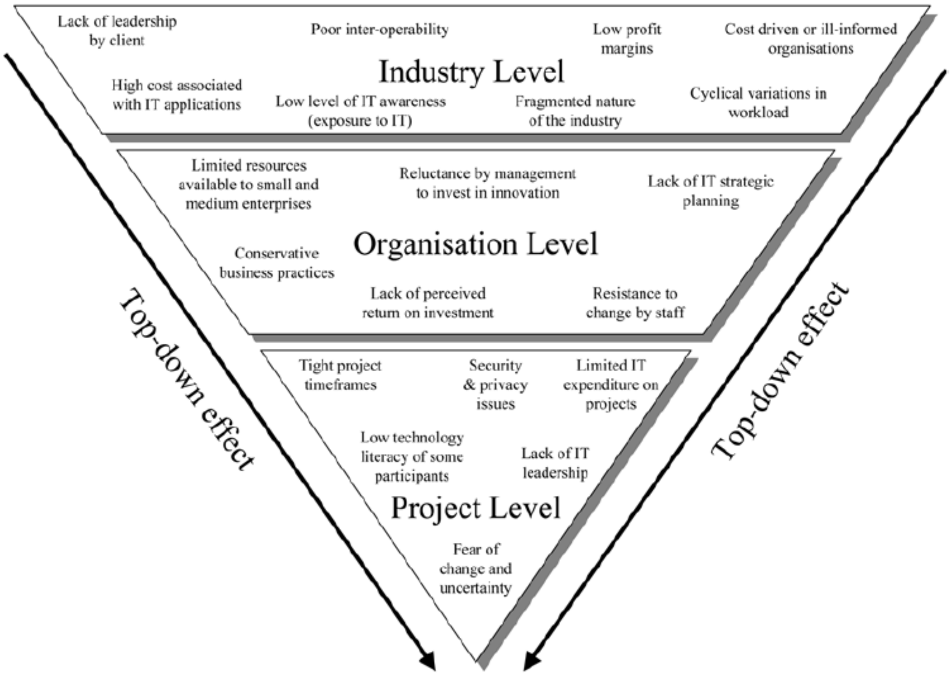

Figure 2.1 *Technology implementation barriers (Stewart et al., 2004, P.157).*

Since those obstacles have different degrees of impact on the construction industry, it is necessary to rank them and highlight the most significant ones in order to prioritize solutions that deal with those barriers.

The barriers of implementing robotics and automation in the construction sites could be categorized according to the model provided by Stewart et al. (2004). On the industry level, cost is highlighted as a major obstacle, and introducing robotics in construction could be a heavy investment, especially in the initiating phases were high cost is needed and low progress is achieved (Balaguer, 2000). Another obstacle related to the industry specifications is the harsh work environment in the construction sites, working in open sites makes it more challenging for the technology to adapt with the different weather cases and the uncontrolled circumstances

(Van Gassel, 2005). This challenge collaborates with the one-project oriented character of the construction industry where companies tend to evaluate the return on investment for every project by its own (Stewart et al., 2004). On the organisational level, the resistance to change and lack of planning and commitment pop up as the main obstacles. The construction organisations have a conventional structure and processes for a long time, and implementing automation on a high level might require a change in these processes, which a lot of organisations prefer to avoid. On the project level, obstacles related to the lack of awareness of the technology arise (Balaguer, 2000), especially with the fast development of the available technology, which enlarges some barriers like the security and privacy issues. Robotics and automation systems are working according to a system and data input, and the risk of a cyber breach together with the low awareness of technology push the decision makers back when such an initiative is proposed (Kaivo-oja et al., 2016).

3- Organisational learning and information management

Learning within the organisations plays a major role in organisation sustainability (Smith, 2012), where the organisation can survive in vital business environments, adapt and even make business out of it sometimes. Huber (1991) identifies four major components of the organisational learning: Knowledge acquisition, information distribution, information interpretation, and organisational memory.

- Knowledge acquisition: acquiring the knowledge and information within the organisation can be done through formal activities, like analysing competitors' and customers' behaviour, surveys, research and development and performance evaluation or through informal activities like reading.
- Information distribution: the distribution of the information helps in creating some kind of learning through combining the information that is shared from different departments and units. Also, when this information is shared and distributed within the organisation, it helps the organisation to realize what they know and how much they know about different topics. Organisations, in general, have a problem of identifying where specific information is located in their systems and structure. However, when the information is widely spread and shared within the organisation, the source numbers for retrieving this information will be doubled many times.
- Information implementation: can be identified as the process of giving meaning to the acquired information, through this interpretation the event is translated and a common understanding is developed (Daft & Weick, 1984). The process of learning is enhanced when the different interpretation is being developed.
- Organisational memory: The human factor as part of the organisational memory is not efficient. However, this problem is way more complex beyond the human factor. The movement of the employees within or out of the organisation cause a great loss of the organisational memory, especially for the information that is not registered. Additionally, the failure of anticipating the future needs cause a great loss of memory as the information is not stored and recorded. If the information that is stored by the different members is not structured according to the organisation standard, this makes it unknown and non-existing, for the other members.

When it comes to robotizing, additional types of information may also need to be acquired like human physical behaviour, can be captured and acquired through sensors, cameras and surveillance technology (Walker, 2016).

The amount of information that is created over the construction project's life cycle is massive. This information is articulated through drawings, documents, contracts, and it would need to be shared and distributed within the project organisation to get the ultimate benefits out of it (Huber, 1991). The Building Information Modelling (BIM) provides an exemplary repository where information can be shared and coordinated between different stakeholders in real time (Eastman et al., 2011). BIM serves as a central repository for sharing and coordinating information between different stakeholders or visualize the final product. In addition, it can play an advanced role when it comes to robotizing through presenting information in digital form that the robot's computer can read, code and transform into actions, or what Walker (2016) calls the machine-logic rules. Additionally, BIM can empower the robots by sharing the information within its context and with additional information that describes and explains the basic project information. Lubas et al. (2013) call this type of data *metadata*. The National Information Standard Organisations (NISO) defines metadata as *"structured information that describes, explains, locates, or otherwise makes it easier to retrieve, use, or manage an information resource"* (NISO, 2004, p. 1). Metadata can help the robot to mimic human behaviour and decision making.

Walker (2016) finds that in order to turn the machines into a smart technology that can simulate human behaviour, we need to create knowledge from the information and data that we have and bear in mind the machine rule-based logic. Institutional theory states that humans are using the three logic paradigms and then they are balancing the messages from those paradigms in order to interpret institutional rules. The first paradigm is the responding literally to the logic rules through the white and black lenses. The second paradigm is using their own understanding for the social norm of the workplace environment in addition to the ethical and professional expectations in order to interpret the rules. The third paradigm is about using the cognitive sense to understand the implication of the rules and to deal pragmatically with the different paradoxes (Scott, 2003). Integrating this human learning approach with the enormous advancement in the computer science, especially in storing and processing capacity, enable the machines to make decisions and mimic human behaviour (Walker, 2016). In the construction industry, this means collecting information and human analysis, and understanding of the project information, structuring and analysing the collected information, using the information to execute the job and finally measuring the performance to evaluate defects and their reasons in order to update the system. This will result in changing in the information management system and a huge amount of data to deal with.

Collecting all the previous information to empower robotisation will result in a large amount of data that brings a lot of opportunities and helps to create in-depth knowledge (Bilal et al., 2016). Accumulating this data from the different disciplines and projects can move the industry into the Big Data era where the normal common software is incapable of capturing, organising and analysing this data in a reasonable time (Waller & Fawcett, 2013). More information about the Big data specification and analysis can be found in the *Appendix I*.

3.1 Virtual Reality (VR) and the design reliability

BIM represents a good repository for data and information in addition to the graphical and visualisation capabilities that it supports. However, Garg & Kamat (2014) suggests that using the Virtual Reality (VR) environment helps in testing the performance and the design virtually before moving forward to the physical execution. They also add that the simulation helps in testing the design and observe any problem in addition to improve the design and remove all the pitfalls. The VR can be used to help in conducting a feasibility study as well before a major investment is committed (Aziz, 2012). The result will be a redundant and sounded design with almost no errors and requires almost no human interpretation during the execution (Choi & Chan, 2004).

The aim of using the VR environment is the achieving of the following two benefits:

- VR can enhance the understanding of the product and facilitate the participation of all the stakeholders (Jayaram et al, 1998).
- VR can provide a collaborative environment through an interactive interfaces (Wang et al, 1999) this can be very helpful in either amending the design, programming the robot or providing any other alternative.
- The VR can provide an effective tool for evaluating the change, and enhance a better decision making.
- A better safety can be achieved as the VR environment can show the required working space for the robot to execute the job, which helps in planning the site logistics.

The amount of information created during the simulation have a very high value and can enrich the data centre if it is saved in a structure way. It can shorten the time, cost and efforts required in the future for creating a design that is more buildable and can be executed by the robots.

4- Change management

The construction industry proved itself as one of the most resistant to change industries in the market. When looking at the construction projects nowadays, we do not see a big change in the processes and tools used in construction for a long time. The construction methods almost reached their limits in achieving higher performance, and there has been no significant development achieved for decades Bock (2015). In order to push the construction industry forward and implement automated construction methods, a major change in the structure, processes and culture of the construction industry is required. The S-curves in the *Figure 4.1* illustrate the change needed from Conventional Construction to Automated Construction in order to raise the performance of construction.

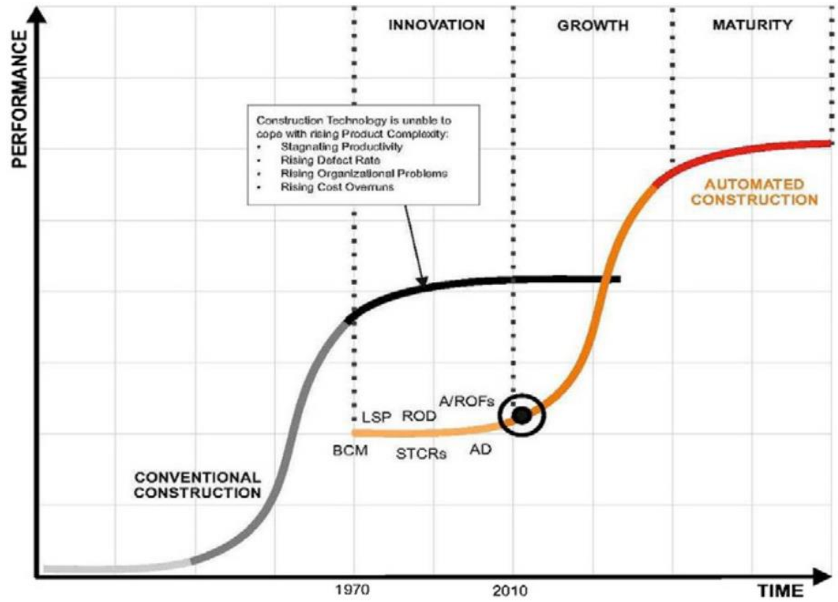

Figure 4.1. Foster's (1986) S-curves applied to future development of construction industry and technology (Bock, 2015, p.142) Drawing by (B. Georgescu, Chair of Building Realization and Robotics).

Turner (2014) describes the evaluation of people's focus when implementing the technical changes. In the mid-1980s people focused on technical changes believing that organisational changes will follow automatically or they are not required at all. Gradually, people started to understand the necessity of the organisational, strategic and cultural changes which should be the main focus and the technical changes are merely somethings that facilitate the change.

4.1 Strategic change

De Wit and Meyer (2014) state that change is a necessity for organisations and not only a choice and the important part is to know when and how to change. Whereas some changes are considered as normal tuning changes to remain efficient and effective such as upgrading procedures and improving activities, the strategic changes affect the business model or the organisational structure and provide a new alignment that fits out the basic setup of a firm to its environment.

Since firms have a complex system, analysing it into various areas eases the implementing of the potential change for every area separately. The organisational system could be divided into 3 components: organisational structure, organisational processes and organisational culture. The organisational structure refers to dividing tasks and people into small groups to be able to work efficiently and effectively. The organisational processes refer to the regulations and processes that the firm should follow to control and coordinate between people and different divisions (small groups). The organisational culture refers to the behaviour, values and view that is shared between people within the organisation. The *Figure 4.2* illustrates the three components of the organisational system (Ibid).

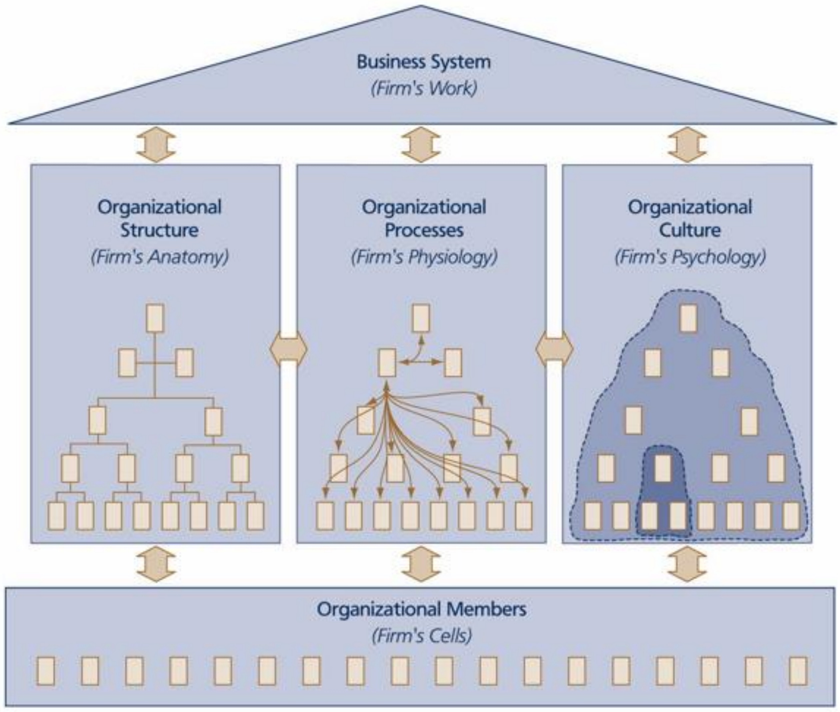

Figure 4.2 Detailed view of the components of the organisational system (De Wit & Meyer, 2014, P387).

To issue the change two important components should be studied, the magnitude and the pace of change. The magnitude of change refers to the scope which is required to be changed and the amplitude which is the size of change. Whereas the pace of change studies when and how fast the change should be made (Ibid). As a result, *"The variables of timing and speed of change, together with the variables of scope and amplitude of change, create a wide range of possible strategic alignment paths"* (de Wit & Meyer, 2014, pp 391).

4.2 Implementing organisational change

After planning a major change such introducing automation and robotics into the construction industry and understanding the parameters of such a change like timing, speed, scope and amplitude, it is important to look into the process of implementing change into the organisation. Tushman & Anderson (1997) believe that the most important factor that impact implementing the change process is "The problem of anxiety". Which is the resistance of change from individuals that are worried about the impact of the change on their position in the organisation, and if their skills will be valued afterwards. The resistant to the change does not need to be direct but the individuals might tend to deal with the change passively with stress and anxiety feelings. Kotter (1995) provides a model of 'eight steps to transforming your organisation'. This model was built after consulting practices with 100 organisations going through change. Kotter highlights the eight key steps to make change happen. The first step is establishing a sense of urgency for the change and showing why the change is important, then forming a group of people who are able to work together to drive the change in the organisation, creating a vision to direct the change and communicating this vision to all levels in the organisation, empowering others and plan to create short-term wins. Finally consolidating improvements and institutionalize new approaches. Cameron & Green (2009) analyse Kotter's steps as a burst of energy in the beginning with words like 'urgency', 'power' and 'vision'. Then more of planning and managing and finally accommodating the change. Additionally, they prefer to apply the change process as a continuous cycle instead of a linear progression, as shown in the *Figure 4.3*.

Figure 4.3 Cycle of change (Cameron & Green, 2009) adopted from Cameron Change Consultancy Ltd.

The construction industry is described as a project-based industry (Stewart et al., 2004), where a lot of decisions are made on project-to-project basis which appears more in smaller construction companies (bock, 2015). As a result, in order to drive the technological change in construction a further attention should be given to managing change in project-based organisations. Turner (2014) defines the project as a temporary organisation where resources are assigned to deliver beneficial change and this temporary organisation is disbanded when the new state is achieved. Projects are described as an effective way of managing change, they can deliver change in a fast and flexible way and they can be used to prototype new ways of working. The projects work under a sense of urgency and uncertainty so they need to have a strong but flexible plan to coordinate their efforts. After having a goal-oriented plan some basic processes are needed to implement a change in the project-based organisations, which are organising the resources, implementing by assigning work to people, controlling and managing the progress. One of the major keys of driving change in project-based organisation is the good corporate governance which ensures a strong link between the corporate strategy and the project objectives and has a clear ownership from senior management. Additionally, the corporate governance should assure a good engagement with stakeholders, have an organisational capabilities and evaluate the project proposals based on their value to the organisation, not their capital cost (Ibid).

Another key factor of driving change in project-based organisations is managing the stakeholders. People react to change in different ways, depending on the level of change in organisation. Immediate changes in organisations are often faced with resistance, so changes should be introduced carefully by getting people to understand the benefits of change and know that it will not unduly affect their position in the organisation. The emotional intelligence that aims to build a relationship with stakeholders and influence them is a significant competence for the project leaders and it has the greatest contribution to the project success. The stakeholders' engagement process starts with defining the stakeholders and their interest, developing a persuasion strategy and a communication plan, monitoring the response of the stakeholders and finally, making changes to the strategy if necessary (Turner, 2014).

4.3 Cultural change

The organisational culture can be defined as *"The set of values, beliefs and social norms which tend to be shared by its members and, in turn, influence their thoughts and actions"*. (Flamholtz et al., 1985, p.158). This definition shows the importance of the organisational culture as an intrinsic factor which affects how individuals think, react and behave. As a result, the change in the culture is one of the main drivers to introduce change to the organisation. Erez & Gati (2004) and Leung et al. (2006) provide a multilevel model for the culture which starts with the Global level then National, Organisational, Group and finally Individual level of culture. This approach provides a better understanding of the multi-level structure of culture, and how those levels interact with each other, which is called the dynamics of culture. The formation of culture could be influenced by a top-down and a bottom-up processes through the multi-levels of culture. The top-down process is when the change comes from a higher level to a lower level which is explained as being dependent on the scope of influence from the higher level. A bottom-up process is the transmission of effects from a lower to a higher level, which happens when behaviours are shared by the most of the individuals, whereas the higher level adapts to these shared behaviours (Erez & Gati, 2004).

Implementing an advanced technology to the construction industry requires a change in the processes and behaviours on different levels of the industry. This change of culture could require more of a top-down process than a down-up processes. Brown & Malami (2008) provide some tools that managers use to direct their employees' behaviour like planning, cybernetics, rewards and compensations, administrative and culture. According to Brown & Malmi (2008) culture could be used as a control system to direct the behaviour of employees. This might be possible by communicating values and purposes of change with employees which enhance the feeling of commitment to such a change. Another way to control culture might be through implementing a visible expression like a dress code or a motto to develop a particular type of culture, or even creating subcultures within the organisation which have a kind of boundary and exposed to a socialization process like departments and teams. Those three types of cultural controls are used to affect the culture and bring change to an organisation.

4.4 Changing the organisational processes

The processes and practices are the '*Physiology*' of the organisation, so in order to introduce a change like robotics in construction, this physiology needs to be adjusted. *"Organisational processes refer to the arrangements, procedures and routines used to control and coordinate the various people and units within the organisation"* (De Wit & Meyer, 2014, p.389).

Construction and civil projects can be divided into different stages. Each stage has its own time frame and objectives that complement the whole project objectives. At the end of each stage and before moving to the next one a review is conducted for the key decisions and results, followed by evaluation and comparison to specific criteria to evaluate if the project can move to the next stage or not (Zerjav & Ceric, 2009).

One important challenge for implementing robotics is the designing and developing of multimodal communication frameworks that aspire to simplify the programming process of complex tasks (Jasanoff, 2006). Enabling technologies that are important for implementing the construction automation require developing the robot-oriented design (ROD), which helps adapting construction products and processes to the robotic technology. This adaptation in the design makes the robotics simpler and more efficient. The concept of ROD is used in the automated construction sector and developed to adjust the conventional processes to the needs of the new technologies (Bock & Linner, 2015). As a result, it would be easier for the robot to understand and handle the information which is produced during the design and preparation stage, additionally, understanding and interpreting the changes.

Making the decision at an early stage of the project life cycle will help to evaluate the benefits and chances of using the robotic technology and compare it to the other alternatives (Pachon, 2012). Involvement of the technology producers and the suppliers will help in developing the best procurement practice and to articulate the type, quality, quantity of the data and how it should be delivered and stored from the stakeholders in order to carry out the job using the robots.

5- Methodological outline

5.1 Research approach

This study tries to provide possible proposals to ease the implementation of robotics in construction sites, in order to do so, it investigates and analyses the most relevant obstacles that hinder this implementation. The focus of this study is on two related aspects. First, the role of information management in employing robotics in construction. Second, managing the required change in a contractor firm in order to facilitate robotics. To inference the best explanation an abductive reasoning has been used. *"Abductive inference, commonly called inference to the best explanation, is reasoning from given data to a hypothesis that explains the data"* Walton (2014, pp. xiii). So, the research tries to review the limited available literature that is related to the managerial aspects of implementing robotics in construction, and then complements the theoretical research with the empirical data to find answers, *"abduction does not move directly from empirical observations to theoretical inferences, as is the case in purely inductive research, but relies heavily on theories as mediators for deriving explanations"* Modell (2009, p. 213). The topic of this study has complex characteristics like the ones related to the human behaviour, beliefs and relationships. Additionally, it tries to identify intangible factors like the social and structural norms of organisations. Hence, a qualitative method could be the most appropriate to understand people from their own frames of reference and experience reality as they experience it (Corbin & Strauss, 2008). The qualitative methodology tends to look beyond the descriptive data collected from written or spoken words and observed behaviour. According to Rist (1977), the qualitative methodology is more than a set of data techniques. It is a way of approaching the empirical world.

5.2 Research design

The robotics in construction is a quite new subject which does not have a wide application yet in the construction industry, very few contractors have tested the robots in construction and very few are working on developing robots to execute some construction activities. In order to collect empirical, input the authors chose to use a single case study to develop a qualitative understanding about this phenomenon. Baxter & Jack (2008) define the case study as a type of qualitative research which widely uses the qualitative approach to provide a detailed description of the case study's definition, classifications, and several advantages and disadvantages. Since the focus in this study is related more to the managerial aspects of implementing robotics in construction, a case study could be an effective method to collect data, *"the case studies have been largely used in the social sciences and have been found to be especially valuable in practice-oriented fields (such as education, management, public administration, and social work*" Baxter & Jack (2008, pp.29).

5.3 Data collection methods

This study uses the semi-structured interviews as tool to collect the qualitative data, Jennifer (2002) believes that the term 'qualitative interviewing' is usually intended to refer in depth to the forms of interviewing that is semi-structured or loosely structured, where open-ended questions are assumed to continue qualitative interviewing. In order to semi-structure the interviews for this study. Each interview was planned to be held in approximately one hour, three set of fixed questions were prepared for three groups of interviewees: the managers, the developers and the consultant. The focus fixed questions were prepared in a way that provides the possibility for asking follow-up questions to direct the interview and focus on issues that seem to be important during the interview, this strategy enhanced the flexibility of the dialogue. Jennifer (2002) believes that the semi-structured interviewing has four common core features: The interracial exchange of dialogue, relatively informal style, a thematic approach, and finally, the interviews operates from the perspective that knowledge is situated and contextual, so the job of the interview is to focus on the relevant contexts so that situated knowledge can be produced.

The rebar-cages robot project is still under development, and currently, there is a working prototype on scale 1 to 4 at the research institute which is being tested and improved, so there is no real implementation for the project on-site, as a result, the data were collected from several interviews with people involved in the project both in the contractor company that is funding the project and the research institute that is developing the robot. Additionally, an interview was arranged with a consultant that works on a project of presenting a blueprint for a completely digital construction process. In the contractor company, three interviews were held with senior managers involved in developing and managing the project, Manager A, B and C. Manager A is working with the research and development division in the contractor company, he works with a small group but a wide network with people working in innovation and he has contacts in each business whom he meets frequently. Manager A has connection with the division in Sweden were they are developing the rebar cages robot, and other connections with automation projects in the organisation. Manager B is a research and development manager in Sweden and he has been working with robotizing the construction activities since 2014, he is one of the people working directly on the rebar cages robot and he focuses on the feasibility of this project and how to build the business model for the implementation phase. Manager C is a Design manager and he is working in the Major Projects division in Sweden where they build bridges and tunnels. He is the one that came up with the idea of rebar cages robot after noticing the high demand on such activity and he is one of the people that has initiated and followed up on this project, he has a valuable knowledge in the connection between the rebar cages robot and the impact on the design phase in the construction process.

A group interview was held with three developers in the research institute and they have been working for a long time with developing industrial robotics. Currently, they are working on developing the rebar cages robot with the help from the contractor company and an engineering company works with robotics, at the same time, they are developing another construction robot which fixes gypsum boards on site. The authors chose to interview the people working on developing the rebar cages robot in order to get a further understanding about the barriers, requirements and achievements of this project. For this reason, an interview was held with Developer A, B and C. Developer A is a Project Manager in engineering company but he is working now with the research institute on the rebar cages robot project, he has knowledge about the technical aspects in robotics and a basic knowledge in building. Developer B is a Research engineer in the research institute. Developer C is a Project Manager and his main focus is software engineering. The interview with the people working on the direct development of the project provides valuable input about the change in processes which is required for implementing robotics in construction and more about the data and information needed to facilitate this change. Additionally, their knowledge of previous experiences from other manufacturing industries and reflecting this knowledge on the construction activities helps utilizing this knowledge and using it to automate the construction activities. Finally, an interview was arranged with a consultant which is working now as a project manager supported with funds from the government to look into the digitalization for the construction industry, the partners of this project are a group of large organisations in Sweden and they represent a turnover of more than $ 10 BN and approximately 20% of all residential development in Sweden. The *Table 5.1* summarizes the interviewees' relation the case study.

Relation	People related to the rebar-cages-robot project		People related to the subject
Organisation	**Contractor firm**	**Research institute**	**Consultancy**
Interviewees	Manager A	Developer A	Consultant A
	Manager B	Developer B	
	Manager C	Developer C	

Table 5.1 The interviewees and their relation to the case study

The interviews that have been held to investigate five main areas in order to collect the data related to this research. The first set of questions are the general questions and they help gaining an overview on the interviewee's background and his\her relation to the subject of robotics in construction, furthermore, to understand the vision of this subject from various point of views. The second set of questions are related to both the barriers and benefits of introducing robots to construction with having a close attention the most relevant barriers in the project level. Additionally, prioritizing these barriers and collecting information about the possible solutions for them. The third set of questions are related to the information management and how it affects and gets affected the implementing of robotics in construction, giving more attention to the type of data needed for this implementation and the right way to collect, share and analyse this data. The fourth set of questions are related to the change in processes that enables the construction robotics, especially the design phase and its relation to robotics application in construction. The last set of questions was intended to gather input about facilitating the change management with the main focus on the required change in the organisational culture and structure to facilitate the implementation of the STCR, if exists.

5.4 Data analysis

Since the major source of data for this study is the interviews and because of the limited amount of available data, an extra attention was given to structure, analyse and compare those interviews. At least one of the authors attended the interview with the managers face-to-face in order to be able to collect non-verbal information. All of the interviews were recorded and transcribed in order to be analysed. Furthermore, the transcripts were coded with the main keywords that represent the main themes of this study which are vision, benefits, barriers, information management, change management and design management. These codes are used to link the collected data and compare it to the theoretical study.

5.5 Validation and trustworthiness

While collecting the data in the interviews, there was a tendency to ask all the managers the same set of questions, and the same strategy with developers. This way helped assuring the validity of the collected data and determining any contradiction. Furthermore, the follow up questions used to clear any contradicted or fluctuated information. When analysing the empirical data, more reliability was given to the information taken from the informants that his position is related more to this information, for instance, further reliability was given to the managerial related data collected from the managers with considering the opinions of consultant and developers.

5.6 Ethics

All of the interviewees were asked in advanced if they confirm the possibility of recording, transcription and publishing the information obtained from the interview, and if it is possible to identity the informant or refer to him/her as an anonymous. Some of the interviewees were positive to use their name and their organisation's name in the research, others preferred to delete the recordings after transcribing the context of the interview. In this research the confidential demands were adhered as required by the informant.

6- Case study

The rebar cages robot is under development by the contractor firm and the research institute with the help from engineering company. The project has been started from the increasing demand on automating the rebar assembling activity in bridges projects which is very time consuming, requires a lot of labour and described as tough work for workers on-site. In order to answer this demand, the contractor firm started this project with a collaboration with the engineering firm to develop a working model in research institute. The project aims to develop a single task robot which is able to produce reinforcement cages on-site starting with the rebars that could be rolled in coils. So the robot station will straighten the rebars and then use the given program in order to cut the bars and bend them. The technology until this level is wide available and used in the construction industry but what makes the project unique is the last process: the rebar station is provided with a three-arms robot that grabs the rebars, assembles them as designed and ties them together. So, the final product will be a ready rebar cage which will be lifted by a crane and fixed in place. Currently, there is a robot prototype on 1 to 4 scale in the research institute. The developers are working for six months to develop a system that is able to translate the BIM model into a program that enables the robot to function automatically. Furthermore, the managers in the contractor firm are trying to find the best application for the robot in the future by connecting it to the business model and dealing with the logistics and managerial issues that enable the use of the robot on site. The case study focuses on the project of the rebar cages robot as a single task robot, looking through the current development stage and the prospective applications of this project. To serve the purpose of this research the attention is given to the information acquisition and sharing, and the change management in the contractor firm which are needed to facilitate the project.

6.1 Robot for the fabrication and assembly of rebar cages

One of the main components of the reinforced concrete is the rebar in this section we are going to investigate how to integrate the robots in the reinforcement activity. The type of the robots that are the main focus of this study, are of those type of Single Task Construction Robots (STCR), where the robots have the capability to execute the major part of a single construction activity, here the activity is the cutting, bending and assembling of the concrete reinforcement rebars, with a minimum or no need for human involvement.

6.1.1 Employing robotics in the reinforcement activities:

The rebar is contributing in about one third of the total cost of the reinforced concrete, of which 30% of this one third is going for labour cost. (Illingworth, 2000). Fabrication and assembly of the rebar cages are both a dangerous and time consuming activity, also the activity requires a very high accuracy in placing the stirrups and bars in their places and uniform concrete covers which are not achieved by doing the job manually (Garg & Kamat, 2014). The productivity and quality are taking a huge size of the current industry focus in order to achieve lean and sustainability. The criteria that differ between any two rebar cages are: Location, geometry, and reinforcement details, which are related to the functionality and the loads applied on the reinforced concrete element, rebar diameter, span and reinforced concrete element's dimensions (Jarkas & Abdulaziz, 2010).

The production of the rebar cages consists of two sub-activities: rebars production and rebar assemblies.

The rebars production is a sample of activities that can be fully automated as it can be produced by bulk quantities. In addition, the rebars are similar with shapes with some difference in diameters dimensions, which makes the production activity more or less a repetitive work, currently there are many available fully automated rebars production lines (Dolinšek & Duhovnik, 1998).

As for the assembly, it is much more difficult to automate as the diameter, amount, shape and dimensions of the reinforcement is changing across the reinforced concrete element (Dolinšek

& Duhovnik, 1998). Moreover, it is more desired that the assembly is being done on site as the transport of assembled rebar cages is volume consuming which can increase the overall cost. The onsite construction activities require the equipment to be weather resistant and handle the harsh working conditions which makes the robots more suitable than the conventional concept of the automated production lines. Other characteristic of the rebar cages is that they continue to the next reinforced elements and overlap with its reinforcements which optimize the use of the intelligence system that the robots provide (Haas et al. 1995).

Design and reinforcement detailing

The decision of using the robot at the early stage, can guide the designer to produce a more buildable design. The aim is not to restrict the designers, instead it will guide them to produce as sophisticated design as possible, however integrate the flexibility and consider the different solution to enables the robotisation of the activity (Dolinšek & Duhovnik, 1998). This could be achieved through the different alternative and buildability consideration.

Buildability is defined as the extent of which the design helps and facilitate an easy construction method within the restrictions of the stakeholders' requirements (CIRIA, 1983). Integrating the robot designers with the stakeholders at the early stage of the project, can increase the buildability and introduce alternatives to overcome the obstacles and limitations to the robot performance.

The design information needs to be well organised and structured, that is easily updated, monitored and transferred to the robot in order to create the required knowledge to execute the work (Santoro et al, 2006). All of that promote the needs for a system like the one proposed by Wilkinson (2005), where all the information is saved in a single repository so it can be shared, coordinated, communicated, controlled and updated. The Building Information Modelling (BIM) provides the previous required environment, in addition to it is capability to save the project information digitally so the robot can understand it (Walker, 2016) and in addition to its graphic and visualization capabilities.

6.2 Collecting and analysing data in rebar robot

The VR environment will help to minimise the mistakes and stream the design. However, this is not enough. The information needs to be collected during and after the activity finishes in order to be compared with the design information and evaluate the deficiencies and the problems that could happen during the execution. Such information collection and analysis of the execution phase represent the last part of the closed loop to empower robotisation and improve the future product (Waehner, 2016).

The previous process can be used to develop the robot, the design or to calibrate the robot as well. The integration of the computational environment could facilitate the real time feedback, where the information can be captured at the time of occurring and actions can be recorded just in time.

This sharing information is essential to create the knowledge required to avoid making the same mistake in the future (Wen & Qiang, 2016).

The information coming from the feedback needs to be shared within its context and not isolated from that.

Tippmann et al. (2013) emphasize the importance of the temporal factors in the learning process when sharing the information, Min & Bjornsson (2008) explain the relation between the information flow and the time factor as follow : the lack of reliable information can mislead the decision makers through non-reliable knowledge, while the excessive flow of the information over a short period of time, out of the human capability to deal with it, will reduce the value of the information as it will not be analysed and used to get benefits out of it.

The rebar cages robot, by sharing the information in real time with the BIM model, compare the production with the design and do verification measures, will produce a huge amount of the data, the computational environment supports the robot to deal with this data and overcome the obstacle of size and time factors.

The later review of the data to evaluate the strengths and the weakness of the whole process from the design till the end, can create the knowledge and gives some hints about the obstacles that have faced the robot and how to cope with them in the future, either through the design conciliation, upgrading the robot, better programming or data analysis for best logic solution and/or developing the construction processes to help in overcoming some of the obstacles.

Through this close loops of collecting, analysing and improving the data (Waehner, 2016) the rebar cages robot should be able to process any future event automatically mimicking the same human's logic.

7- Empirical findings

7.1 Vision about robotics in construction

The expectation of the wide use of the robots in the future construction projects is shared among the interviewees because of the huge benefits that they provide and the available technology that we have today. However, there has been no common vision about how many activities could be robotized and when it could be available. Manager A thinks that about 30% of the construction activities could be automated, while manager B declares that he has not considered this issue. Manager C is the most optimistic about the uptake of automation in construction, and he believes that the construction sites could be fully automated in the future which will take time and effort but still it is possible. The contractor firm is trying, as other construction companies, to investigate the construction industry in order to know what to robotize and how to do it, and there are already PhD and MSc researchers who are investigating this issue right now. Manager C's expectation is that we would be able someday to reach the full robotized construction site and run the work as a video game, this will require apart from the time and effort a new way of thinking and utilizing different skills like the video gamers for instance. The common belief is that we need to start to develop construction robotics in order to move the momentum of change, afterwards it would be easier to implement robots as people will see their benefits. However, this topic is new and there will be no knowledge about all of its barriers until facing them, and after facing the barriers it would be possible to solve them and move forward.

7.2 Barriers and benefits

7.2.1 Barriers

A wide range of barriers that hinder the implementation of robots in construction have been referred to in the interviews. Manager A believes that the biggest obstacles are related to the *lack of resources and budget* that are allocated for R&D and the *lack of governance*. The construction industry is described as project-based, every project has its limited budget and resources, employees are overwhelmed with their work to achieve the project targeted profit with no time left to think about change and innovation. Additionally, a limited budget is allocated for each project, which is evaluated based on its final financial results. According to Manager A "*if there is no budget in the bid for R&D it will not happen*", this short term focus in the construction industry together with being busy dealing with the current problems and challenges hinder the implementation of new innovations in construction like robotisation. Manager A and manager C refer that a *big investment* required to develop this technology, such an investment is hard to be initiated by small companies and subcontractors which are working directly on the construction activities. However, the big companies which are probably the main contractors can afford to invest in such technology but they outsource most of the project activities to specialised subcontractors. Manager A and manager C have an idea that collaboration with subcontractor and helping them to develop robots could be beneficial for both parties, while manager B has insisted that the subcontractors should depend on themselves to develop robotics without the help of the main contractor. Another barrier mentioned by Manager A and manager C is *changing the current processes and mind-set* that has been developed in the construction industry, there is a tendency to underestimate the design phase and start constructing very early with almost a half ready design, this challenge could be one of the most important issues that is needed to be solved to facilitate the use of robotics in construction. Manager B highlights the barrier of *fragmentation* in the construction industry, the business model of the construction industry is complicated and further collaboration and integration between designers, contractors and subcontractors is needed to implement robotics. All of the interviewees believe that the *conventional design process* with incomplete 3D model could be one of the most important barriers that makes it harder to apply robots in the construction sites. The developers see that the *required specifications* for the construction robotics differ from the industrial robotics. Construction robots need the feature of mobility and might demand the ability for handling elements with big volume and weight which puts more payload on the robot. At the same time, the robot will need to be flexible and work in an open environment with humans which can increase the complexity of the safety dimension and/or site logistics. The consultant A believes that there is lack of collected information in the construction industry, especially if we compare it to other manufacturing industries, this could hinder the robotisation in construction. Additionally, the manager C and the consultant A believe that the current *logistics of construction sites* are not prepared for robotics yet, especially that robotics will add complexity for safety on site, having robots and human working in the same open environment could be dangerous and will add further demands.

Barriers for robotising the construction activities		
Industry level	**Organisation level**	**Project level**
Heavy initial investment	Lack of resources allocated for R&D	Low awareness about technology
Fragmentation	Lack of governance	Fear of change
Complicated business model	Resistance to change by staff	Site Logistics
		Safety issues

Table 7.1 Most relevant barriers for the robotisation in construction

7.2.2 Benefits

There has been a common belief that implementing robotics in construction will help *reducing time and cost and increase quality*. Manager A and Manager C highlight that a lot of current construction activities are harsh and unsafe for human beings, and there is always shortage in skills required to carry out those activities as people refrain from doing it. Another benefit could be *covering the shortage of labour* that the construction companies suffer from. Currently, the companies tend to import manpower to cover this shortage but this is not a sustainable solution. Manager A believes that robots are able to do such work and implementing robotics for this kind of work will help solving this problem. However, the managers and the developer B believe that if the robots have been implemented correctly, they can execute the work quickly. This will *shorten the activities' duration and reduce the project lead time* in general, especially if the activities that are on the critical path like reinforcement of the concrete. The consultant A believes that digitalizing the construction activities might enable the construction industry to move toward mass production like other industries. Additionally, the robots could perform work with higher quality. Regarding the rebar cages robot, Manager B believes that it is too early to judge the project since it is under development right now. However, the current results show that it is feasible and its future is related to the ability of creating a successful business model to manage the robotic solution and generate profits out of it.

7.3 Information Acquisition and transferring

7.3.1 Data management during the development process

The robotics technology is available and it is described by Manager A as a commodity which could be bought from any supplier. However, as agreed by all the interviewees, the big challenge is to develop a system that is able to translate the available design data to a workable program which enables the robot to deliver the activity, manager A calls this system "*The black box, which is a translator between the BIM model and the robot studio that steers the robots*". The developers see that lack of standardization in the construction projects enhances this challenge and require a system which is able to generate a different program for each project. The higher demand when talking about the information management and overcoming this challenge was developing a perfect BIM model which has all the required input for robots to function. Both the manager C and the developer C, see a potential benefits of using the visualization tools, their view that the BIM model is great to prepare the design and share the information, however, the virtual reality tools have a great value when using the robots as well, as they help in testing the reliability and buildability of the design virtually, in the computer laboratories, in order to overcome all the pitfalls and facilitate a smooth and efficient execution, before the real physical execution starts on site by the robot.

The developers in the research institute believe that an intensive collaboration is needed between the developers' side and the construction side in order to understand each other and build up a workable system for the robot. Manager C believes that their experiment in the rebar cages robot showed that it is possible to develop such a system, relatively, this system could be developed for other construction activities like excavation for instance. Manager A highlights another issue of missing information because of the project-based attribute of the construction industry. He believes that there is a lot of knowledge developed in the construction projects, but a big part of this knowledge is lost because it is not acquired and recorded in order to be used in other projects "*There is a lot of innovations taking place in construction projects in order to speed up the process than what we have in the bid and make more profit, but the problem is that the knowledge disappears with the project, when the project is over that information is gone*".

When asking about the collaboration with competitors and starting a joint venture with them to develop the robotics in construction, interviewees tended to decline the idea explaining that this technology is quite new and expensive and the first one reaches a working application for it will gain high revenue out of it so the current tendency is to keep all this information inside the company. On the other hand, Manager C provides a new perspective, a collaboration with the subcontractors will be more beneficial, the current relation between contractors and subcontractors is short termed so there is no big collaboration between them, the previous experiences of including and helping the subcontractors had very big value on both sides and this could be reflected on implementing robotics in construction.

7.3.2 Data management of the developed robot

For the developed robot, data is collected from sensors, the developers describe this data as adjustment input for the robots in order to find the tolerance between the perfect model that the robot has and the actual reality that the robot deals with. This type of data is not saved after the end of the project because there is no current application for it apart of statistical analysis. Manager A mentions that the concept of Big Data is not utilized yet in construction and the first company that knows how to use this data will benefit a lot of it in terms of effectiveness, competitiveness and processes improvement. In the rebar cages robot, data were collected also from the human behaviour on site. Manager B says that there were master thesis students from KTH studying how rebar workers are doing the work on site in order to start programing the robot's software. For this purpose, data were collected about the way workers place rebars and in which order they assemble them, and this data was transferred to the machine learning system.

The interviewees see the construction industry lacks the information needed to apply the current available technologies, but as soon as this information is available, it would be easier to apply technology more in construction.

The common view is that the construction industry is still immature in applying advanced technology like robotics, as a result, there is no clear vision about the type and amount of data needed to employ robotics in construction. Consultant A had a rough estimation that we will need in the future 10 to 100 times of the amount of data that we have today in the construction process in order to efficiently employ robotics. Currently and as a start, the main focus from all the interviewees is developing the design information in order to have all the data required for the robot to function, including the perfect BIM model, the construction sequence, logistics of materials, etc.

7.4 Change management

The construction industry is still using the conventional methods in various activities and there is a need coming from the bottom up to change the current situation of construction, as Manager C mentioned, "*the scaffolding for instance is not that much different from what we had in the seventies, there is some development regarding some tools like cranes but the nature of the work has not witnessed big change yet*". Today the technology is available, and as agreed by the interviewees, the first company that will reach a valid application for robotics in construction will gain a lot of it. This change will reduce the cost of the projects which will help the contractor company to be competitive and win more bids as Manager A believes. Regarding the rebar cages robot, there are different point of views about the magnitude and pace of change. Manager A was pushing forward to invest more in the project in order to move the momentum of change. On the other hand, Manager B has a different approach, he believes that steady steps should be taken towards this change in order to facilitate it and connect it to the business model.

Consultant A was interested in the change that is needed in the organisational structure, showing that the construction industry runs in silos where different parties have different responsibilities, and there is no one responsible for the whole process. Implementing robotics will require a better collaboration and flow of information among the client, architect, engineer, contractor and other parties involved in the construction process. This will require a change in the total structure, one example from the consultant A is the companies that produce standard houses, they have a manufacturing structure that proved itself as a successful one. The contractor managers were less interested in studying the change of organisational structure that is needed for implementing robotics, the manager A suggested starting new units in the organisation that could take care of the digitization and automation to keep the knowledge after the end of the project, while manager B was not so sure about the need for the change in structure.

The culture of the construction industry was described as conservative and resistant to change especially in the initiation of this change. Developer B believes that changing people and the way they think could be one of the biggest barriers when implementing the robots to the construction industry. The people always tend to worry about changing the conventional way of working that they are used to. This resistance to change could be broken when people see the positive effect of implementing robotics in construction as mentioned by some interviewees. On the other hand, workers could be afraid that robots might take their jobs. Manager A mentions in this respect that those are jobs that no one wants to have anymore, and he proposes to use the savings gained from applying technology to improve the quality of the job. Another barrier according to Manager C is related to changing the 'mind-set' that has been developed in the construction industry through a long time, as mentioned before, people tend to start constructing very early before completing the design, which makes it very hard to implement the robots in construction. Manager B, believes that people are open to use new solutions on-site, and in the construction industry, when one project succeed a lot of projects follow to implement the same solution, so it is a matter of starting to show a success. Manager A believes that in order to solve the resistance to change in the organisation a higher commitment from the higher management is needed *"they should talk more about automation"*, an example from the manager A is the safety standards in the contractor firm. When senior management started to talk a lot about safety, the positive impact was seen in changing towards safety in organisation. Manager A proposed the spreading of knowledge in the organisation and letting people know more about the robotics and involving them in the change. In order to do so, the contractor firm is using various tools, there has been some seminars talking about robotics in the organisation, webinars and online communication methods are used to spread knowledge about automating the construction, and presentations for the higher management introduced this approach.

7.5 Processes and Design management

The managers in the contractor company believe that robotics in the construction organisation should prove itself as a valid application to the business model in order to survive. The challenge is figuring out the role of the main contractor and the subcontractor in developing and running the robotics in various activities. Manager C sees a gap in the current situation in construction, the relation between contractors and subcontractors is limited to the task they are doing. So he provides the solution of further collaborating with the subcontractors and helping them to implement robotics which will bring benefits to both sides giving that from previous experiences, a satisfied subcontractor will not negotiate much about the economy and he will produce faster. On the other hand, manager A thinks that helping subcontractors might include a risk of transferring valuable information to the competitors.

Consultant A explains that this is something that the construction industry should learn from other industries, solving problems on site is a common action in construction while it is described as "*catastrophic*" in other industries, a clear separation is needed between a complete design and then a construction process. The developers and consultant agree that changing the construction process into more standardization and prefabrication will ease the implementation of robotics. The developer A believes that the current lack of prefabrication in construction and the need for the robot on site adds a lot of requirements on the normal industrial robots, such as the need for adoption to the physical situation, mobility and safety issues. This standardization and prefabrication is usually encountered with refusal from people believe that it will make buildings look similar. The consultant explains that this is a big misunderstanding, prefabrication will help producing parts of buildings much more faster and cheaper, which will make it possible to build more individual buildings with lower prices. Additionally, applying this approach to the construction industry could help breaking down the complex construction activities into smaller standard ones, which are more efficient and could be delivered in higher quality. Consultant A believes that the challenge in the construction industry is that it is closed on itself. Most people working in construction used to study construction and work with construction all of their lives, so they do not learn from other industries about developing the production, he proposes training in order to help people make the right choices to facilitate the robot implementation. In the rebar cages robot, the manager C believes that the BIM tool should be used to produce a design with sufficient details and can be translated to a robot logic rules. This improvement in design will increase the cost of design, but manager A believes that when the robot will start to deliver the total cost of the project will decrease. Manager C provided an example where they have developed a perfect model for a big project, in this model all the clashes were fixed before the start of the project, it took more time to develop the model but the result was a straightforward construction process with no interruptions and better results.

8- Discussion

This section aims to discuss the main pattern of the findings and compare it with theoretical and literature review relatively, in order to answer the research questions of this study.
The abductive method that is used in this this research, means that both findings and literature, complement each other and can be used to answer the research questions subject of this study.

8.1 Construction and the need for improvement (Why robots?)

Bock (2015) mentions the need for employing new technologies in the construction industry in order to make a breakthrough, as the conventional methods and techniques adopted in the construction have reached their limits in term of efficiency and productivity. This was the main reason at the contractor firm to start looking at the robotisation, with aiming to increase the productivity that has been decreased over the last decades and shorten the overall lead time that is required to deliver projects. The robots seem to be the hot topic in the construction industry and the contractor is trying to develop and robotize different activities in their attempt to master this technology. The resources that have been invested from the different contractors, show that the robots are perceived as the competitive advantages that will thrive the business of the contractor and increase their efficiency.
The project that the contractor firm is working on is a prototype under development and has not been employed in real construction projects, also all the parties involved in this development and integrating the robotic solution focus their efforts on overcoming the technical obstacles, while the managerial aspects have not been taken into account yet. However, it is recommended based on Moiz & Krings (2016) to analyse and study the managerial aspects as it can help in dealing with the risks and obstacles that can threat the project.
The empirical data shows different expectations and evaluations for the robotisation within the contractor firms. Trying to unify these visions, by identifying the activities that can be subject to robotisation, based on the available technology, the company needs, the expectations and the business strategy, is essential to achieve success as Robert (2012) lists. The strategy that is based on the one future vision regarding the robots technology can reduce the lead time and the cost required for developing and accommodating such a technology by presenting one compatible and complete development and implementation method. This can increase the demand and accelerate the whole process.

8.2 Benefits and barriers of utilizing robots within a contractor firm

The main barriers for employing the robots that could be identified during the collection of data are related, according to some of the interviewees, to the conventional way that the construction is being practiced within the firm. The current measures that evaluate the project success are based only on the last financial results. Stewart et al. (2004) describe this method of practicing construction as the project oriented method and they identify it as barrier for implementing any new technology in construction on the industry level.
Interviewees add that practicing construction in the previous method puts a huge pressure on the employees and direct them to focus on the job and how to do it in tested methods that have been tried previously and proved their results. Stewart et al. (2004) explain this behaviour by the fear of change and the uncertainty when using new ambiguous methods that include new technologies, practices and routines, in order to achieve the awaited results from the project.
Additionally, this conventional way ignores the importance of the design phase and its role in solving most of the problems if it takes its time and is done in a proper way, moving to robotic based activities require the design to be developed with more accuracy and details, where the work can not be commenced unless the design stage is fully cleared in term of scope and accuracy. Bock & Linner (2015) highlight the importance of the design to be robot oriented when the robots are utilised to do the job. It is worth to mention that the incomplete design

means the incomplete BIM model by necessity, which has been perceived within the contractor firm as a main requirement when it comes to robotisation.
Moreover, the current conventional methods within the contractor firm tend to outsource a lot of the construction jobs to subcontractors, so if those activities are robotized, they need to be accommodated within the contractor firms which will require skills and new business models that the contractor firms do not have currently.
The fragmentation in the current construction processes that Anumba &Ruikar (2002) and Skibniewski & Nitithamyong (2004) identify as one of the barrier for adopting any new technology in the construction, seems to be an obstacle for employing the robots in the contractor firm a well. The complexity in the construction industry on the level of creating design, sharing information, number of the stakeholders their interests, backgrounds, inputs and expectations from the project and the interface between the various teams, requires a high level of coordination and collaboration in order to achieve success. Nevertheless, the communication and understanding capability that the humans have help in solving the problems because of the fragmentations. However, when the robots are being employed, new dimensions of complexity would be added as the parts of the human logic thinking and understanding in addition to the way of communication will be missed and only the provided information will be executed, which means that this information needs to be fully coordinated before being sent to the robots, otherwise robots will face problems. All the previous means that some of the conventional construction process forms the barriers on the project levels for adopting the robots.
The heavy initial investment for employing any new technology in the construction forms a barrier on the industry level according to Balaguer (2000), this finding is applicable on the robot solutions as well, where the small contractors and subcontractors do not have the financial capability to carry such a development, while the big contractors are outsourcing most of their activities. Employing robots requires solving this conflict of interests through some kind of new business strategies and partnerships between the different parties in a way that can grant benefits for all them.
While Van Gassel (2005) identifies the tough work environment in the construction as an obstacle for employing robots, we could identify the additional logistics and safety dimensions when the robots work in an open environment next to the humans as additional barriers. Although those looks like additional complexities than barriers hindering the employing of the robots on sites, and can be eliminated through the robot oriented logistics and safety practices.
Finally, the lack of recording and acquiring of the information that is produced during the projects' life cycle has been identified as a huge barrier, as the robot will require this information to be programmed and do the jobs using the human understanding and interpretation of the design information..
The benefits of utilizing robots in the construction sites that could be identified when collecting the data are of the tangible nature that Löfgren (2006) identifies when implementing new technologies in construction. The savings in time and cost related to the implementation of robot solutions have been identified as the major benefits. This means that the final product will be produced with less time and resources than in the conventional construction method which means the improvement of the construction efficiency that Balaguer (2000) mentions when employing robots. Additionally, the interviewees have reported the robot as the potential tool to improve the quality, in line with Kim et al. (2010) study about improving the effectiveness through the robotisation.
One of the barriers have been identified for utilizing robots, the lack of collecting information in the conventional construction method, Henderson & Ruikar (2010) explain that the robot can help in overcome this obstacle through improving the performance and record the information in the real-time continuously which can which can help the decision maker and equip him with the required information to make a sounded decision. All those benefits cumulatively can lead change the current construction and transform it to become a mass production industry.
However, not all the benefits that have been identified during the collection have been of the tangible nature, improving the safety on site have been of a great importance as the robots could be employed to do the risky tasks in difficult areas that could be very dangerous if they are executed using the human factor and the conventional construction method. Demsetz, L. (1990)

in his study lists the improvement in safety as one of the aspects when employing robots. Henderson & Ruikar (2010) highlight the importance of recognizing those intangible aspects as they can be the reason to overbalance the decision towards robotisation when evaluating the benefits of such a technology. It has been interesting to recognize that implementing the robots will add some new safety constraints when working side by side with humans, but the overall result will be improving the safety conditions on site.

8.3 Organisational learning and information management

Huber (1991) highlights the importance of the information and knowledge acquisition for the organisational learning. Although, the construction projects produce a huge amount of data, only a small amount of data is captured, which emerges the need for a structured information centre that can collect the information, organise it, and distribute it within the entity, in such a way that the data can be analysed and used supporting in creating organisational learning. The contractor firm like all other contractors in the construction industry is facing the problem in acquiring project information, and they look at the BIM model as the potential solution for solving this problem through forming a single central repository where all the project information can be stored, distributed and retrieved in a way that can give it a true reliable meaning, which can support in creating organisational learning within the project organisation and achieve the four components of the organisational learning that Huber (1991) lists. Beyond the BIM, there is awareness about testing the design by using virtual reality tools among some of the interviewees, and the benefits of the VR environment to develop a complete and mistake free design, Garg & Kamat (2014), Choi & Chan, (2004) and Wang et al, (1999) report in their research the importance of the VR tools for enhancing the design when employing the robots in order to smooth the execution. They also report that using the VR can help in overcome the additional safety complexity dimension that is caused by the robots, which the consultant sees as barrier for the robotisation.

Moreover, when the contractor firm uses the BIM as the default repository for storing and sharing the information, they aim that the information will be in the digital form that Walker (2016) describes as the machine logic rule, which is essential for the robot to interpret this information, understand it and execute the job.

When the idea of the robotisation started at the contractor firm, there was research and collection of the information regarding the human behaviour of the workers who were executing the same activity manually,

In order to understand how the worker were reading the design information, interpret it and execute the job. Walker (2016) finds that analysing and understanding the human's behaviour and how they interpret the messages they receive using the three logic lenses of Scott (2003); then creating knowledge of this analysis and use the power of the current computational systems can help in developing smart machines that can makes decisions by themselves. The contractor firm is many stages behind of developing such a robot that can read the design information, make decisions, solve problems, interpret and complete the missed information, as the only purpose of the collected workers' behaviour is to copy the human interpretation of a totally right and fully completed design, so the robot under the development does not have the capability to correct the design pitfalls or complete the missed information.

Although the empirical data shows that the construction projects produce a huge amount of data, the data required for employing robots within the construction sites is still way bigger, something that Bilal et al. (2016) see as the reason to open the construction to the Big Data concepts. The contractor firm is aware about the opportunities that Big Data has, although they do not really use it yet. However, the robotisation will require more than huge amount of data, a specific and relative type of data needs to be continuously collected, reviewed and updated. Waller & Fawcett (2013) finds that the proper way to get the ultimate benefits out of this huge collected data by structure it, organise it and analyse it using the Big Data methods.

8.4 Change management

The empirical findings agree with Bock (2015) that the conventional construction has reached its maximum, and there is an urgent need to accommodate innovative thinking and technology to make breakthrough for one of the most traditional conservative industries. Integrating technology and innovative thinking into the construction are perceived as the key factor to improve the performance and creating value. For the interviewees the robots are perceived as the technology that can make this breakthrough. No matter how the design is different or the project is unique and complex, when the construction activities are broken down into small basic components all the activities are the same. This means that complexity in construction is equal or even less than other industries that use the robots and prove efficiency in their process and values in their final products as per the consultant.

The change needed in the construction firm in order to implement robotics is described by some managers as a major change that might impact various areas in the organisation. A change like this is reported as a strategic change by De Wit & Meyer (2014), who identify change on the business model of the enterprise as strategic changes which require identifying areas of the change and manage it properly to get the potential objectives out of the change. The contractor firm is in a race to acquire and master this technology before the competitors, so they need to invest more and increase the pace of the whole process from development to implementation. This might be a little bit risky and it needs to be taken step by step on a small scale in order to prepare the firm internally for the robots on all levels and dimensions, such as technical, financial and managerial dimensions, the good acknowledgement of the right timing, speed, scope and amplitude of the change is required to assure a successful change in the organisation and that is by knowing when to change, how fast, what to change and how big the change is (De Wit & Meyer, 2014). However, in order to assign the right resources and time frame which can identify the milestone of each stage and its objectives for controlling and evaluation, the managers from the contractor firm have to have a common plan for the change and a common implementation that aligns the firm with its surroundings in order to get the required results as De Wit & Meyer (2014) explain. In order to stay ahead of competitors, the contractor firm has made a strategic decision to invest more in innovation and to collaborate with other parties like the academic institute and the engineering firm in order to learn from other industries and provide working solutions that can promote and utilise the change in the industry.

As the project is still under development and most of the attention is being paid to the technical issues, the implementation model of the change does not seem to be clear yet. The current focus in the contractor firm is creating the sense of urgency and awareness in the organisation, which is the initiating step of Kotter's (1995) model. This step is very important to acquire the resources, attention and commitment to the change as Cameron & Green (2009) say, something that the contractor's firm management is spending much time on, in order to prepare the organisation for the change.

The collected data showed less attention about the organisational strategic, structural and cultural change, this could be because the movement into automation and robotisation is still in its initiating phase in the contractor firm, but in order to facilitate a wide change further attention should be needed for these aspects. De Wit & Meyer (2014) see that the strategic change should be studied extensively in terms of the organisation structure, processes and culture. When applying a major change, the organisational, strategic and cultural changes should come first then comes the technical change as a facilitator (Turner, 2014). Some people see that the robotic solutions in the construction sites require a change in the project structure that can facilitate collaboration between different stakeholders is a key to overcome the silos that the conventional construction works with. However, these silos could be reduced by the use of the information collaboration technologies. BIM is one of those technologies and it is proving the capability to integrate the different stakeholders and create a collaborative environment for the different types of the construction projects' structure (Eastman et al., 2011).

There is maybe a need for a change in the organisational structure and the uprising of new departments specialized with digitalization and robotics. Such a new department can play a role in developing and automating new activities, search and development, information management for robots, programming and maintenance. This change might be small in the pilot phases of applying robotics, as in the studied case. But comparing to other cases like the standard houses manufacturers or even other industries, it was observed that the wide application of advanced technologies like robotics will require a change in the organisational structure which is the firm's anatomy, and a change in the business model to align the organisation with the new technological demands (De Wit & Meyer,2014).

The managers in the contractor firm see that the project-based specification of the construction industry makes it harder to implement robotics in the organisation, where every project has its own budget and resources and robots could be a heavy investment for the project's budget. Turner (2014) on the other hand sees that the project-based organisations could have an advantage when implementing a change, projects could be flexible tools to implement a change but it is important to know that such a change is measured by its value to the organisation not to the capital cost of the project.

The construction has been identified as one of the industries that is most resistant to change, this culture has been built over time in terms of using conventional methods and it is not very open to other industries which are more experienced and used to fast change. People tend to resist the fast changes and this could be solved by breaking down the change and initiating it steadily Turner (2014). Additionally, when it comes to robotics in the construction industry, the data found that people tend to worry about their positions and if their skills are going to be needed in the future. However, a success in implementing the robotic solution in one project might make a breakthrough and increases the acceptance and demand for this technology. This view is based on the culture definition for Flamholtz et al. (1985) by recognizing the value of success in the construction as a shared value and influencing the behaviour by introducing a successful model that encourages people to try it. This is similar to Brown & Malami (2008) suggestion about changing the people's behaviour through using the cultural dimension, which is also confirmed by the data showing that senior management commitment is essential to increase the acceptance. Erez & Gati (2004) call this type of influencing people's behaviour the top-down process. In the studied case study however, it is interesting that the whole idea behind the development of the robot was a bottom-up demanding model, while the implementation will require a more senior management and top-down process – so a reverse of the model.

Finally, the strategic change resulting from implementing the robotic solution, should be analysed on the organisational process level to identify how the processes are going to be affected. The interviewees see the design process as the activity that needs to be improved and done in a different way in order to facilitate the application of robotics. The design is identified as vital for the robots, and without a complete and fully detailed design, the robot will not run smoothly. The completion of the design phase is needed when using the robotic solutions, unlike to what happens in the conventional method where the work could start before finalizing the design. However, completing and producing a full detailed design without any mistake is not enough, Bock & Linner (2015) mention that the produced design should be a robot-oriented design which is a design that takes into consideration the special needs for the robot, this design is needed in order to enable robotics to interpret the information coming from the design stage and execute according to it. Additionally, attention should be paid to the fact that the robot-oriented design will take longer time to prepare which can increase the cost of the design, even though the robot will have the capability to reduce the overall time of the project lifecycle and cost. This robot-oriented design could be achieved by using the computer to communicate the design information with the robots, decomposing the complex elements into small simple elements and finally taking advantage of the BIM environment to produce a sounded design after testing all the possible alternatives and choose the best one using BIM. At the end we should mention Pachon's (2012) recommendation about making the decision for employing the robots at the early stage of the project lifecycle, as this decides if the design will be prepared for a conventional construction method or the robotised way.

9- Recommendations

There are many levels for robotisation and automation, the *Figure 9.1* shows those levels, this Robotisation pyramid shows that the process of robotizing one activity totally to be executed by a Single Task Construction Robot (STCR) includes many dimensions. Managing those dimensions efficiently is essential for getting the potential results out of this technology.

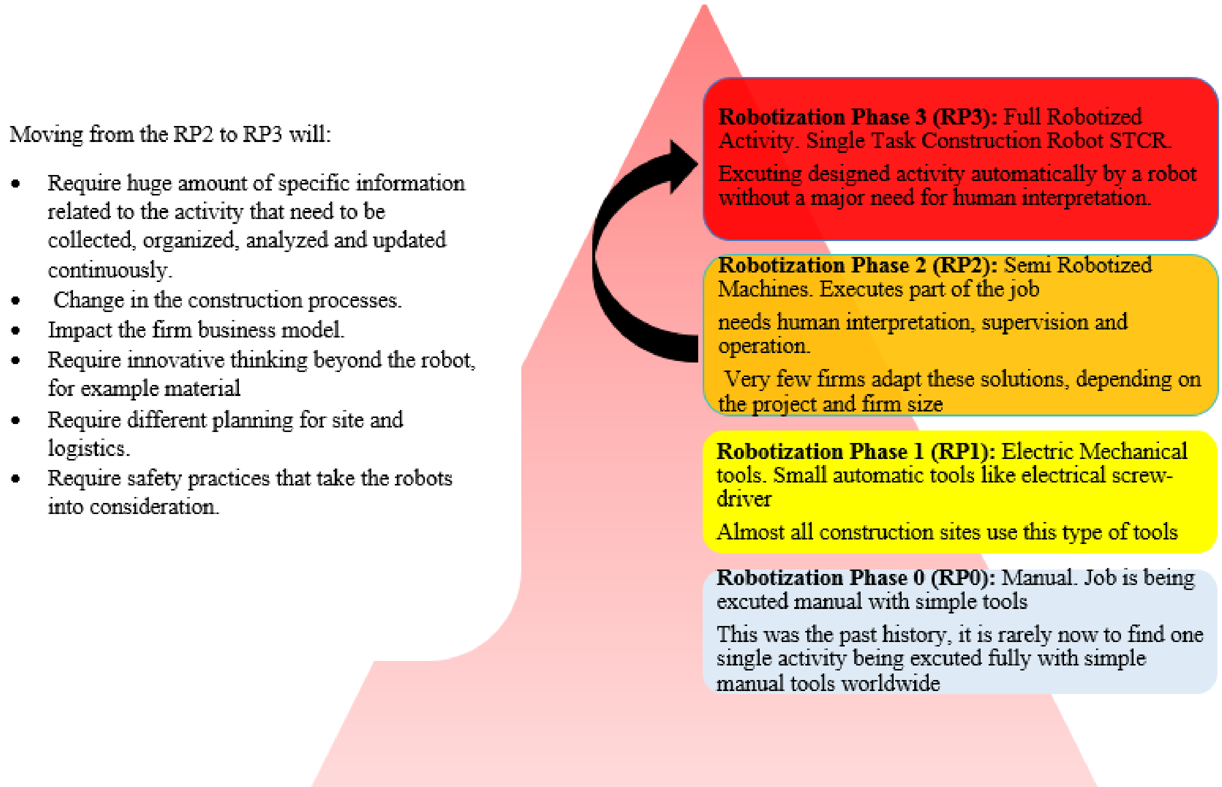

Figure 9.1 Robotisation Pyramid

The explanation of each level of the pyramid is as follow:

Robotisation Phase 0 (RP0): In its simplest definition: The level where there is no employment of any kind of robotisation in construction, the job is being done totally manually, like using shovel to execute some excavation work. This method can be considered as a history, consumes a lot of time and manpower and productivity can be very small, it is a secondary method nowadays and use just to execute small parts where machines do not fit.

Robotisation Phase 1 (RP1): This is the level where most of the construction firms are working. It is the phase where electrical and mechanical equipment are the main tools to execute the construction activities. These tools can be described as dumb tools, it needs full human involvement for operating and controlling. Without human interpretation the machine will be a piece of steel. Examples of this type of equipment: Jackhammer, excavator, dumper, dozer, nail-gun, jacksaw and many more. The equipment in this level vary in their size, productivity, power and capacity based on the job to be done and the manufacturer. Although they have a higher productivity than the equipment in the RP0, they share the need for the human operators.

Robotisation Phase 2 (RP2): It is distinguished by the small number of firms adopting this level of technology. The high initial cost of investment is the main barrier, but it will pay back by increasing the productivity, shorten the time and reduced the labour cost. Komatsu the earth work machines manufacturer is a good example for a developer of this type of machines. Komatsu has embedded the Intelligent Machine Control (IMC) into two types of their excavators. The IMC employs the sensors technology to receive the GPS and GNSS signals and direct the machines in the space, all of that will provide guidance for the operator so he executes the job as per the 3D model map that should be uploaded before starting the work (Jackson, 2017). Job quality that is produced by this type of technology is high. However, main problem with this type of the machines is the need for the human presence to interpret the design information, control and direct the machines. Communicating the change in the design or time schedule would be done manually and through the human factor.

Robotisation Phase 3 (RP3): Moving the construction activity to this phase is where this study has been conducted. At this point the machines and robots should be able to understand the project criteria like the design information, time schedule and quality requirements, then execute accordingly. Any change should be communicated immediately and information should be shared by the type of data that the machine or robot can read and understand. In addition, the machine should be able share and record the information in the real time and spatial concept.

Moving to Robotisation phase 3 (RP3) and employing the Single Task Construction Robot (STCR) as per the previous model, requires a huge amount of data, this data needs to be collected and updated continuously. Currently the construction industry is facing the problem of losing a lot of the data that is produced over the project life cycle, using auxiliary technology to collect this information can help in overcome this problem, like the sensors, GPS and surveillance that can help in acquiring the information in the real time. Additionally, this auxiliary technology can help in recording the data and information within its context, something that can give the recorded data huge additional value. Collecting all this data will introduce the Big Data to the construction. Acquiring, structuring, analysing and updating the data using the Big Data concepts, can be the tool to deploy the robots on site and provide them with the artificial intelligence required to make decision and solve problem without the need for the human interpretation.

Implementing the robotic solution can not happen overnight, it is a process that should take it is time in order to acquire the awaited results out of it. This includes creating one vision within the entity regarding the robotics technology and its potential benefits and future, in order to help developing sustainable managerial solutions that fit the construction entity, instead of developing separate isolated managerial solution for each type of the robotized activities. Having a common vision and expectations can help in building the strategy required to accommodate and integrate this technology within the contractor firm activities, including the training of people, assigning the resources and aligning the processes to fits with the new technology and with each other. Additionally, adopting such an advanced technology, require change in the conventional way of thinking toward the construction processes, especially the design one, that should take its time, be of the robot oriented type and be finalized completely before the construction starts unlike what is going in the current time. This change in thinking should extend to a wider perspective, as not only the design should be robot oriented but the construction material, logistics and safety practices all should be of the robot oriented type. Moreover, the early start on looking and analysing the consequences of employing the robots, helps in identifying the area of the change on the organisation and project level and identifying the best model to manage those changes, as the process is a long process and require unifying the vision as well so the change model that has been introduced in the literature review by Cameron & Green (2009) in the *Figure 4.3*, seems to be the best model to manage this change. However, managing the change itself is not enough, as reducing the resistance to this change is also essential for the success, this could happen through integrating the people, explain for them the reason behind the change and through managing the cultural dimension.

Finally, integrating the robots' developers and other stakeholders can help the contractor in mastering the robotic technology and present better, cheaper and more efficient solution than the requested by the contractor to fill his need. Furthermore, extending this collaboration to include the different competitors who work with robotics, can help in exchange the knowledge and move the whole construction industry to a totally new level, however, this looks to be not so welcomed by the contractors.

Taking all the previous steps help the contractor to analyse his business model and how it will be impacted by the robots, in order to identify and build the best business model that can accommodate the robotic technology and achieve the contractor strategy.

10- Conclusion

This study investigates the use of robots in the construction sites, looking through the information and change management as main facilitators that could widen the range of application of robotics on site. Complementing the literature with a case study helped creating a good understanding of the possible approaches which help introducing the construction activities to a new horizon. The construction industry has a great opportunity to utilise the current advanced technology and develop its practices. The use of the conventional methods in construction is still wide common but as far as new methods prove their effectiveness and efficiency a big change will impact the construction industry and will affect all the parties that are working with construction, the first ones that maintain a correct change will harvest the biggest part of its benefits, while ignoring such a change might lead some organisations to be out of the highly competitive construction market. The technological change might be the most appealing one to focus on when implementing such a change but the organisational and cultural change are the ones that are harder to implement and more important for the success of the change. The question that this study investigates is *How could automation and robotics improve the construction industry on-site through information and change management?* Information and change management appeared as ideal areas to investigate this change. The information acquisition sharing and transferring is the main facilitator for robotics on site, and providing the right tools to manage data could bridge the gap that prevents the industrial robotics to function on-site. Then come the change in the organisational processes, culture and structure that is needed to widen the scope of the change and make it applicable on a high level. In order to answer the main question this study investigates further sub-questions to direct the research. *What are the impacts of adapting robotics on the construction site?* At the beginning the impact could be limited in size but as far as the momentum of change starts to happen a major impact will affect the construction organisations. *What are the main hinders for the adoption of robotics technology in the construction industry?* The hinders vary on the industrial level, the organisational and the project level, the resistance to change and the lack of the data system that enables robotics appear as the biggest barriers that encounter the adoption of robotics in construction. *What is the role of information management in employing robotics in construction?* Robotics automate the activities but they need a special kind of data that is not available yet in construction. Managing the information could provide the data needed and facilitates robotics on sites.Additionally, Big Data can be the key to develop the artificial intelligence required to imitate the human understanding, interpretation and decision making. *How to implement the change in a contractor firm?* The unique structure of the contractor firm makes implementing change even harder, but a closer study of the *Anatomy, Physiology* and the *Psychology* of the organisation eases the planning and applying of the needed change.

Future possible studies could focus on the impact that the implementation of robotics will have on the supply chain and the shift of the work nature that will change from working with basic activities like rebar assembling to working with activities related to running the robots. The business model drives the wheel of the organisation and there is a need to further study how it will affect and be affected by introducing an advanced technology like robotics to the construction industry. Other studies should look into widening the perspective of the construction industries and enhance it with more innovation that could leads to a boost in its efficiency and productivity. Last but not least the impact of the robotic utilization on the job market.

References

- Abdul-Aziz, A.R., & Mohmad, M.-D. (2010), *“Project manager competencies in undertaking construction project”*, Seri Iskandar, Perak.

- Anumba, C.J. and Ruikar, K. (2002), *“Electronic commerce in construction – trends and prospects”*, Automation in Construction, Vol. 11, pp. 265-75.

- Aziz, Z. (2012), *"Supporting Site-Based Processes Using Context-Aware Virtual Prototyping"*, Journal of Architectural Engineering, vol. 18, no. 2, pp. 79-83.

- Balaguer, C. and Abderrahim, M. (2008), *“Trends in robotics and automation in construction”*, University Carlos III of Madrid, Spain.

- Balaguer, C. (2000). *“Open issues and future possibilities in the EU construction automation”*. In Proceedings of the IAARC International Symposium on Robotics and Automation, Taipei, Taiwan.

- Barfield, W., Zeltzer, D., Sheridan, T., & Slater, M. (1995). *“Presence and performance within virtual environments”*, *Virtual environments and advanced interface design*, 473-513.

- Baxter, P., & Jack, S. (2008), *“Qualitative case study methodology: Study design and implementation for novice researchers”*, The qualitative report, *13*(4), 544-559.

- Bilal, M., Oyedele, L.O., Qadir, J., Munir, K., Ajayi, S.O., Akinade, O.O., Owolabi, H.A., Alaka, H.A. & Pasha, M. (2016), *"Big Data in the construction industry: A review of present status, opportunities, and future trends"*, Advanced Engineering Informatics, vol. 30, no. 3, pp. 500-521.

- Bock, T. (2015), *“The Future of Construction Automation: Technological Disruption and The Upcoming Ubiquity of Robotics”*, Automation in Construction, vol. 59, pp. 113-121.

- Bock, T & Linner, T. (2015), “*Robot Oriented Design—Design and Management Tools for the Deployment of Automation and Robotics in Construction”*, Cambridge University Press, The Cambridge Handbooks in Construction Robotics, Cambridge.

- Cameron, Esther & Green, Mike. (2009). “*Making Sense of Change Management: A Complete Guide to The Models”,* Tools & Techniques of Organisational Change, 2nd edition.

- Choi, S. H. & Chan, A. M. M. (2004). “*A Virtual Prototyping System For Rapid Product Development.”* Computer-aided design,Vol.36,Elsevier Science, New York, 401–412.

- CIRIA (1983), *“Buildability: An Assessment”*, CIRIA Publications, Special Report No. 26, Ascot.

- Clough, R.H., Sears, G.A. & Sears, S.K. (2008), *“Construction project management”,* 5th edition, John Wiley & Sons, Hoboken, N.J.

- Corbin, J. & Strauss, A. (2008), *“Basics of qualitative research: Techniques and procedures for developing grounded theory (3rd ed.)”*, Thousand Oaks, CA: Sage.

- Courtney, M. (2012), *"Puzzling out big data"*, Engineering & Technology, vol. 7, no. 12, pp. 56-60.

- Dean, J. & Ghemawat, S. (2008), "*MapReduce: simplified data processing on large clusters"*, ACM, New York.
- Dabirian, S., Khanzadi, M. & Moussazadeh, M. (2016), *"Predicting labor costs in construction projects using agent-based modeling and simulation"*, Scientia Iranica. Transaction A, Civil Engineering, vol. 23, no. 1, pp. 91.
- Daft, R.L. & Weick, K.E. (1984), *"Toward a Model of Organizations as Interpretation Systems"*, The Academy of Management Review, vol. 9, no. 2, pp. 284-295.
- Demsetz, L. (1990), *"Automated Construction: Manufacturing has become highly automated - so why not building construction?"*, Construction Dimensions, pp. 79-85.
- De Wit, B. & Meyer, R. (2014), *"Strategy: an international perspective"*, Andover, Cengage Learning.
- Dolinšek, B. & Duhovnik, J. (1998), *"Robotic assembly of rebar cages for beams and columns"*, Automation in Construction, vol. 8, no. 2, pp. 195-207.
- Eastman, C., Teicholz, P., Sacks, R. & Liston, K. (2011), "*BIM Handbook",* Wiley.
- Egan, J. (1998), "*Rethinking Construction: Report of the Construction Task Force"*, HMSO, London.
- Evbuomwan, N.F.O. & Anumba, C.J. (1998), *"An integrated framework for concurrent life-cycle design and construction"*, Advances in Engineering Software, vol. 29, no. 7, pp. 587-597.
- Flamholtz, E.G., Das, T.K. & Tsui, A.S. (1985), *"Toward an integrative framework of organizational control"*, Accounting, Organizations and Society, vol. 10, no. 1, pp. 35-50.
- Garg, A. & Kamat, V.R. (2014), *"Virtual Prototyping for Robotic Fabrication of Rebar Cages in Manufactured Concrete Construction"*, Journal of Architectural Engineering, vol. 20, no. 1, pp. 6013002.
- George, G., Haas, M. & Pentland, A. (2014), *"Big data and management"*, Academy of Management Journal, vol. 57, no. 2, pp. 321.
- Gong, J., Caldas, C.H. & Gordon, C. (2011), *"Learning and classifying actions of construction workers and equipment using Bag-of-Video-Feature-Words and Bayesian network models"*, Advanced Engineering Informatics, vol. 25, no. 4, pp. 771-782
- Grembergen, W.V (2000). *"The balanced scorecard and IT governance"*, Information Systems Control Journal 1, 40-43.
- Haas, C., Skibniewski, M. & Budny, E. (1995), *"Robotics in Civil Engineering"*, Computer-Aided Civil and Infrastructure Engineering, vol. 10, no. 5, pp. 371-381.
- Henderson, J. R. & Ruikar, K. (2010), *"Technology implementation strategies for construction organisations"*, Engineering, Construction and Architectural Management, Vol. 17 Issue: 3, pp.309-327.
- Huber, G.P. (1991), *"Organizational Learning: The Contributing Processes and the Literatures"*, Organization Science, vol. 2, no. 1, pp. 88-115
- IFR. (2017), *"Executive Summary World Robotics 2017 Industrial Robots"*. [Available Online] .

https://ifr.org/downloads/press/Executive_Summary_WR_2017_Industrial_Robots.pdf . Accessed on ［16-02-2018］

- Illingworth, J.R. (2000). *"Construction Methods and Planning"*, 2nd Edition, E & FN Spon, London.

- Jackson, T. (2017), *"Komatsu launches second-gen PC210LCi-11 semi-auto excavator with improved controls",* Equipment World. ［Available Online］ https://www.equipmentworld.com/komatsu-launches-second-gen-pc210lci-11-semi-auto-excavator-with-improved-controls/ . Accessed on ［17-02-2018］

- Jagadish, H.V. (2015), *"Big Data and Science: Myths and Reality"*, Big Data Research, vol. 2, no. 2, pp. 49-52.

- Japan Federation of Construction Contractors. (2012), *"Construction Industry Handbook",* Tokyo, Japan.

- Jarkas and Abdulaziz. M. (2010), *"The influence of buildability factors on rebar fixing labour productivity of beams"*, Construction Management and Economics, vol. 28, no. 5, pp. 527-543.

- Jasanoff, S., Ed. (2006); "*States of Knowledge: The Co-Production of Science and Social Order"*; Routledge: Abingdon, VA,USA.

- Jayaram, S., Angster, S. R., Gowda, S., Jayaram, U., & Kreitzer, R. R. (1998), *"An architecture for VR-based virtual prototyping of human-operated systems"*. In Proceedings of the 1998 ASME Design Technical Conference and Computer in Engineering Conference , pp. 13-16.

- Jennifer, M. (2002). *"Qualitative researching"*. 2nd edition, Sage, London.

- Kaivo-oja, J., Roth, S., & Westerlund, L. (2016). "*Futures of robotics. Human work in digital transformation"*. International Journal of Technology Management, vol. 73, no. 4, pp. 176.

- Kamaruddin, S.S., Mohammad, M.F. & Mahbub, R. (2016), *"Barriers and Impact of Mechanisation and Automation in Construction to Achieve Better Quality Products"*, Procedia - Social and Behavioral Sciences, vol. 222, pp. 111-120.

- Karabegović, I. (2016). *"The role of industrial robots in the development of automotive industry in China"*. International Journal of Engineering Works, 3(12), 92-97.

- Kim, T., Lee, U. K., Yoo, W. S., An, S. H., Cho, H., Lee, Y., & Doh, N. (2010). *"Benefit/cost analysis of a robot-based construction automation system"*. In Control Automation and Systems (ICCAS), 2010 International Conference on, pp. 616-621

- Kitahara, S., & Takashi, Y. (2006). *"Deployment of construction robots applying the information technology and network system"*. In Proc. Int. Symp. Automation and Robotics in Construction (pp. 19-23).

- Kotter, J, P., (1995), *"Leading change: why transformation efforts fail"*, Harvard Business Review, 73 (2), pp 59–67

- Latham, M. (1994), *"Constructing the Team: Joint Review of Procurement and Contractual Arrangements in the United Kingdom Construction Industry"*, HMSO, London.

- Leonard-Barton, D. & Svikola, J, J., (1995), *"Wellsprings of knowledge: building and sustaining the sources of innovation"*, Harvard Business School Press, Boston, Mass

- Lubas, R.L., Jackson, A.S., Schneider, I. (2013), *“The metadata manual: a practical workbook”*, Chandos Publishing, Cambridge, UK

- Löfgren, A. (2006), *“ICT investment evaluation and mobile computing business support for construction site operations”*, Proceedings of Helsinki Mobility Roundtable, Sprouts: Working Papers on Information Systems, Vol. 6 No. 29.

- McAfee, A. & Brynjolfsson, E. (2012), “*Big data: the management revolution”*, United States.

- Manzo, J., Manzo, F.IV. & Bruno, R. (2018), *“The Potential Economic Consequences of a Highly Automated Construction Industry”,* Midwest Economic Policy Institute , Illinois.

- Min, J.U., Bjornsson, H.C. (2008), *"Agent-Based Construction Supply Chain Simulator (CS2) for Measuring the Value of Real-Time Information Sharing in Construction"*, Journal of Management in Engineering, vol. 24, no. 4, pp. 245-254.

- Mintzberg, H. & Waters, J.A (1985). *“Of Strategies, Deliberate and Emergent: Summary”*. Strategic Management Journal vol. 6, no. 3, pp. 257.

- Modell, S. (2009), *“In defence of triangulation: A critical realist approach to mixed methods research in management accounting”*, Management Accounting Research, 20, 208–221.

- Moniz, A. & Krings, B. (2016), *"Robots Working with Humans or Humans Working with Robots? Searching for Social Dimensions in New Human-Robot Interaction in Industry"*, Societies, vol. 6, no. 3, pp. 23.

- Moon, H. S., Kim, H. S., Kang, L. S., & Kim, C. H. (2012). *“BIM functions for optimized construction management in civil engineering”*. Gerontechnology, 11(2), 67.

- NISO. (2004). *“Understanding Metadata”*, National Information Standards Organization: ［Available Online］ http://arizona.openrepository.com/arizona/bitstream/10150/105486/1/niso.pdf . Accessed on ［18-02-2018］.

- Pachon A. G., (2012), *"Construction Site Automation: Guidelines for Analyzing Its Feasibility, Benefits and Drawbacks"*, Advanced Construction and Building Technology for Society, p. 38

- Reinhardt, F.L. (1999), *“Bringing the environment down to earth”*, Harvard Business School Press, United States.

- Rist, R. (1977). “*On the relations among education research paradigms: From disdain to derente.*, Anthropology and Education, Vol. 8, no. 2, pp.42-50.

- Roberts, P. (2012), “*Strategic Project Management: Creating the Conditions for Success”,* 1st edn, Kogan Page Ltd, London.

- Russom, P. (2011), *“Big data analytics”*, TDWI best practices report, fourth quarter, Vol.19, pp.1-34.

- Santoro, F.M., Borges, M.R.S. & Rezende, E.A. (2006), *"Collaboration and knowledge sharing in network organizations"*, Expert Systems With Applications, vol. 31, no. 4, pp. 715-727.

- Scott, W.R. (2003), *“Organizations: rational, natural, and open systems”*, 5th edition, Prentice Hall, Upper Saddle River, N.J.

- Skibniewski, M.J. and Nitithamyong, P. (2004), *"Web-based construction project management systems: how to make them successful?"*, Automation in Construction, Vol. 13, pp. 491-506.
- Smith, P.A.C. (2012), *"The importance of organizational learning for organizational sustainability"*, The Learning Organization, vol. 19, no. 1, pp. 4-10
- Sorock, G. S., Smith, E. O. and Goldoft, M. (1993), *"Fatal occupational injuries in the New Jersey construction industry, 1983 to 1989",* Journal of Medicine, vol. 35, pp. 916—921.
- Stewart, R.A., Mohamed, S. and Marosszeky, M. (2004), *"An empirical investigation into the link between information technology implementation barriers and coping strategies in the Australian construction industry"*, Construction Innovation: Information, Process, Management, Vol. 4, pp.155-71.
- Sørensen, A.Ø., Olsson, N. and Landmark, A.D., (2016). *"Big Data in Construction Management Research"*. Tampere University of Technology, vol. 3, pp. 405-416
- Tallberg, T., Mattila, M., & Lepisto, J. (1993), *"Fatal occupational accidents in Finland"*, Advances in industrial ergonomics and safety, Vol, 615-619.
- Tippmann, E., Mangematin, V. & Scott, P.S. (2013), "*The Two Faces of Knowledge Search: New Solutions and Capability Development"*, Organization Studies, vol. 34, no. 12, pp. 1869-1901.
- Tucker, R (1988), *"High Payoff Areas fix Automation Applications",* Proc. of the Fifth International Symposium on Automation and Robotics in Construction, June 68, 1988. Tokyo, pp 9-16.
- Turner, J. R. (2014). "*The handbook of project-based management: Leading strategic change in organizations"*, 4th edition, McGraw-Hill Education, New York.
- Tushman, M. L. & Anderson, P. C. (1997). "*Managing strategic innovation and change: a collection of readings",* New York, Oxford Univ. Press.
- Van Gassel, F. (2005). *"The development of a concept for a Dutch construction system for high-rise buildings"*. In Proc. of the 22nd International Symposium on Automation and Robotics in Construction (ISARC 2005), Ferrara, Italy.
- Waehner, K. (2016), *"How to Apply Big Data Analytics and Machine Learning to Real Time Processing"*. Codemotion slides [Available Online] . .https://www.slideshare.net/Codemotion/how-to-apply-big-data-analytics-and-machine-learning-to-real-time-processing-kai-waehner-codemotion-milan-2016 . Accessed on [25-02-2018]
- Wakisaka, T., Furuya, N., Inoue, Y. & Shiokawa, T. (2000), *"Automated construction system for high-rise reinforced concrete buildings"*, Automation in Construction, vol. 9, no. 3, pp. 229-250.
- Walker, D.H.T., (2016), *"Reflecting on 10 years of focus on innovation, organisational learning and knowledge management literature in a construction project management context"*, Construction Innovation, vol. 16, no. 2, pp. 114-126.
- Waller, M.A. & Fawcett, S.E. (2013), *"Data Science, Predictive Analytics, and Big Data: A Revolution That Will Transform Supply Chain Design and Management"*, Journal of Business Logistics, vol. 34, no. 2, pp. 77-84.

- Walton, D. (2014), *"Abductive reasoning",* Tuscaloosa, University of Alabama Press.

- Wang, Y., Jayaram, S., Jayaram, U., Lyons, K., & Hart, P. (1999). *"Representation of swept volumes in a parametric CAD system using trajectory information from virtual environments".* In Proceedings of the 1999 ASME Design Technical Conference and Computers in Engineering Conference (pp. 11-15).

- Wen, Q. & Qiang, M. (2016), *"Coordination and Knowledge Sharing in Construction Project-Based Organization: A Longitudinal Structural Equation Model Analysis"*, Automation in Construction, vol. 72, pp. 309-320.

- Wilkinson, P., (2005). *"Construction collaboration technologies: the extranet evolution".* Taylor & Francis. pp. 5 -8

- Witten, I.H., Frank, E., Hall, M.A. (2011), "*Data mining: practical machine learning tools and techniques",* 3rd edition , Morgan Kaufmann, Burlington, MA.

- Zerjav, V., & Ceric, A. (2009), *"Structuring communication within construction projects—a communication breakdown structure"*. In Proceedings of the 25th Annual Conference. Nottingham, UK.

Appendix I

The Big Data is not identified by the size only but it has five features or what can be called the five Vs. Russom (2011) lists and explains the Volume, Variety and Velocity, while Courtney (2012) adds the Veracity and Value as the main features of the Big Data.

- Volume: Is the data size or quantity, either generated by users, machines or acquired from the external environment. Size can vary from terabytes to petabytes.
- Variety: Refers to the data different formats and resources. The additional data captured with the data to give it accuracy like, location, time and other different metadata generate structured and unstructured sets of data.
- Velocity: The speed that the data can be available to use after generation, recording, updating and measuring. Data can be updated monthly, weekly, daily or continuously. The real-time accessibility and availability of the data adds enormously to the company competitiveness (McAfee & Brynjolfsson, 2012).

As Russom (2011) clarifies, the term "big" comes from the variety and the velocity features of the data rather than the volume of the data itself.

- Veracity: The reliability of the data sets, where only the data consistent, complete and clear should be stored, used and disseminated.
- Value: Is the description of the data sets objectives, and how the business can generate a value from those sets.

George et al. (2014) believes that keeping those five Vs under control is not low hanging fruit, so the parameter of the smart data should take the place of the big data where the fine grained of the data is more important and helps in solving major problems directly or through dividing it into smaller problems easier to manage and control.

The importance of the Big data is the facilitation of better decision making through presenting better predictions (Jagadish, 2015), which enhances the intelligence of the machines to take the proper action that suits various situations.

The analysis of the data adds a huge value for the data (Sørensen et al., 2016).

Big Data Engineering (BDE) forms the base and infrastructure aids the Big Data Analytics (BDA) (Bilal et al., 2016). Big Data Engineering (BDE) includes the processing and storage activities. Different stakeholders in construction projects are producing a huge amount of data stored and shared in different ways, depends on the client demand, projects size, available technology, stakeholders and previous experiences. The most powerful method of storing and sharing the information is by creating central repository where the information can be stored, shared, communicated and audited in the real time, through the employment of the collaboration technology (Wilkinson, 2005). The *Figure 3.1* provides a schematic explanation for Wilkinson's (2005) thoughts.

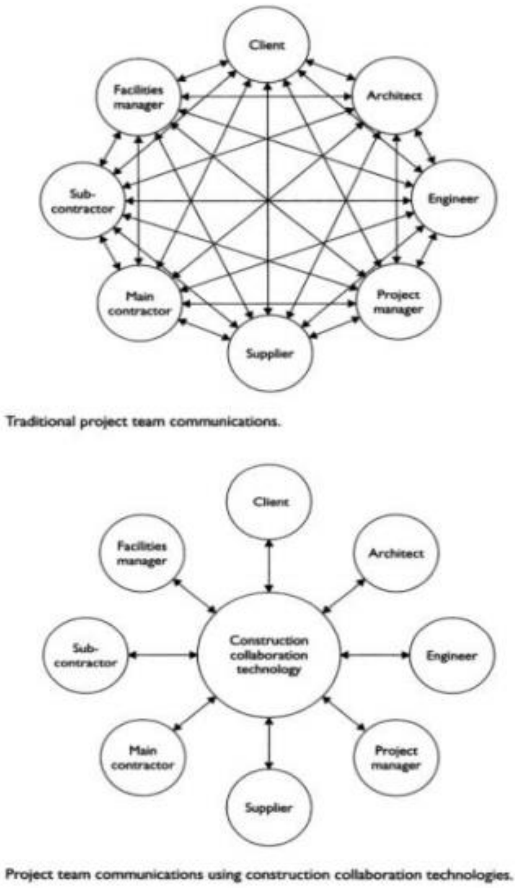

Figure 3.1 Traditional Method against Collaborative method in Communication and sharinginformation (Wilkinson, 2005, p.8)

The previous repository will provide a reliable save information for the whole project's life-cycle. Although this type of technology will reduce the leak and loss of the information, it will inflame the information and intellectual assets for the company that collect the data in this way from different projects. To structure this data, filter it and get the ultimate benefit out of it, we should process it. The most redundant Big Data processing model has implemented in the construction industry is the MapReduce model (MR) (Bilal et al., 2016). Through the MR model the Big data is being processed in distributed parallel model (Dean & Ghemawat, 2008). During the Map part the data is being read, with some kind of processing to produce the intermediate results, while in the Reduce part the intermediate results from the Map part will be processed in to get the final results that will be saved din the file system.

The *Figure 3.2* provides a visual explanation of the MapReduce process.

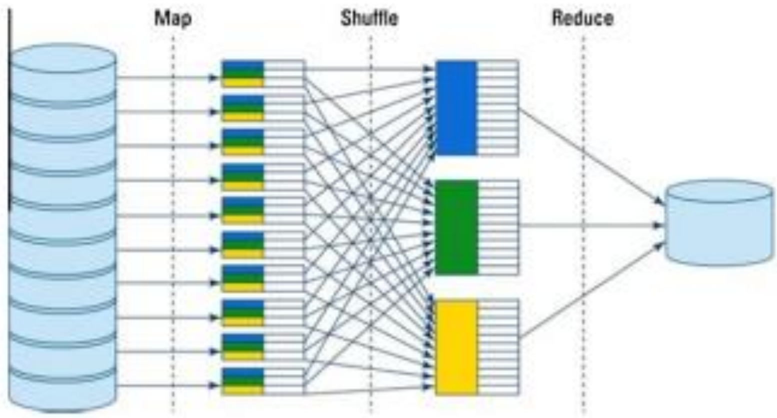

Figure 3.2 Visual Overview of the MapReduce Process (Bilal et al., 2016, p. 3)

The Big Data process part should operate in the real time manner, where the information is, in order for the machine to call the information and execute with no time delay that impacts the quality and reduce the efficiency.

There are many techniques for analysing the Big Data, for the scope of this paper we are going to focus on those that could help in the topic of automation and robotics only.

- **Data Mining:** The main purpose of this technique is to find a pattern or rule through full or semi-automatic investigation and analysis of huge amount of historical data. This technique has the power to answer complex questions and generate prognostic results like finding rules, predicting and assessing probability (Bilal et al., 2016).
- **Machine Learning**: One of the artificial intelligence fields, aims to present an automatic learning about specific task through empowering the computational systems. This type of analysis can help in optimising prediction and supervised learning (Witten et al., 2011). We are going to explain the classification techniques, as it will help in utilising the collected information in automating machines.:
- Classification Techniques: Is Machine Supervised Learning Techniques where the computational systems make decisions automatically from reviewing the right and correct decisions have been made previously for similar case. It is more suitable for the situation where singles and focused decision is required. The quality and accuracy of the previous decisions are the main driver of the quality of the current decisions. Later on the algorithms are employed in this type of the analysis can imitate the right decisions. Some of the classification techniques algorithms are (Bilal et al., 2016)
    - Naive Bayes Classifier: Can generate a framework to automatically classify the actions of the labours and heavy machines in a complicated construction site. Naive Bayes is simple but very popular algorithm with wide degree of employment in different industry (Gong et al., 2011). This type of the analysis can help the automated machines to assess the activities in the neighbourhood and take the right action.
    - Genetic Algorithms: Using the Genetic Algorithms Moon et al. (2012) could develop a BIM system help in evaluating the risks arise on the workspace when putting the schedule, and helps avoiding such conflicts that normally happen during the execution phase, this system called active BIM. The automated machines can use such algorithm to generate logic thinking and behaviour similar to the human behaviour.

The automated machines or the robot and after reading the design and project information should be able to access the central repository that contains the historical information about similar activities with all the metadata related to it and the capture human knowledge and behaviour, then throw one of the previous algorithms and analysis method it should be able to copy the human behaviour and logic understanding in executing the job.

It is necessary to collect the information during the execution and evaluating the performance in order to take action and rectify either the data or the algorithms, which facilitates moving to streaming analytics. In addition, this close loop will enhance the capability of the of the robot which will add to the firm competitive advantage (Waehner, 2016), as per the *Figure 3.3*

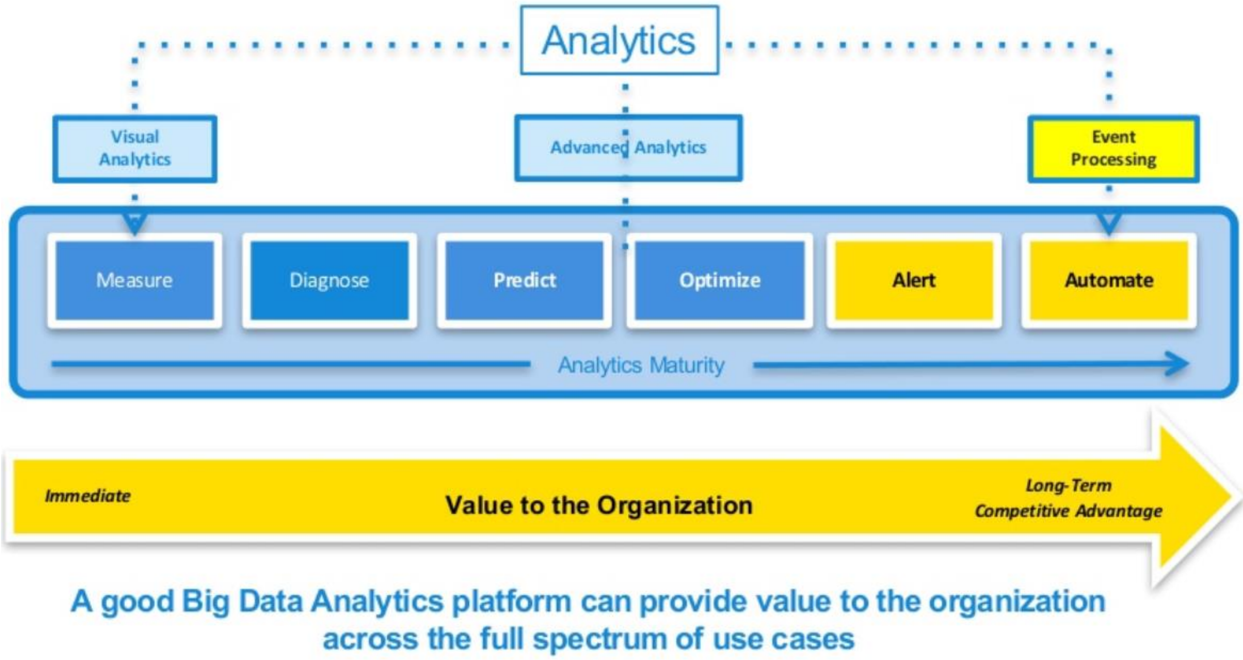

Figure 3.3 Big Data analysis loop for the automation purpose (Waehner., 2016, p. 37)