Reflection

1. The graduation project: a long process

Starting from the last September, this graduation project covers quite a period. In the first year of the program, all the courses were finished within two months, while the graduation project lasts nine. After working on the project over an extended period, the initial passion fades off; meanwhile, the more I know in this field, the more leaks I found in the previous works. The whole project is dynamic and iterative: every time I read something that I wrote down earlier, I found many flaws to be fixed to fit new ideas. Therefore, the process is filled with struggling, frustrations, and difficulties. At the same time, it is also a journey of discoveries, surprises, and excitements. Each time a problem is fixed, a fresh idea is got from an interviewee, or a creative solution flashes, the pleasure inspires me to continue on the way.

At the very beginning, I wanted to focus on the relationship between the robotics level of onsite construction works and the prefabrication level, to see whether prefabrication helps to enhance the robotics level of on-site works. I thought maybe it is the prefabrication level that affects robotics level of the construction industry, especially after our excursion to the prefabrication factory in Amsterdam.

In the first draft of the research proposal, I adopted a quantitative strategy, by measuring the levels of robotics and prefabrication in a set of cases, to evaluate the relationship between them. However, this strategy was later proved to be unpractical. First, the defining and measuring of robotics level and prefabrication level are difficult, lacking technical support from literature. Second, projects are unique, which means it is impossible to exclude other factors which may affect the robotics level of a project except for prefabrication level. Therefore, this topic was finally given up.

At the same time, I reviewed the abstracts of the ISARC papers in recent years, to see what are the researchers doing in the construction robotics field. By doing so, I found that, compared with the starting phase of construction robotics, currently the technologies applied in construction are much more diverse, making the whole picture of the construction robotics dazzling, or even confusing. However, there is not an overview of the technologies applied in construction robotics available. Therefore, I generated the idea to make a simple and concise overview of the construction robotics technologies. This overview could also be used by the practitioners as a reference when they are going to adopt new technologies to solve the problems they are facing.

My second mentor, Pieter Stoutjesdijk, suggested that maybe it will be more scientifically and practically relevant to expand the focus from the current status to the future landscape of construction robotics technologies. Therefore, the final research question was decided to focus on the various technologies applied in construction to enhance a higher robotics level, including both state of the art and the state of the future.

2. Lessons learned from the process

From the process, some lessons have been learned. They are not only helpful in academic works but also inspiring

in life.

To systematically know the field before the project starts

As mentioned in the foreword, I choose the graduation lab construction robotics because of some personal motivation. Then I chose the topic of the relationship between prefabrication and robotization. The choice based on my personal experience, without systematically knowing what other researchers are doing in this field. To avoid the risk of redoing some work that somebody else had done, I also conducted some search on the topic. The topic is by then hardly studied. Therefore, I thought it could work. However, soon after that, I came across difficulties in elaborating the research proposal for the topic: very little related literature and research methods were available to support this topic, making the research more like an air castle. Finally, the original topic was hard to continue and finally given up.

Therefore, knowing the field well is crucial for topic selection. It does not only guarantee that the research work is unprecedented, but also helps to figure out the most proper topic. Scientific research is a collective activity, with many researchers co-operating; generally, each study contributes slightly to the whole structure. The upper part of the pyramid is fine, but supports from related studies are required to reach there. Without a full picture of the field, it is very likely to choose a topic that is not feasible enough.

Research plan need to be adjusted dynamically to adapt to the process

The only constant in the world is the fact that it is changing ceaselessly, the research as well. When the research plan is conducted, many uncertainties impede it from being realized as originally planned. For instance, according to the original plan, in some interviews, interviewees are required to read the narrative I made and then evaluate the future development of each technology in the three scenarios. However, after the first interview, I found that it made the interview lengthy and boring, and also, difficult for interviewees to answer; at the same time, the interviewees do not necessarily completely agree with the narratives. Therefore, the strategy was adjusted, with some more open questions to discuss the three scenarios themselves with the respondents, to establish more reasonable scenarios as the base of future study. The evolvement of specific technologies is later investigated by desk research. It turns out that the new strategy works well. It is important to keep flexible in the work, to handle the unexpected difficulties, getting the best outcome with limitations.

More perspectives help

The involvements of experts with different backgrounds provide different perspectives, which contribute to making the research well-rounded. The interviews come from both practice and academia, concerning different fields in the construction robotics. They observed construction robotics from various perspectives and provided different inputs from their points of view.

Should try better to sell the research

In this research, the future study is based on the scenario planning. To establish the scenarios, some factors that may affect the future development of construction robotics need to be identified. In the initial planning, this process should be done in a workshop with all the participants together, so that they could inspire one another in a brainstorm. However, most of the participants had difficulties in adjusting their timetable to travel to another place during weekdays, therefore, finally, the identification and assessment of the factors are done in an alternative individual way (see chapter 2). Although the new method also works, it is not as ideal as the original one.

This could be done better by improving the 'advertising' of the research. The experts were not willing to adjust their timetable because they were not so interested in the research, only involving in the research from the perspective of 'helping a student to finish his graduation project'. If the invitation could attract them by revealing the potential outcome they may get from participating in the research, maybe they will be more willing to take part in a group work, despite the possible inconvenience it may cause.

Things will never be perfect

There are some limitations in the research. For instance, the future study in this research is established on inferring the possible future evolvement of the currently available technologies in different scenarios. This is only a part of the future technologies, and definitely, there will be some new technologies appearing in the future. However, It is impossible to predict these new technologies, even for the experts; and there is not a solid method to do so. Therefore, it does not make much sense to focus on these technologies, which were finally skipped. Thus, the future exploration is not complete enough, but focusing on the more significative part. Such flaws are difficult to completely avoid in research activities; if currently no proper research method could be found, the best way is to accept it and admit the limitation of the research, leaving it to smarter researchers in the future.

3. Scientific relevance

The scientific relevance of this research is illustrated in three aspects.

First, it explores the trend of the evolvement of the construction robotics research. Robotics has been applied in the construction industry for several decades. With such a long span of time, it could be imagined that the interests of the related research might have shifted from the original ones. However, very few research has tried to reveal the shift. By systematic reviewing the paper from ISARC Symposium, this research tries to conclude the recent trend in this field, revealing the hot point in construction robotics research.

Second, it reveals a full picture of the currently available construction robotic technologies (in the two selected fields). It could be observed that since the 1990s, technologies in the construction robotics has expanded from the 'traditional' ones, which are mainly about mechanism and engineering, to a wider spectrum, including virtual reality, GPS, RFID, etc. With the development of informationalization since the first decade of the 21st century, many technologies related to information process and management have involved in industrial sectors, contributing to the 'fourth industrial revolution' (Industry 4.0). This is also happening in the construction industry. By far, very few overview of these 'new' technologies' application in construction robotics is available. This research tries to summarize the currently available robotic technologies and the pattern of their application in construction.

Third, this research tries to provide a perspective to explore the future development of construction-robotic technologies. The landscape of the construction technologies is dynamic, and evolves at an increasingly fast rate, being affected by many uncertain factors. In this research, scenario planning is employed as a tool to manage these uncertainties. Then based on the most relevant uncertainties, a set of scenarios for the future world are developed to cover the possible future of the technical innovations in the construction industry. It is not a prediction or forecast of the future, which aims at a most probable single landscape, but a spectrum covering the possible landscapes. This method provides an all-around perspective to observe the future development of construction robotics technologies.

4. Societal relevance

The construction industry is one of the major economic sectors in the Netherlands. However, similar to its counterparts in other countries, the Dutch construction industry suffers from a relatively low efficiency and

productivity. Robotics as a solution has been introduced into this industry, hoping to enhance the efficiency. Unfortunately, by far not a greate deal of progress has been made. This research tries to help the industry to improve its robotics level by sweeping some of the obstacles in adopting new robotic technologies in construction activities. It summarizes the emerging technologies in construction and infers the possible future landscapes in construction robotics technologies. This study could assist the related practitioners' decision-making processes in adopting and investing in robotic technologies, thus help the construction industry to improve its efficiency, saving a significant amount of sources.

5. Utilisation potential

The utilization potential of this research also has a three-fold meaning.

First, it could be used as a reference for the practitioners in the construction industry to figure out technologies that could help to fix the problem they are facing. As mentioned previously, the technologies that could be used in construction right now are various, which is probably confusing picture for the practitioners.

Second, this research reveals the possible directions of the emerging technologies' future development in different scenarios, providing a clue for the research and development activities in construction. The technologies that are likely to boom in the future deserve more attention. The actors in R&D activities in the construction industry could adjust their policy according to the evolvement of the scenarios, maximizing the effectiveness of their R&D investment.

Third, by comparing the development of the emerging technologies' development in the three scenarios, the overlap of the scenarios is figured out, as the most solid field to invest for the contractors. Investment in the technologies located in this field, including the equipment, worker training, software purchase, will be most worthy, playing a role in all the three scenarios, with the lowest risk of waste.

6. Validity of the results

This research consists of two parts: the state of the arts, and the state of the future of the construction robotics technologies. The issue of validity mainly exists in the second part, which is the future study.The future study is based on scenario planning, which requires involvements of experts in the construction industry. The selection of respondents affects the validity of the results.

Experts-involving research process

The experts are interviewed to identify the major factors that may affect the future development of the emerging technologies, and then they are required to evaluate these factors. According to their evaluation, two key factors with high impacts and low predictability are selected to establish a scenario matrix. Thus, a set of scenarios is constructed. By inferring the evolvements of the emerging technologies in different scenarios, the future landscapes of construction robotics could be depicted.

Effects of limited number of participants and countermeasures

However, in the conduction phase of the research, it turns out that it is not easy to find enough number of experts who are willing to take part in the research. Mostly, invitations do not get any response or the replies refusing the requirement. Finally, six experts accepted the invitation and joined in the research (for details see Appendix C). The limited number of interviewees may damage the validity of the results in two aspects.

First, limited interviewees mean limited information that could be collected. To deal with that, literature and

available publications are employed to reduce the possible omissions. For instance, in the factor identifying phase for scenario planning, the participating interviewees are expected to provide as many factors as possible. Considering the limited number of interviewees, some desktop research was done beforehand, to investigate the factors that have been mentioned in existing literature, and they were classified with the PESTLE framework, as a reference in the interviewees. Another example is that in the future development of the currently available technologies, blog posts about the technologies' future application were used as supplements.

Second, in the quantitative assessment of the factors, the small sample size affect the results. The assessment was done via an online survey. In the survey, the participating experts are required to evaluate two parameters of each factor: the impact and the predictability, using a seven-point Likert scale, and the average of the scores are taken as the final scores. To make the results are as valid as possible, in the process of calculating final score of each parameter, not only the average score is calculated, but also the deviation. A lower deviation reveals that the experts have a higher level of agreement on the specific issue. For the issues with high deviation, further analyses would be conducted to make sure that the results are proper. Fortunately, the deviations of the results for all the factors are acceptable, which means the experts have relatively close opinions on impacts and predictabilities of these factors, thus the results are to some extent solid.