SPATIAL INFORMATION

An investigation into the impact of lacking spatial information in Dutch infrastructure projects

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Delft University of Technology
Construction Management and Engineering

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Preface

This thesis document is the final part of the two-year MSc degree Construction Management and Engineering (CME) at the Delft University of Technology. The research project has been performed at the construction company Dura Vermeer, within the division Infra Landelijke Projecten in Hoofddorp. This document also represents the end of a chapter and the beginning of a new chapter in both my professional career and personal life. It has been a great learning experience with some ups and downs. I am proud to present my final work.

First, I would like to take this opportunity to acknowledge and thank my graduation committee members - Prof. dr. F.M. Brazier, Dr.ir. S. van Nederveen, Dr. S.G. Lukosch – for their constructive feedback and valuable suggestions during the entire process. The meetings provided me with the necessary feedback and desire to improve my work and keep moving forward. Their input and guidance were essential for this research and for that I am deeply grateful. It was a pleasure to work with such bright and passionate supervisors.

Secondly, I would like to thank J. van Bezooijen manager procesmanagement for providing the opportunity to conduct this graduation research at Dura Vermeer and for his guidance in the entire process within the company. I would like to thank all the interviewees and participants providing me with all the necessary information for this research. It has been a real pleasure speaking with all of you and getting the opportunity to learn from these experienced engineers.

Lastly, I would like to thank my family and friends for keeping me motivated during the process.

I hope you enjoy reading it.

Amresh Rambaran

Delft, 2017

Abstract

This research project focuses on lacking spatial information in the execution phase of Dutch infrastructure projects. In this research project, spatial information is defined as a combination of geometric and geographic object related information, which in the execution phase of projects is related to the shape, size and location of a construction object. Advancements in modern technologies and tools has provided the Architecture, Engineering and Construction industry with the option to design progressively more complex buildings and construction objects. This advancement in modern technologies and tools is not implemented in the quality assessment of constructed objects which leads to a sub optimal feedback loop of information from the construction site to the project management team. It has been proven to be a challenging task for this industry to check the quality of construction for compliance with the design. This research project has been performed at the construction company Dura Vermeer who has the ambition to be in the top three of construction innovators.

The objective of this research project is to help improve the optimisation of the feedback information loop from the construction site to the project management team. That can be achieved through implementing modern technologies, tools and methods that improve the quality assessment of constructed objects during execution. To achieve this objective the following research question has been formulated:

What are the implications of lacking spatial information during the execution phase of Dutch infrastructural projects and how can they be tackled?

To provide a deeper understanding of spatial information and an answer to the main research question the following sub questions have been formulated:

1. *What spatial information is missing in the execution phase?*
2. *What are the implications of lacking spatial information, during the execution phase, in terms of project end results?*
3. *Which technologies or other means can help improve the lacking spatial information*

This research project uses qualitative research methods to answer the research questions. The study includes a theoretical analysis in the form of a literature study. The literature study goes deeper into the topic of quality assessment in the construction industry. Initially some preliminary interviews have been conducted to explore the problem area of spatial information within the construction industry from a practical point of view. Three project cases have been selected by Dura Vermeer. From these three projects, two project team members have been interviewed: from each project a construction planner and construction executor. The interview questions are a structured set of questions to dive deeper in the problems, implications, challenges and solutions related to spatial information the interviewees experienced in the projects. With the interview results a set of scenarios are constructed which are tested in the co creation session. The co creation session is performed to validate and test the results from the previous research methods and participants included both a construction planner and a construction executor. In the co creation session five different scenarios are presented to the participants with the question where do they see the greatest challenge in the scenario and how they would solve it.

The preliminary interviews show how quality assessment of constructed objects is performed and where they face the greatest challenge. These interviews have been performed to quickly obtain information of what is constructed on site complies with the design intent. From the literature study a set of modern technologies and tools have been found to be addressing the issue of optimising the feedback loop from construction site to project management team. The findings can be categorised into data representation techniques, data acquiring techniques and process methods and tools. Since BIM is becoming more familiar in the construction industry, modern technology options mostly focus on integration with BIM. Especially AR and VR in combination with BIM would seem to be promising for optimising the information feedback loop from the construction site. The results from the interviews show a better understanding how a lack of spatial information has originated in the projects, what the implications are on the project and how the project team solves it. The results show a broad spectrum of answers as the term spatial information of itself is quite broad.

Examples from project cases for lacking spatial information:

Examples of lacking spatial information in projects:
• Deviation supplied information and reality • Corrections not documented/updated • Incomplete design • Unclear subjective requirements structural outfitting • Tiny construction site with many parties and tight planning • Constant effort to create space to construct the project • Technology to represent data on site is not practical • Working with old versions of drawings • Potential to combine gaming industry aspects with BIM aspects for better project results

The examples of lacking spatial information vary from lacking spatial information on drawings and in design to aspects from the construction site and dealing with the environment and parties involved in the projects. The most important implications are related to time, cost, quality and stress. Projects seem to be delayed from weeks to months when they must deal with lacking spatial information. These delays are observed in projects with an average of 1 to 2 years duration. Costs are also directly impacted by lacking spatial information. It is difficult to estimate the cost increases as they can result from poor logistics, practicality and environmental impacts. For quality it is difficult to measure the implications. Project team members must quickly find solutions for the challenges. Even if these solutions comply with the structural requirements and design of the client, it differs from the initial design. It is often questionable if these changes are beneficial for the quality of the object. In solving these challenges, it is not unimaginable that the project team could also negatively impact the quality of an object. The last implication is mentioned as most negatively impacting the project team members on various levels. It is the stress and uneasiness from high workloads because of lacking spatial information. In the execution phase when lack of spatial information is detected, project team members must come up with solutions fast while also maintaining the regular deadlines and planning.

With the results from the interviews the basis of the co creation is formed. The participants are asked to determine the greatest challenge they see and how they would solve it. The five scenarios are formulated as follows:

1. *Unclear requirements by the client and a design with loose/open ends*
2. *Supplied/obtained information does not match with the reality on site*
3. *Corrections have been made on site but is not updated on drawings*
4. *Subcontractor falls behind with his designs (installations)*
5. *Very small construction site in busy city centre with many parties, high workload and little space*

Results from the co creation session:

	Greatest challenge	*Solution*
1.	Having proper execution design in time	Engaging with client in a conversation, while diving deeper in his wishes, desires expectations and objectively stating them in the contract
2.	Knowing on paper what the current situation is on site and how it impacts the project and activities	Depends on contract, as a contractor conducts own measurements prior to construction so they can control it
3.	Maintaining the processes through the entire project	Keep checking if the processes are executed and if the project team members are sticking to them
4.	Knowing with whom you are collaborating with and guarding the process	Choosing competent partners whom can be trusted and not the cheapest like usual, Design leader who keeps parties accountable
5.	Contractors and parties who you can trust and know that you can complete the project with	This is a task for the managing board of the company, project team members are too busy with deadlines

The results from the co creation session show a noticeable difference with viable solutions from the literature study. From the participants point of view dealing with the consequences of human influences proves to be most beneficial. These co creation results align with a statement from one of the interviews; people in the construction industry are not ready yet to implement modern technologies such as AR and VR.

As an answer to the research question, people seem to be the key. The greatest advancements on the issue of lacking spatial information currently seem to lie in the management of human errors. Project team members do not give project processes such as updating drawings, working with most up-to-date documentation and sticking to the initial plan, the attention it perhaps requires. This research shows how most of the lacking spatial information seem to originate from a human cause. On the short term the greatest advancements are gained by managing these human interferences with the project processes. On the long-term implementation of innovative and modern technology is necessary.

Professionals in the construction sector, specifically in the infrastructure sector must adopt and implement a new way of working. This includes more modern technologies and transparency that can cause fear to some people. Fear of change in their functions and responsibilities causes these people to reject implementation of modern technologies for instance. Then there is also a group of people, mainly the older generation, that needs extra instructions and education on adapting to a new way of working. This issue could be solved by pairing older and younger generations of engineers together. This way the older generation can learn to adapt to modern technologies from the younger engineers since they generally progress faster through a learning curve. The younger generation learns from the experience and knowledge of the older generation. This group of professionals in fear and resistance must be educated and accustomed to a new way of working. This process starts in the tender phase where changes must be explained and implemented. For instance, including a construction executor in the design phase to increase the practicability of a design. But also during the project searching for interaction and beneficial experiences of project team members. One example of increasing interaction is to improve documentation and communication among team members with images or video clips. Sharing images when challenges occur in a project can also quickly place responsibility where it belongs in the project team or organisation. This way the WE-culture is also stimulated as people must accept responsibility but are also supported when challenges do occur. For some people it takes a mindset shift to adapt to a new way of working and it could require an expansion of project teams with individuals who supervise these changes. Modern technologies such as BIM, AR and VR, seem to evolve faster than professionals in the infrastructure sector, that is way the emphasize should be on adaptation and education of these people.

Furthermore, recommendations are made for future research. Below some are elaborated on. Due to time constraints, a limited number of projects are reviewed, and limited interviews are conducted. Further research needs to be conducted with a larger set of data for a more complete representation. This could include longer and deeper interviews to produce more accurate results. More projects need to be researched to identify the causations and implications of lacking spatial information over a larger set of data which could provide more reliable results. Further research also needs to examine the accuracy and practicality of modern technologies more closely. This needs to be in the form of testing the technologies in real projects and see how they preform against normal project processes. That could be performed by two different project teams in the same project. If construction companies quickly want to check the constructed objects against their design intent, these modern technologies are necessary and could result in greater efficiency and less costs increases.

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1. Introduction

This research project focuses on the level of spatial information in Dutch infrastructure projects and its implications on project results. In this research project, spatial information is defined as:

"a combination of geometric and geographic object related information"

Spatial information represents the size, shape and location of an object by combining points, lines, polygons and other geometric information that can be mapped by locations on the planet in latitudinal and longitudinal degrees. Spatial information may also include additional information about the represented object such as object specific meta-characteristics. This research project focuses on the execution phase of Dutch infrastructure projects and aims to investigate how a lack of spatial information impacts construction projects. This research project is conducted at the construction company Dura Vermeer.

This chapter starts with an elaboration on the general background information in section 1.1. In section 1.2 the problem statement is described and lastly, in 1.3 the conclusion of this chapter.

1.1 General background information

A construction company is an organisation with the intended goal to make a profit through the means of constructing objects. The level of achieving this goal depends on completion of the undertaken project within the anticipated budget, time and quality targets. A construction project can be seen as a micro-economic environment because of the many interrelations among all the involved parties. Among others, these interrelations are one of the causes for construction projects having high risks and severe cost overruns. These risks are also considered high-impact risks, when these risks occur they have a high impact on the entire project. Almost all of these impacts are cost related, and thus are mentioned as cost overruns (failure costs). For this research cost overruns are defined as the difference between initial forecasted budget and actual construction costs (Cantarelli, Molin, Van Wee, & Flyvbjerg, 2012). Furthermore, transportation infrastructure is defined as the basic physical and organisational structures and facilities (e.g. buildings, roads, power supplies) needed for the operation of a society or enterprise[1], for the functioning of transportation systems. Where transportation is defined as the action of transporting someone or something or the procedure of being transported[2].

In the (transportation) infrastructure sector, cost overruns have a bigger impact compared to other sectors in the construction industry (Flyvbjerg & Holm, 2016). These infrastructure projects are more expensive compared to projects in other sectors. Also, as the projects become more expensive than initially planned, additional budget is required to complete the project. Where projects in other sectors can cope, for infrastructure projects, the initial infrastructure investments generally tends to be fixed (Cantarelli et al., 2012). This means that cost overruns in (transport) infrastructure not only negatively influence the project under consideration, but will also result in fewer infrastructure projects being realised than planned. According to (Flyvbjerg, Skamris holm, & Buhl, 2003): the most disturbing part of cost overruns is the fact that over the past 70 years cost escalation has not decreased. (Cantarelli et al., 2012) investigated the cost overruns in infrastructural projects between 1984-2010 in the Netherlands. They concluded that the majority, almost 55%, of the projects end up costing more than initially was intended with an average cost overrun of 16.5%. Over the period of 1984-2010 data showed that the cost estimations of project had not improved, therefore technical explanations (inadequate forecasting

[1] https://en.oxforddictionaries.com/definition/infrastructure
[2] https://en.oxforddictionaries.com/definition/transportation

techniques) have been ruled out as the main reason of project cost overruns. If this was the main reason for project cost overruns, the cost estimates should have improved assuming all other factors remain constant. Since this scenario is not the case these technical explanations can be ruled out. This means that cost overruns have other non-technical explanations in the sense of budget estimation techniques. The problem lies within the understanding of cost overruns; a cost overrun is defined as: the fact of spending more money on a project than was planned in the budget, or the extra amount of money that is spent[3]. In essence this means virtually everything that leads to an increase in cost is defined as a cost overrun. Cost overrun causes can vary from extra material to extra time needed, even to overworked people who need time to recuperate. According to professionals in the construction industry almost everything can be linked to a monetary cost overrun.

Research has shown that the majority of cost overruns occur in the pre-construction phase where both the frequency and the average overrun is larger compared to the construction phase (Cantarelli et al., 2012). This difference can be explained with four possible explanations, to begin with the incorrect estimates. From the start onwards, every project will be planned in more detail and this can cause more cost overruns. This is also related to the next explanation which is the character of the cost estimates. Initially the estimation is a rough indicative estimation whereas at the start of construction are more detailed and thus has a more restrictive nature with room for fewer adjustments. Thirdly, over the course of the project duration the cost estimates start out as optimistic and become more realistic over time. And lastly, in order to get the project proposal accepted, cost can be kept deliberately low. All these explanations lay in the domain of process management and have hardly any links with the technical aspects like design, construction methods etc. Process management deals with the unknown goals and partly unknown actors. The goal of a design phase is to reach an agreement with the majority of the involved parties/actors which results in a project plan. The philosophy of the design phase is to seek the goal of the project that satisfies most of the parties/actors. This goal-seeking process can vary from months to years which underlines the urgency to interact with parties/actors in order to reach an agreement as soon as possible and more important to keep cost overruns to a minimum. When the agreement is reached, and the goals and actors are identified, the philosophy of the project turns to a more control approach which is the nature of project management. Even though the largest cost overruns tend to occur in the pre-construction phase, for a clear picture of cost overruns, the construction phase should also be included. This research project focuses on the construction phase, to be precise, the execution phase of Dutch infrastructural projects.

The construction industry tends to have a conservative nature. For instance, working with traditional construction quality assessment methods that are often time consuming, laborious and prone to human error (Akinci et al., 2006). According to construction executors from Dura Vermeer (Appendix A), the construction industry must adapt and innovate to modern technologies in order to improve the project end results and lower the cost overruns. However, the construction executors also think professionals in the construction industry should be cautious not to accept technical results from modern technologies and stop using their own technical frame of reference and experience. Within the construction phase of projects, the conservative nature is expressed as the lack of visual representation of information. Projects used to be very primitively worked out on paper in 2D. Currently the construction industry is opening up to the modern technologies and possibilities that improve the visual data. For instance, BIM and 3D modelling. However, 3D and BIM models are just the tip of the iceberg and that leads to the aim of this research project.

[3] http://dictionary.cambridge.org/dictionary/english/cost-overrun

This research project focuses on the execution phase of Dutch infrastructural projects and aims to investigate the lack of spatial information that eventually leads to cost overruns. The research question is formulated as follow:

What are the implications of lacking spatial information during the execution phase of Dutch infrastructural projects and how can they be tackled?

Chapter 2 contains the research design parameters. Chapter 3 contains the literature study. Chapter 4 contains the case studies. Chapter 5 contains the results and lastly chapter six contains the conclusion and recommendations.

1.2 Problem statement

The problem statement is developed and described based on preliminary interviews (section 2.2, appendix A) and orientation work in the form of casual conversations and brain storm sessions.

As described in this chapter, this research project focuses on the consequences of lacking spatial information in the execution phase of Dutch infrastructural projects. It seems that most consequences can be expressed in a monetary value and is therefore in conflict with the mission of every construction company which ultimately is to make a profit. To make a profit the project plan should be as effective as possible to minimise the cost overruns and at the same time maximise the profits. Developing the project plan is challenging but critical for delivering a successful project (Chevallier & D Russell, 2011). These construction plans contain all aspects to bring the entire project to previous determined goals in time, cost and quality. These aspects involve many activities such as analysing construction site conditions, preparing construction equipment, tools and temporary facilities, to assessing the feasibility of the developed plans (Kim & Cho, 2015).

During the design phase the parties explore the challenges, problems and how to realise the desires and wishes of the client. This part of the project is usually bound to a budget intended for the development of tenders/project plans. So, with the limited resources a tender team must develop a tender/project plan as accurately as possible. It seems that these project plans do not go in great depth and detail since the tender teams have a budget to maintain. In the construction phase these plans are converted in more concrete plans for the actual execution of the work. According to employees of Dura Vermeer, most projects the execution starts with a general guideline of the project plan in mind. However, there are projects where construction execution starts even when the plans are not completely ready. In such projects the design is divided into work packages and whenever a design of a work package is complete the construction of that package can start.

It seems like many projects have an unforeseen or unexpected event that will lead to a change in the project plan, this only stresses the point to keep the information cycle within the project as fast and accurate as possible. According to the employees of Dura Vermeer information flow currently seems to be mostly top down, meaning from the project management team to the construction workers on site. The information flow from the construction site to the project management team is slower and usually less frequent than the other way around (top - down). This is where the quality assessment of project design comes into play. In the execution phase, it is common to squeeze in a work evaluation when the planning and time allows it (appendix A.2). The work is evaluated in quality assessment reports (bouwkundige opname). In short, an expert assesses the build work against the design in terms of predefined conditions (geometric, geographic characteristics of the object) and checks if the (mis)alignment is sufficient enough. According to employees of Dura Vermeer this type of information is desired more often but also faster. Especially in renovation projects or in projects where new object has to be constructed in connection with already existing objects, this information is highly valuable and is needed as fast as possible (appendix A.2).

These reports are based on the project design requirements and a baseline measurement of the environment of the project area (appendix A.2). With this report the project management can evaluate and measure their success with previously determined standards and goals. For instance, with the baseline measurement the team can evaluate what their impact is on the surrounding project area but also checking if the work is built within the prescribed limits. The most important goal of such reports is to quantify if the client's demands are met, in other words, if the project is executed within pre-set standards, demands and wishes (appendix A.2). These quality assessment reports are executed by an expert which in the peak of a project execution phase is highly occupied and therefore assessing the work rather very occasionally. This information flow (from construction site to management team in the execution phase) should be optimised to improve the project end results in time, cost and quality. By optimising the information flow from the construction site to the project management team, misalignments of any kind can be identified and tackled faster and more efficiently.

According to the construction planners and executors from Dura Vermeer, professionals working in the construction industry are very visual and like to communicate with drawings and images (appendix A). Therefore, the level of spatial information seems to be essential in dealing with the challenges of the construction quality assessment and optimising the information flow from the construction site to the project management team.

As the Architecture, Engineering and Construction (AEC) industry embraces new technologies and methods, designs and buildings are becoming more complex (Kalyan, Zadeh, Staub-french, & Froese, 2016). This means that for future projects the chance of misalignments (in terms of object related geometric and geographic characteristics) with the project plan will increase, if designs become complex and quality assessment techniques and methods stay the same thus the project will result in cost overruns. Therefore, it is necessary to revise and modernise current quality assessment techniques in order to keep project cost overruns to a minimum and simultaneously maximise project benefits. Assessing the quality of construction for compliance with the design intent has been proven to be a challenging task for the AEC industry (Kalyan et al., 2016), this research project aims to investigate the problems in the execution phase of Dutch infrastructural projects, related to the lack of spatial information which ultimately led to an increase in anticipated budget of the project.

1.3 Chapter conclusion

Due to infrastructure projects having a high risk, high impact profile, project teams should strive to minimise risks by optimising the feedback information loop from the construction site to the project management team. Assessing the quality of the constructed object seems to be a challenging task for the AEC industry. Professionals in the construction industry seem to be very visual and that is why the level of spatial information is essential in dealing with the challenges in this industry. Currently the quality assessment is conducted with traditional methods that are often time consuming, laborious and prone to human error which increases risk and cost overruns. The next chapter provides the guideline for this research project.

2. Research design

Chapter one has explored the challenges and their related repercussions in the construction industry. It shows how the level of spatial information relates to the construction quality assessment which is currently conducted with sub optimal methods. This chapter provides the guideline for this research project and the used research methods.

This chapter starts with a quick recap of the problem context in section 2.1. The preliminary interviews are described in section 2.2. Section 2.3 contains the research objective. Section 2.4 elaborates on the scope and limitations of this research project. Section 2.5 describes the research variables. Section 2.6 elaborates on the research questions and section 2.7 describes the research methods and elaborates on them. Lastly chapter 2.8 contains the chapter conclusion.

2.1 Problem context

Before going into the actual research parameters, the problem context and background from the previous chapter is recapped.

- *What problems are involved within the research context?*

The construction industry seems to be a very conservative sector with high risk, high impact projects. This means every error can cause a project to end up losing money which ultimately is the opposite goal of construction companies. It seems that the industry is facing challenges in quality assessment of constructed objects (Akinci et al., 2006). Preliminary interviews show that in the infrastructure sector, checking the build constructions against their design tends to be very time consuming and is often scheduled flexibly into the planning when there is an unexpected gap of free time (appendix A.2). According to the interviewees this information is often needed to manage the activities within the execution phase and to keep the project on track and within budget.

- *What is the background to these problems?*

The main issue seems to be the traditional nature of this industry which leads to working with sub-optimal methods and tools who can greatly improve the project end results (Akinci et al., 2006). Where architects and designers have the option to use modern technologies more frequently, project team members seem to stay behind. Buildings/designs are becoming more complex, making it more difficult and time consuming to check executed work against its design (Kalyan et al., 2016). According to the interviewees, this checking of the executed work is currently done using 3D laser scanning. Designs seem to be increasing in complexity, checking the executed work against the design will also become increasingly important.

- *What alternatives are stakeholders considering?*

According to the interviewees, the most commonly used technique to check if the work is properly executed is 3D laser scanning. This technique requires a well-trained expert to properly assess the executed work (appendix A.2). Apart from a lot of expertise and knowledge, this technique takes time. Another alternative seems to be photogrammetry, this image-based technique combines many photos to produce a 3D point cloud.

2.2 Preliminary interviews

Prior to this research project a number of preliminary interviews, casual conversations and brainstorms have been conducted within Dura Vermeer to pinpoint the essence of this research project. Over ten different employees from Dura Vermeer have been consulted in more than fifteen sessions. These employees vary from construction planners and construction executors to tender managers, division leaders and constructors. The preliminary interviews have been conducted with employees selected by recommendations from the representative of the company. The main findings of these sessions are recapped in this paragraph.

The employees of Dura Vermeer whom participated in the interviews, conversations and brainstorms can be placed into two categories; 1) open to new methods/technologies but still very sceptical to the benefits. 2) Very open to the implementation of new methods and technologies and proponent of investing in innovation. This difference should be mentioned as it was noticeable during these meetings and the content and character of the conversation heavily depended on which category the participants fit into. Overall the majority of the employees are open minded and therefore contradict the generalisation of construction industry as being conservative.

The reoccurring problem is that these employees are open to change and innovation, but they do not know where to start making changes or they are very sceptical about the benefits. Examples of tools and methods the employees seem to be interested in are serious gaming and virtual design and construction. During multiple preliminary interviews and casual conversations these two are mentioned by multiple employees with different functions. These employees are curious about the potential benefits that serious gaming and virtual design and construction could provide. It should be mentioned that project managers in this firm can opt for the use of BIM-modelling in their projects. However, it is not a set standard for each and every project since the investment and maintenance costs of the models are still high and require a lot of time and effort to keep it up-to-date. In other words, it is not (cost) efficient enough for it to be a company standard. Other methods or technologies are still in the experimentation phase, like a 3D-pointcloud generator. One of the reasons this research project is done is that it should mobilise the employees to prove to the companies managing directors that investing in these new technologies is profitable in both time, costs and quality.

One of the interviewees was a tender manager, whose function is to manage a tender team to successfully produce a tender plan within the designated budget. The most common problems he named were misalignment among different activities within the tender process which led to increased time and costs to align the activities. A tender team starts with examining the project area, construction location and condition, client’s demands, etc. Afterwards they make a project plan without going in to too much detail and within the tender budget. Even here the tender manager saw a number of technologies and methods that could help improve this process in a couple of ways. Also, two construction planners were interviewed (uitvoerder, werkvoorbereider). Both of them have experience with 3D-BIM from different points of perspective.

One of the construction executors was open to the idea of implementing new technologies, but underlined the importance of thinking logically in their own frame of reference. His experience with a 3D-BIM model was that it did not give all the clashes in the model, resulting in a clash on the construction site that was not mentioned in the model. He also thought that such technologies and methods will not be able to describe all the possible clashes and problems on site or more importantly under the construction site. Therefore, his conclusion was to use these kinds of new technologies and methods very carefully as they will lead people away from their own reference frame and logical thinking.

One of the construction planners was more optimistic, his experience was a 3D-BIM model used for a tunnel renovation project. He described the implementation of new technologies and methods as more promising in time management since he looked at it from a renovation project point of view. In such projects a lot of the drawings and visual information can be decades old. Most of them were even hand-drawn and could cause a lot of problems if not handled correctly. He mentions that the main problem with these old 2D drawings was the 3D information that potentially can get lost if drawn in a couple of 2D drawings. In addition, these planning activities were conducted using 2D or 3D building drawings alongside construction bar charts.

2.3 Research objective

Construction planners have to mentally simulate the expected construction site conditions while relying on their intuitive understanding of construction methods and their experience over the years, because static views of object cannot visualise the dynamic and time-based construction processes and the construction schedules in bar charts cannot explain geometric conditions of construction projects (Halpin & Riggs, 1992). These challenges are very taxing and mentally demanding for construction planners while most construction projects are often also short on staff for construction planning (Kelsey, Winch, & Penn, 2001). This level and intensity of stress can be reduced by products such as Building Information Modelling (BIM) which contains advanced 3D modelling to visualise object appearances accurately and consistently (Williams, 1996; Collier & Fischer, 1996). BIM models can be integrated into the planning schedule activities where expected progress of the construction plans can be graphically visualised in specific time intervals (Eastman, Teicholz, Sacks, & Liston, 2011). In modern day projects, the quality of the constructed objects should be assessed in a short period of time to avoid problems later on. In essence the goal is to improve the communication/information cycle that runs throughout the entire project.

Based on the problem context, the preliminary interviews and the description above a need of further research has been identified and the research objective has been formulated.

The objective of this research project is to contribute to the implementation and modernisation of visualisation techniques and tools in the Dutch infrastructure construction industry. By using up-to-date technologies and tools, the information flow within a project can be optimised which in turn improves the quality assessment of constructed objects during the execution phase. Improvements for construction quality assessment will be analysed through case studies, in-depth interviews and an expert review.

2.4 Scope and limitations

To provide an accurate answer to the research questions, it is important to clearly define the scope and limitations of this research project. As stated earlier this research project focuses on cost overruns of construction projects. It is obvious that this scope is far too broad for a thesis. Therefore, the scope of this thesis is defined as shown in the figure below. On the most detailed level this research project focuses on lacking spatial information in the execution phase of the Dutch infrastructure projects which eventually leads to cost overruns.

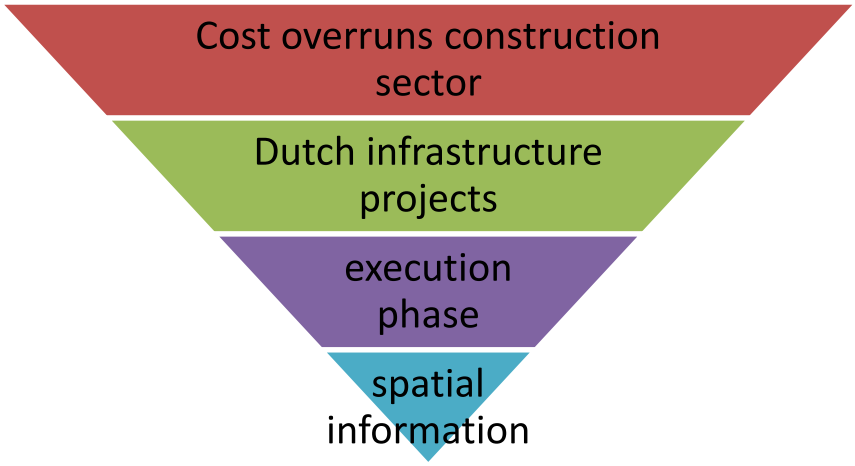

Figure 1: overview scope (own illustration)

This research project is limited to spatial information as a cause for cost overruns in the above-mentioned scope. Cost overruns, as mentioned earlier, can be caused by almost everything. According to construction executors form Dura Vermeer, almost every undesired/unplanned event or action can lead to an increase of costs that are not included in the project budget. That's why it is extremely important to specify the part of cost overruns on which this thesis will focus. That part is the specific spatial information related cost overruns, more specifically the lack of spatial information in the execution phase as seen by construction planners during the execution phase of Dutch infrastructural projects. In this thesis, spatial information is defined as a combination of geometric and geographic object related information.

2.5 Research variables

As mentioned in the previous paragraph this thesis focuses on the execution phase of Dutch infrastructural projects. Next to the mentioned scope and limitations it is also important to define the research variables, both dependent and independent in order to arrive at a substantial answer.

Dependent variable

The dependent variable in this thesis is defined as cost overruns in construction projects. The changes in cost overruns across several projects in the Dutch infrastructure sector is reviewed. The dependent variable is influenced by the independent variable which causes variations in cost overruns. Cost overruns can also be divided into sub-dependent variables: time cost and quality.

Independent variable

The independent variable in this thesis is defined as the level of available spatial information. The amount of spatial information influences the cost overruns. By studying the levels of available information across several projects, this research project aims to identify a pattern and link them to possible measures to increase the level of spatial information. The level of spatial information is determined by case studies and in-depth interviews.

2.6 Research questions

With all the given research design parameters, the following research question can be formulated.

Main question:

What are the implications of lacking spatial information during the execution phase of Dutch infrastructural projects and how can they be tackled?

To provide an answer to this main question, a couple of sub questions will be derived to provide a better understanding and basis for the main research question. These sub questions are:

Sub questions:

1. *What spatial information is missing in the execution phase?*
2. *What are the implications of lacking spatial information, during the execution phase, in terms of project end results?*
3. *Which technologies or other means can help improve the lacking spatial information?*

2.7 Methodology

This section provides an outline for the research project to answer the research question. With the research question as a starting point this section describes a guideline how this thesis has been conducted. The research project started with the motivation to reduce the project cost overruns by improving the level of spatial information in the execution phase of Dutch infrastructural projects. This section describes the steps to arrive at the end desired result and answer to the research question:

What are the implications of lacking spatial information during the execution phase of Dutch infrastructural projects and how can they be tackled?

To answer this question, the following steps have been taken:

- Preliminary interviews
- Literature study
- Case studies / In-depth interviews
- Expert review co creation
- Results evaluation
- Conclusion

The chosen research methods are based on gaining insights in the challenges and impact related to a lack of spatial information in the execution phase of projects and how they are dealt with. The research method that suits this goal are in-depth interviews, since the interviewer can continue asking questions to obtain precise and profound answers. The preliminary interviews have described the practical challenges related to a lack of spatial information. A literature study is necessary that describes the theoretical challenges and possible solutions related to a lack of spatial information. With the insights of the literature study and the preliminary interviews an in-depth interview question list is generated. Combining both practical challenges and possible theoretical solutions, it is necessary to validate these findings by experts. For this research project the validation is in the form of a co creation session with employees from Dura Vermeer as the experts. Afterwards the results are evaluated and the answer to the research question is given followed by conclusions for this thesis.

Preliminary interviews

This research project started with an exploration of the problems related to a lack of spatial information in the form of preliminary interviews. The preliminary interviews have been conducted with employees selected by recommendations from the representative of Dura Vermeer. This method is chosen to use the experience and knowledge of employees from Dura Vermeer to describe the challenges they face related to spatial information and how the employees deal with these challenges currently. These interviews also included discussion about which research methods to use. The results are the steps shown above. After the preliminary interviews the literature study is conducted to describe a theoretical framework for the challenges and possible solutions related to a lack of spatial information in construction projects.

Literature study

This research method is performed to describe the current literature on the challenges of lacking spatial information in the construction industry. The literature study provides a theoretical framework with possible solutions for the construction quality assessment and information flow optimisation. As said earlier, the professionals in the construction industry are very visual and like to communicate in drawings and images. Therefore, this research step focuses on modern visualisation technologies to take advantage of the nature of this industry. Furthermore, the concepts of serious gaming and virtual design and construction have also been mentioned multiple times in the preliminary interviews and therefore they are reviewed in the literature study.

Case studies / in-depth interviews

As stated above, this thesis starts with a selection of case studies and in-depth interview to pinpoint the exact problem related to the lack of spatial information and its implications. These cases are obtained from the construction company Dura Vermeer section Infra Landelijke Projecten. This division's majority of projects consists of midsize infrastructural projects in the range of €1 to €10 million and that is also the category from which the cases have been selected. The selection criteria for these cases is, either a renovation project or a project where the new object had to be constructed in connection with an already existing object. Also, in these projects there should be cost overruns due to errors in the execution phase of the project. Preferably cost overruns originated from construction errors related to a lack of spatial information. For instance, not building within predetermined limits (bouwen binnen tolerantie). Three cases are reviewed due to limited time.

The selection of interviewees for the in-depth interviews, depends on the availability of the employees whom participated in the relevant projects, preferably construction planners and executors are interviewed (uitvoerders, werkvoorbereiders). The interview questions are designed to explore as deeply as possible what the cause of the cost overruns (related to the lack of spatial information) are and describe them as detailed as possible. Interviewees are asked about their strategies for dealing with these lacks of spatial information and also how the lack of spatial information impacted their processes and project results. The guideline in the interviews is to let the interviewee describe the entire process from the origination of a lack of spatial information to detection, to solving it. See appendix B for the interview questions.

Expert review co creation

The last research method is to take the results from the interviews and use them as input for the expert review, which is the co creation method. This step aims to validate the previous interview results and simultaneously test if the possible literature solutions are considered by working professionals in this sector. According to (Sanders & Stappers, 2008), this method has been around for almost 40 years but was named participatory design and has been used in Europe, research projects on user participation in system development dating back to the 1970s. The method put together the expertise of the systems designers/researchers and the expertise of those workers impacted by the changes. Building on workers own expertise and providing them with the resources to be able to act in their current situation. (Bodker, 1996). Basically, any process that brings together different parties like designers and users for instance, that work toward a shared goal, is a co creation process. This process is often in a workshop where participants collaborate to explore a problem and generate solutions together. By doing so more value is created as different points of view and interests are considered. The essential part of this method is to provide a safe environment for different parties to communicate with each other and collaborate towards a shared goal or interest.

For this research project, the shared goal in the co creation session is to minimise the impact of the level of spatial information which also means increasing the level of spatial information. The co creation in this thesis is conducted with employees of Dura Vermeer. Participants for the co creation are selected based on their function, at least one construction planner and one construction executor are necessary for the co creation session. In a one-hour session the participants are presented with challenges and are asked to describe the greatest challenges they see and how they would solve it. These challenges are based on the in-depth interview results and are described in section 5.2.

Results evaluation

After the results from the expert review co creation, all results and findings are combined and evaluated in order to provide an answer to the research questions. This step provides the basis for the next and final step, the conclusion of this research project.

Conclusion

In this step, the thesis is reviewed entirely, and all the results and findings are taken into account to answer the research question and also to elaborate on the objective of the research project. The conclusion is followed by the discussion and recommendations for future research on this topic.

2.8 Chapter conclusion

This chapter describes the necessary steps and methods to answer the research question. Gaining insights in the challenges and impact of a lack of spatial information plays a key role in this research project. Therefore, the main research method in this thesis is in-depth interviews since they allow to obtain precise and descriptive data regarding the issues with spatial information encountered in construction projects. Preliminary interviews have described the practical challenges in the construction industry. For the theoretical challenges and possible solutions, the literature study is conducted. The last research method is the expert review co creation, this step is conducted using Dura Vermeer employees as experts. Lastly, all results and findings are evaluated and the research question is answered. The next chapter provides the literature study to frame the theoretical challenges and possible solutions.

3. Literature study

As mentioned in the previous chapter, the literature study is conducted to review the theoretical challenges and possible solutions related to the construction quality assessment challenges in the AEC industry. This chapter starts with an elaboration on the construction quality assessment and its challenges in section 3.1. Section 3.2 provides insight in project cost overruns and the link to modern technologies. Section 3.3 elaborates on modern visualisation techniques and the process methods serious gaming and virtual design and construction. Lastly in section 3.4 the chapter conclusion is provided.

3.1. Construction quality assessment

Each and every project starts with the preconstruction phase wherein the parties negotiate among each other to satisfy everyone's demands and wishes as much as possible. This results in a schedule of requirements for the object to be built. In construction projects these requirements consist of a reference frame of the quality assessment criteria, legislation but also codes of conduct. Especially the technical part of the schedule is of importance for this research project. For instance, in an infrastructural project these requirements can be:

- function of the object
- object capacity
- size of the spaces/rooms
- relations among the spaces/rooms
- technical legislation
- facilities
- design

More importantly, the schedule of requirements also prescribes how each and every requirement should be assessed. From the preliminary interviews, it seems the most common method to prescribe these criteria is with the SMART-method. This acronym stands for Specific, Measurable, Acceptable, Realistic and Time-related. By following the guidelines for this method, the Schedule of requirement's quality prescriptions becomes a quantifiable document. Assessing the quality of the constructed objects has become increasingly important since designers are able to develop more complex architectural concepts as a result of the increase in computational methods such as BIM (Kalyan et al., 2016). Assessing the quality of such complex project are even more challenging with higher levels of complexity. The main reason for this increased complexity is the difficulty in identifying the quality issues and comparing the design with the built object. the process of checking the design with the built object can cause an increase in the project cost as a result of the aforementioned difficulties.

Traditionally the built object is checked against its design by independent third parties like consultants and other experts. If the project does not incorporate a BIM-model, then checking the built object and its design often becomes time consuming, laborious and prone to human error (Gordon et al., 2003; Tang, Huber, Akinci, Lipman, & Lytle, 2010) Preliminary interviews also show that these independent experts are overscheduled in the peak of the projects. In reality they are often scheduled into the planning when a (unexpectedly) time slot pops open (appendix A). This could mean that some parts of the project have to proceed with construction without checking the already built objects which can lead to high costs and time loss on the long run. If projects do make use of a BIM model, the design and construction phases can be optimised in accordance with each other. The BIM model can identify design coordination by clash detections. With 4D BIM models the construction schedule efficiency can also be analysed from a time perspective. The potential of using BIM for quality assessments still seems to be untapped. One of the biggest obstacles in this regard is the comparison in design models and the as-built objects/conditions on site. This obstacle can be tackled by developing 3D as-built models that represent the current construction site conditions which can be compared to the design model using suitable tools. Two of the most dominant tools, most researched tools and most used by professionals in the industry seem to be 3D laser scanning and photogrammetry. Both these tools can capture data and also contain modelling techniques (Kalyan et al., 2016). These tools have their limitations which will shortly be described in the visualisation technique section. As the technique, tools and methods for designing projects evolve, so should the means to assess the design in order to keep the projects within budget and time by balancing both sides of the scale.

3.2 Project cost overruns

As mentioned in the introduction, the construction industry is a high risk high impact industry. This could be one of the reasons why this industry is considered to be conservative when it comes to work methods, tools and technology (Akinci et al., 2006). While already dealing with a lot of risks during projects, with some high impact ones, they cannot afford to deal with the risks related to new tools and technologies, so it seems. A project plan is critical for a successful project but also challenging to develop (Chevallier & D Russell, 2011). Tools like Building Information Modelling (BIM), serious gaming, virtual reality, augmented reality could improve the development of project plans. It should be mentioned that BIM seems to gain more traction among the construction companies compared to previous years. In the Dutch construction environment, it can be noticed that more and more parties are experimenting and opening up to the idea of new technologies and working methods (appendix A).

Considering the new possibilities to check the built environment against it design, could lower the risk profiles of construction projects (Kalyan et al., 2016). Also, these modern technologies can potentially manage the construction site environment which could also contribute to less risks and lower impact risks. Of course, these are all assumptions and further research needs to be conducted to quantify these statements. However, Other industries like the automotive and aviation industry are significantly further with implementing modern technologies compared to the construction industry. For instance, some of the biggest automotive companies seem to be experimenting with the implementation of augmented reality. Both industries are also using robotics on a bigger scale compared to the construction industry. The construction industry should explore and identify some of the modern technologies and research how to implement them, instead of waiting for evidence that modern technologies do improve project results.

3.3 Visualisation techniques

This paragraph elaborates on a number of the most prominent visualisation techniques and tools in the construction industry. According to (Gordon et al., 2003): "Defects that occur during the construction process account for a large percentage of overall defects in the built environment. Defects waste time and money, and affect the overall performance of the built environment. These problems can be minimised with proactive application of advanced scanners, sensing, and data modelling techniques". New upcoming technologies can make it easier to scan the as-built environment on site and compare that data with the design model. Making it easier to compare real time data in a fast manner to help identifying these defects during the construction phase. A distinction of two major categories can be made among the different as-built data acquiring technologies, the photo/video-grammetry and 3D laser scanning. Then there are also the data representation technologies like BIM, augmented reality and virtual reality. These technologies can display the technical project related information in a graphical way.

3.3.1 Data representation technologies

Building Information Modelling (BIM)

One of the most widely known technologies of digital data processing is the Building Information Model, better known as BIM. This technology was developed in order to integrate the information used within the Architecture-Engineering-Construction (AEC) industry (Elmualim & Gilder, 2014).

BIM is a digital representation of all physical and functional characteristics of a construction project. In essence, BIM is a shared knowledge source of all relevant project related information that serves as a foundation for decision-making. This BIM source is used throughout the project, from the very first designs to maintenance and demolition. The goal of a BIM model is to deal with construction plus installation coordination issues prior to procurement and fabrication of the construction components. This goal can be achieved through integrated collaboration, communication and controlled project delivery by a team (Love, Simpson, Hill, & Standing, 2013). Some of the requirements of BIM are:

- A digital shared database
- Interoperable information (multiple software can use the information)
- Exchange is based on open standards
- Exchange must be accessible in the language of the project team members

It has been shown that the use of BIM has modified the design, construction and operation phase of construction projects (Azhar, Khalfan, & Maqsood, 2012). The use of BIM has been noted by many as very beneficial for all stages of construction (Eastman et al., 2011). Increases in profitability, better time management and better cost management as well as improved client customer relationship have been observed. BIM is also known as Virtual Prototyping Technology or n-D modelling which is reshaping the construction industry (Mehran, 2016). BIM is not just a 3D model; this technology includes the capability of transmitting and reusing the information imbedded in it. A so called 4D time model (W. C. Wang, Weng, Wang, & Chen, 2014), and a 5D cost model (Smith, 2014) can be developed depending on what information is available in the BIM model. More nth-dimensions can be developed and added to the BIM model. According to (Ling, Ke, Kumaraswamy, Asce, & Wang, 2013); there are four factors for successful integration and collaboration for BIM:

- Product information sharing
- Organisational roles synergy
- Work process coordination-Environment for teamwork
- Reference data consolidation

Virtual reality

With the increasing adaptation and implementation of BIM, virtual reality (VR) is also more widely accepted within the construction industry. Virtual reality is defined as follows (Milgram & Kishino, 1994):

"The computer-generated simulation of a three-dimensional image or environment that can be interacted within a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors."

Virtual reality is a relative new technology which has not seen its exponential growth within the construction industry yet. A main distinction of two categories can be made for virtual reality systems (Bouchlaghem & Liyanage, 1996):

1) **Desktop virtual reality**: This version is PC based and these virtual models emerge from animated computer aided design. Users view and interact with computer represented images on a traditional computer graphic screen.

2) **Immersive virtual reality**: The difference with immersive and desktop virtual reality is that the computer screen is replaced by a head mounted display unit in immersive virtual reality. Where users only viewed, and interacted with a computer screen in the desktop version, in immersive virtual reality users feel and experience virtual reality. These types of systems require different hardware such as super computers, high resolution silicon graphic screens, position tracking devices, power gloves and head-mounted displays.

The design phase of construction projects deals with a large amount of goal searching, uncertainties, stakeholder satisfaction and generally speaking searching for common ground/goals among all the parties and aligning goals and expectations of as many participants as possible. Virtual reality technology chimes in with its way of speeding up negotiations and decision-making processes by means of visualising the related project information. For instance, during negotiations on a new motorway a number of parties (stakeholders, contractors, client etc.) could have issues on the design/layout of the motorway. By using a virtual reality model and displaying the various designs, parties can debate variations and reach an agreement faster compared to this process without having the virtual reality model. For the execution- and maintenance phase the application of virtual reality is still being researched. According to (Bouchlaghem & Liyanage, 1996): Attempts to implement virtual reality in the construction industry concentrates on the design and construction process. The first application of this technology has been the development of walkthrough systems, other applications have been identified:

In design:

- Space modelling
- Interior design
- Lighting design
- Heating Ventilation and Air Conditioning design
- Ergonomics and functional design
- Space selling
- Fire risk assessment
- Landscaping

In construction:

- Site layout and planning
- Planning and monitoring of construction processes
- Evaluation of construction scenarios

Bouchlaghem & liyanage (1996) conducted a survey among 120 of the leading companies in the United Kingdom spread over all the sectors of the construction industry (Civil engineering, Housing development, Building construction, Road and highway construction). Below a summation of their main findings regarding implementation of virtual reality in the construction industry:

- In general, there is a lack of understanding and awareness of the new technology
- The potential improvements that the technology can offer are generally recognised by those who are aware of its existence
- The high cost of VR is the main reason why it has not been tested by most of the companies involved in the survey
- Larger companies dealing with big projects and having well-established IT working patterns seem to favour the idea of developing new VR applications

- The areas in which VR is thought to have the most contribution, in the majority of practitioners' views, are space modelling and visualisation of design proposals
- It is shown that most companies interested in VR are willing to spend between 10 and 60 thousand pounds to invest in the new technology

With these results, they conclude that the practitioners in the industry do not fully exploit the benefits from the research done in this technology. The survey shows a general lack of understanding of modern technologies. This lack can be partly explained by the costs and the level of involvement of practitioners in the research and development process (Bouchlaghem & Liyanage, 1996).

Augmented reality

Augmented reality (AR) allow users to combine the 3D virtual world with their own real time viewing perspective. This can be done without losing any of the advantages of object movement and individual movement in real-world environments (W. C. Wang et al., 2014). Augmented reality is defined as follows (Milgram & Kishino, 1994):

A technology that superimposes a computer-generated image on a user's view of the real world, thus providing a composite view.

This technology has been researched for several applications in the AEC industry (Bae, Golparvar-Fard, & White, 2013) below are a few out of many more:

- Maintenance
- Manufacturing
- Training
- 3D video conferencing
- computer assisted instruction
- Construction design

The problem with traditional non-BIM projects is the number of information documents used throughout the project. In projects that do make use of BIM, a large number of documents is included in a digital information model. However, accessing this information model on-site tends to be quite unpractical. With the use of mobile devices (phones, tablets) this problem can be partly tackled. Providing project (BIM) related information with augmented reality, accessing this information should be more user friendly (in theory). According to (X. Wang & Love, 2012); the conventional role of AR is the visualisation end, BIM + AR can fulfil some practical rationales for onsite information system for construction site activities. The table below describes them briefly.

Rationale	Description
1. Interdependency	The different roles involved in the current construction practice mainly focus on their individual tasks, with less concern about the interdependencies between different tasks
2. Link digital (paper) to physical	Much money and time are wasted because plans or drawings are misinterpreted, or the information is transferred imprecisely from the plan to the real object. There apparently needs an information bridge that can enable users to get away from information and guide users better to link information with the physical resources in a more straightforward and effective way.
3. Synchronisation of mental models for communication	Prior to immediate construction, onsite communication and coordination can happen in a virtual plan between different stakeholders using BIM. AR can provide a common view for onsite communication, which can provide everyone with a unifying common perspective of the project information.
4. Project control, monitoring and feedback: as built vs. as planned	Work tracing and analysis are available by comparing as planned and as built data on site. AR can tell the exact difference by visualizing the as planned data onto the as built environment. With AR, each building component can be allocated a status - identified, ordered, delivered, checked, installed, fixed, snagged, protected, and complete. It is then possible to indicate as planned and as built so that the progress of every element can be seen graphically.
5. Procurement: material flow tracking and management	Project planning, purchasing, production and logistics can be handled in AR, which visualizes the mapping relationship on the construction site. The information is propagated from the ERP system (production factory) to BIM and becomes available to the site manager, who uses this information for the detailed planning of construction works. Such available BIM data can then be visualized onsite with AR.
6. From design to production: a visualisation gap	BIM + AR can provide a full 3D interactive solid model of the design, giving the workers a visual understanding of details. Therefore, a high level of constructability is achieved and conveyed clearly to the site via AR.
7.Site plan and storage	The BIM model can be used to identify storage areas for different subcontractors and trades and to show how they need to change during the project. Larger items that are delivered such as stacks of bricks, plasterboard and steel need to be located in places that are well-ordered and clean. Trades people spend a considerable time on projects locating where material has been delivered or moved to.

Table 1: Rationales for the onsite information systems for construction activities. (source: (X. Wang & Love, 2012))

BIM + AR systems

The above mentioned seven rationales can be linked to a number of solutions that consist of BIM + AR systems. These BIM + AR systems are explained in this paragraph and are coupled to the rationales mentioned before. See below for an overview of the BIM + AR systems and their relations to the rationales.

BIM + AR SYSTEMS	Rationales						
	1	2	3	4	5	6	7
BIM + AR Walk-through	✓	✓	✓			✓	
BIM + AR Context-aware Mobile Systems	✓	✓		✓	✓	✓	
BIM + AR for Onsite Assembly		✓	✓				
BIM + AR Way-finding					✓		✓

Table 2: Mapping the rationales to the BIM + AR systems (edited)(source:(X. Wang, Truijens, Hou, Wang, & Zhou, 2014))

BIM + AR Walk-through

This AR walk-through functionality allows the users to experience the model from a different perspective. The walk-through functionality provides the user with a full 3D interactive solid model of the design object, that allows workers to facilitate design and constructability review process on site. Traditionally a design is realised with 2D drawings from a 3D object model. With this method, searching for specific details is very time consuming. Generating these 2D drawings is considered a challenging task and tends to be time-consuming and seen as one of the greatest challenges in a project (Moum, 2010). Additionally, another perceived challenge is the limited possibility to rapidly make 3D drawings for spontaneous needs and meetings, a long-term approach to tackling these challenges could be to strive for a situation where the 3D object models replace the need for 2D drawings (Babič, Podbreznik, & Rebolj, 2010).

BIM + AR Context-aware Mobile systems

Industrialisation of the construction process requires a high level of automation and integration of information and physical resources (Babič et al., 2010). Integrating the information developed in a data model such as BIM during design with the physical construction site is a challenge. All design and planning tasks work with information rather than physical resources (Prescott & Conger, 1995). Each project member generally interacts with a project through various information mediums and models. A project generates huge amount of information (paper or electronic) from which project participants construct their mental models. This is a problem in as much site work requires individuals to both work with information and transform physical resources to a constructed object. AR should be omnipresent in addressing this issue and work with accurate positioning systems. This shows that AR-based visualisation of information contained in a database like BIM can provide those on-site with an improved understanding of their work and thus increase productivity

BIM + AR for Onsite Assembly

Assembly is usually guided by paper drawings that contain large quantity of information related to the process of how to combine two or more objects together. A large amount of this information can be redundant and endless, especially for complex tasks for whom this can turn out to be a potential hinder for the assembler's information orientation and his/her ability to understand assembly relations. The implementation of an assembly task based on 2D drawings typically consists of work and non-work piece-related activities (Neumann & Majoros, 1998). Each assembly step consists of a series of physical operations (observing, grasping, installing) and mentally manual related processes (comprehending, translating and retrieving information context) (Neumann & Majoros, 1998). Neumann and Majoros suggested that information related activities tend to be cognitive whereas work piece-related activities are kinaesthetic and psychomotor. They are so connected together that it is easy to overlook the impact of information-related activities on direct work performance. According to (Zaeh & Wiesbeck, 2008): assembly using drawings consumed a mass of invalid time (time consumption invalid to work pieces), the process of assembly based on planar drawings fails to consider the cognitive issues as well as the large number of switchovers between physical and mental processes. The latter can result in operational interruptions and attentional transitions mostly noticed in novice assemblers. Towne also noticed this time-consuming nature of activities. He found that information-related activities (cognitive workloads) accounted for 50% of the total task workload (Towne, 1985). Similarly in the aircraft engineering industry, (Veinott, Kanki, & Shafto, 1995) found that up to 45% of every assembler's shifts were actually spent on finding and reading procedural and related information when preforming their tasks. These issues can be addressed by AR since the core benefit from a cognitive psychology standpoint, it has the potential to merge informational activity with direct work activity to make the overall information access more efficient. AR can change the way we think about instructions and how we use them.

BIM + AR for Way-finding

BIM navigation systems can be complemented with AR technology to optimise navigation related issues like searching for components in a warehouse or construction site. Workers can easily find out where the exact component is located through a geographical coordinate system. One of these coordinate systems is the common method latitude, longitude and altitude (LLA). The difficulty and challenge with said system is the amount of time it takes to get accurate coordinates for a particular location (X. Wang et al., 2014).

Challenges within the construction industry

According to (Arayici et al., 2011); 3D modelling is often seen as an unnecessary complication by practitioners. The construction industry seems to be reluctant in considering the implementation of new technologies within their standard processes. Often if, for instance, some detail information is needed, it is sufficient enough to make a 2D design of it. This line of reasoning is seen also in the preliminary interviews, conversations and brainstorms. Professionals within the construction industry tend to stay inside their comfort zone, rather adopting tried and field-tested technologies, rather than evaluating and adopting modern technologies such as AR. Then there is also the issue of lack of standardisation of Information Communication Technology (ICT) tools. Workers use different tools and datasets causing inconsistent handling of project related information that ultimately depends on the preference choice of an individual project manager.

3.3.2 Data acquisition technologies

These types of technologies are used to create 3D point clouds to provide accurate and comprehensive as-built information which is used within the BIM model. The process of creating BIM information from 3D point clouds is called Scan-to-BIM and currently require a lot of manual user input making the entire process inconvenient and error prone (Son, Kim, & Turkan, 2015).

3D Laser scanning

3D laser scanning, generates a 3D point cloud through means of lasers. The points are then used to generate a 3D as-built model (Jiao, Zhang, Li, Wang, & Yang, 2013; Son et al., 2015). This technique allows users to collect a large amount of data over short periods of time making it very suitable for large projects and also infrastructural projects. The laser scanning technique for assessing the quality of built objects has been studied in several situations by automatically comparing an as-built model with a design model. These studies are often very expensive and involve a steep learning curve, making them unsuitable for small and medium sized companies.

Below the three steps needed to get from a point cloud to a 3D model are described.

1. Data collection, with the use of laser scanners
2. Data post-processing, model assembly and noise reduction
3. geometric modelling to create a 3D model

The figure below shows the steps in a graphical way.

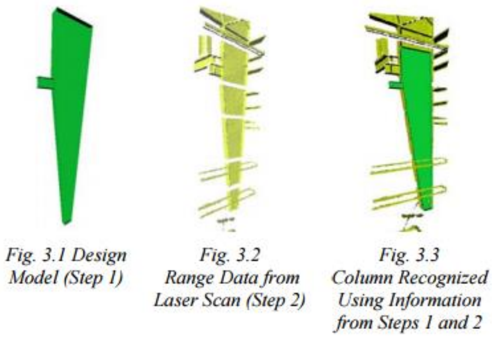

Figure 2: Visual representation of 3D laser scanning steps (source: (Gordon et al., 2003))

Terrestrial laser scanning (TLS) is one example of 3D laser scanning. Using TLS, 3D coordinates are obtainable from the surface of a target object or from a scene that is visible from a laser scanner's viewpoint (Alba, Barazzetti, Scaioni, Rosina, & Previtali, 2011). The 3D coordinates can be obtained in two ways; either time-of-flight (TOF) or phase based technology. TOF scanners emit a pulse of laser light to the surface of the target object or scene and calculate the distance to the surface of the target object or scene by recording the round trip time of a laser light pulse (Gordon et al., 2003). Phase based scanners measure the difference in a phase shift that is continuously emitted and returned sinusoidal waves. Phase based and TOF both have similar measurement accuracies, but they differ in scanning speed and maximum scanning range. Phase based TLS is generally faster than TOF in data acquisition (up to one million points per second), while TOF has a longer range in collecting data points (up to a kilometre).

TLS provides fast collection of 3D point clouds accurately in a short period of time while very little training or expertise is required for users. For these reasons TLS is widely used in the construction industry to survey civil infrastructures (Volk, Stengel, & Schultmann, 2014).

Photo/video grammetry

The core of this technology is to reconstruct 3D spatial information from either photos or videos by means of triangulation. This can be done for both finished and non-finished projects. Photo/video-grammetry adopts images or videos to derive 3D spatial data of the object or scene of interest (Luhmann, Robson, Kyle, & Harley, 2006). Photogrammetry derives geometric information of objects or other scenes of interest by using information from images. Video grammetry does the same by extracting geometric information from video frames (Bhatla, Choe, Fierro, & Leite, 2012).

This technology uses the principles of triangulation to derive geometric information from different images. In short, a new point in space is reconstructed from two converging lines from 2D locations of the point in different images (Fathi & Brilakis, 2011; Golparvar-Fard, Bohn, Teizer, Savarese, & Peña-Mora, 2011). See the figure below for a visual representation of photogrammetry.

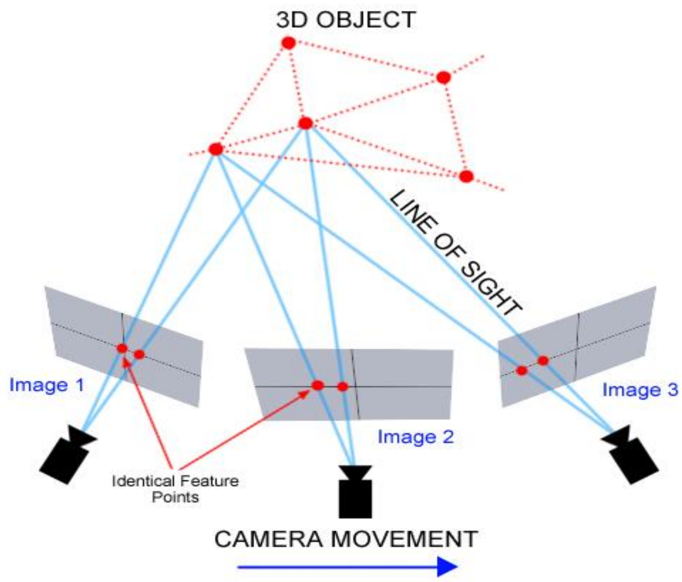

Figure 3: Visual representation of photogrammetry. (source: https://goo.gl/images/rdP1FS)

Photogrammetry usually involves several post-processing stages that tend to be quite time consuming. Also the use of semi-automated tools for generating the 3D geometric model from the point cloud requires intensive manual user input making them more susceptible to human interpretation errors (Son et al., 2015).

3.3.3 Process methods and tools

The literature study also includes the concepts of serious gaming and virtual design and construction as they are mentioned multiple times in the preliminary interviews. Serious Gaming (SG) and Virtual Design and Construction (VDC) are used to streamline the design phase or provide insights into other stakeholders' perspectives. According to the preliminary interviews both SG and VDC could be valuable for infrastructure construction projects.

Serious gaming

The concept of serious games and how serious gaming is defined in this research project are described below. Other topics discussed include history and challenges.

History of Serious gaming

Research about Serious gaming raises debate about the term being an oxymoron, meaning it is a "*figure of speech by which a locution produces an incongruous, seemingly, self- contradictory effect*"[4]. Clark Abt was the first one to use the term "Serious game" as an oxymoron in his book "Serious Games" (C. Abt, 1970). During the Cold War, Abt worked as a researcher in the United States. One of his goals was to use games for training and education and he actually designed several games such as T.E.M.P.E.R. (Djaouti, Alvarez, Jessel, & Rampnoux, 2011). During the Cold War T.E.M.P.E.R. was used by U.S. military officers to study the effects of the Cold War on a worldwide scale. In (C. Abt, 1970), Abt also provides non-digital math-related games to be used in schools and gives a clear definition of serious games:

[4] http://www.dictionary.com/browse/oxymoron

"Games may be played seriously or casually. We are concerned with serious games in the sense that these games have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement. This does not mean that serious games are not, or should not be, entertaining."

Abt later founded his own company and created games like ARPA-AGILE COIN GAME, which simulates revolutionary conflict in a country (C. C. Abt, Blaxall, del Solar, Gorden, & Gordon, 1965).

Serious games have also been used in U.S. politics, in *The New Alexandria Simulation: A Serious Game of State and Local Politics*" (Jansiewicz, 1973), the author explains how to use and play a game designed to teach the basic political mechanisms of the U.S. This game was also implemented in a non-digital format and is still being used in classrooms. This political game was researched and they observed that the game actually indeed improved the results of students studying American politics (Kahn & Perez, 2009).

The Cold War was an instigation for the U.S. army to invest money in the research and development department. Many projects from this era led to technologies that are widely used nowadays. For example, computers, the Internet and also serious games. The U.S. army was very familiar with computer simulations, many of the first computer programs were intended for military purposes. Military officers around the world were using serious "war" games for training purposes (Halter, 2006). Investing a lot of money in research and using war games for military purposes were formed the idea of creating computer-based war games in research departments (Montfort, 2005).

The initiative for serious games at this point has mainly focussed on military applications. The first civilian application was designed by the Research Analysis Corporation (RAC), that also created a military related game. In 1965 RAC designed a series of games called "American Management Association Games". In these games players compete against each other, as company managers, to make as much money as possible within 40 turns of play (Harrison JR., 1964).

It is evident that these games have not been accessible for the general public, but they can be considered as the ancestors of simulation video games that appeared in the 80's for personal computers, with military topics (Dunnigan, 1992)(Dunnigan, 1992) or without military topics (Wolf, 2007).

At this point in time serious games were primarily used for military purposes and some civilian applications were investigated, with all of them being non-commercial. During the 70's the first educational and entertainment games were produced on the first home video game console, the *Magnavox Odyssey* (Baer, 2005). Created by an U.S. defence contractor, Ralph Baer. Nowadays most of the video games are designed for entertainment purposes (ESA, 2010).

Definition

Literature research revealed that serious gaming is not generally defined, or there is not one general accepted definition of serious gaming. This makes it a challenge to describe the concept of serious gaming since it actually contains a broad spectrum of definitions.

To define serious gaming, the definition of a game needs to be clear. In the Oxford dictionary a game is defined as follows[5]:

1. A form of competitive activity or sport played according to rules
2. An activity that one engages in for amusement

By definition a game is bound by rules with multiple participants whom compete with each other while abiding the rules. In this case a game is intended for amusement purposes. However, a game can also serve other purposes for example educational. This leads to following definitions of serious gaming:

1. Any meaningful use of computerized game/game industry resources whose chief mission is not entertainment (Sawyer, 2007).
2. A mental contest, played with a computer in accordance with specific rules, that uses entertainment, to further government or corporate training, education, health, public policy, and strategic communication objectives (Zyda, 2005).
3. Games that do not have entertainment, enjoyment or fun as their primary purpose" (Michael & Chen, 2005).

These are just a small sample of the numerous definitions of serious gaming. However, it is clear that these definitions have quite some variations, where one considers more variables of serious gaming (entertainment, enjoyment, fun) others exclude them from their definitions. For this research project the definition of serious gaming will mostly follow (Sawyer, 2007):

"Any *meaningful use of (computerized) game/game industry resources whose chief mission is not entertainment."*

Since serious games do not have to be computerised or digital the definition above is adjusted. Also the purpose of serious games differs per game and thus each individual game has its own desired end result. The definition above considers this by incorporating "any meaningful use".

[5] http://www.oxforddictionaries.com/definition/english/game

Challenges

Across all the different application areas as listed in the overview, serious gaming has not reached its full potential. Researchers have identified the challenges that prevent serious games from being used on a large scale. (GALA, 2014). The GALA Special Interest Groups (SIG) have looked into the challenges faced within each application area domain. In some application areas, the SIGs found that the deployment of serious games showed clear evidence of effectiveness. However, other application areas resulted in less to none effectiveness. Knowledge transfer among the different application areas is nearly nonexistent.

According to the SIGs application area specific challenges can learn from other application areas which are further in the process of deployment of serious games. SIG leaders therefore revisited the area specific challenges with the objective to identify similarities and dependencies and to produce a synthesis. This resulted in a list of six grand challenges (GALA, 2014):

Figure 7: Serious games challenges. (source: (GALA, 2014))

Like any other innovative concept serious games also need a sustainable *business model* if deployment on a larger scale is desired. *Quasi operability standards* refer to compliance with specific industrial standards but also standards related to accreditation. This leads to high total costs of serious games, that can be explained by small markets and low financial resources. Therefore, the degree of *reusability of digital assets* is also identified as a main challenge. The *utility of learning experience* addresses topics as how to use serious games and how to facilitate collaboration among the players. Often the challenge is to reduce the complexity of the games while at the same time assuring that the game is sufficiently realistic to achieve its goals. *Integration into the learning process* deals with issues related to evaluation, effectiveness, proof of concept, and other pre-requisites that allow acceptance of serious games as a qualified learning tool. The last major challenge is the *link between real and virtual world.* Emotional engagement and Human-Computer Interaction are the major topics for this challenge.

Virtual Design and Construction

This paragraph elaborates on the term Virtual Design and Construction (VDC). Some background information is given and also the definition of VDC. Next an overview of the implementation phases is given and also the application of VDC in the civil engineering.

Background information

The AEC-industry is responsible for making the world liveable through the means of buildings, offices, homes, schools etc. but also systems like water, waste, power distributions. The process in building these objects is highly fragmented due to the number of stakeholders involved and therefore takes a lot of time to complete projects. According to (Teicholz, 2004): The US construction process has measurably declined in its productivity per human hour invested over the past forty years, although sister engineering fields have dramatically increased their productivity during this period. Projects have long latency meaning it can easily take days or even months to get information or decisions. That is why the Centre of Integrated Facility Engineering (CIFE) has introduced the term Virtual Design and Construction in 2001 for the problem of fragmentation within construction processes.

Definition

The term virtual design and construction is defined as follows (Kunz & Fischer, 2012):

´*Virtual Design & Construction is the use of multi-disciplinary performance models of design-construction projects, including the Product (i.e., facilities), Work Processes and Organisation of the design - construction - operation team in order to support business objectives*.

Implementation phases

According to (Kunz & Fischer, 2012); research finds that users implement VDC in three different phases, each with its own value proposition and costs. See figure below for the different phases.

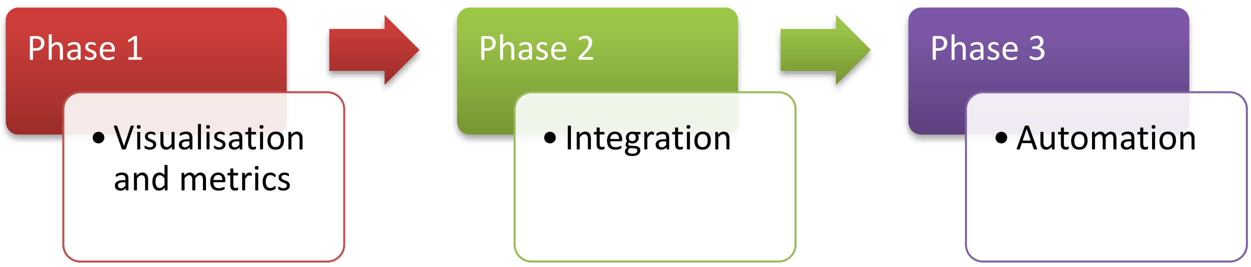

Figure 8: Phases of implementation (own illustration)

<u>Phase 1:</u> ***Visualisation and metrics*** entails project teams creating 3D models of the product, of the organisation that performs design, construction and operations and management and also the process followed by organisational participants to do design, construction and operations and management based on performance metrics that are predicted from models and tracked in the process (Kunz & Fischer, 2012). However, in order for VDC to work it is important for all stakeholder organisations to have the

competence in developing and interpreting visual models, also for multi-stakeholder collaborations there needs to be an incentive to share data which may require strategic change in partnering arrangements. In the visualisation phase, projects (Kunz & Fischer, 2012):

- Routinely model and visualise the most expensive elements of the Product, Organisation and Process (POP)
- Use a social process among project stakeholders to integrate multiple VDC models and model versions
- Justify investment in VDC tools, methods and human resources based on the value proposition to the project, since this phase is (relatively) inexpensive and individual projects receive can significant benefit
- Clarify project objectives, values, responsibilities, designs and expectations because good visualisation enables many more stakeholders to participate in project review far more meaningfully than in routine practice

Phase 2: ***Integration**,* this phase is computer based and deals with project related automated methods to exchange data among different modelling and analysis applications reliably. Most of the time data exchange is supported among different applications as sold by the same vendor. However, this is not the case for different vendors and applications. For integration to really work seamlessly, there needs to be a standard on exchange methods. This may require strategic commitment across different vendors. Also for integration to work well for multiple stakeholders the contracts at least need to allow data sharing and ideally to even incentivise data sharing. In this integration phase (Kunz & Fischer, 2012):

- Projects need to share data meaningfully among Product, Organisation and Process (POP) models and analysis programs using interoperation, or reliable computer-based data exchange.
- Projects cannot justify investment in VDC tools, methods and human resources based on their project value proposition. Rather, the value proposition must support the firm, since this phase is (relatively) expensive and multiple projects must use the same methods for the investment to produce significant benefit.
- IFC's are designed to enable this process, but there is little evidence that they are in significant use.
- Various vendors provide families of software applications that interoperate, often using proprietary exchange methods, which still limit exchange with other applications that might be useful to a project.
- Derive incremental value from integration per se because it can reduce modelling effort and time.

Phase 3: **Automation**, in this phase the routine design tasks are executed by automated methods. Project organisations need to realise that in order for automation to improve design, they really need to change their processes to enable or preform more high-value design and analysis and spend much less time and billable effort for routine design. They can implement this by changing from Design-Build or Design- Bid-Build to Design-Fabricate-Assemble, but this takes strategic commitment to support a new partnering arrangement. Automation requires integration and good visualisation helps make it work well. In the integration phase, projects(Kunz & Fischer, 2012):

- Automate some aspects of routine design or Computer Numeric Control (CNC) manufacturing of assemblies for field installation
- Cannot justify investment in VDC tools, methods and human resources based on their project value proposition. Rather, the value proposition must support the firm, since this phase is

(relatively) expensive and multiple projects must use the same methods for the investment to produce significant benefit.

- Enables dramatic increase in design efficiency and effectiveness;
- Enables dramatic decrease in construction duration, which in turn leads to breakthrough project performance in construction duration, e.g., the CIFE 2015 objective to be able to build most projects within 6 months from ground-break to high value use

As can be seen from the above implementation levels, VDC focusses on three main aspects; product, organisation and process. Each of these components can be found in every construction project and by using VDC they are made visual and measurable by using models, drawings and simulations (Rijsbergen, 2013).

Application VDC in civil engineering

VDC was developed for the AEC-industry in the US, but as a general method it can be applied to other construction-design processes. See figure below for VDC applications in the Dutch civil engineering sector:

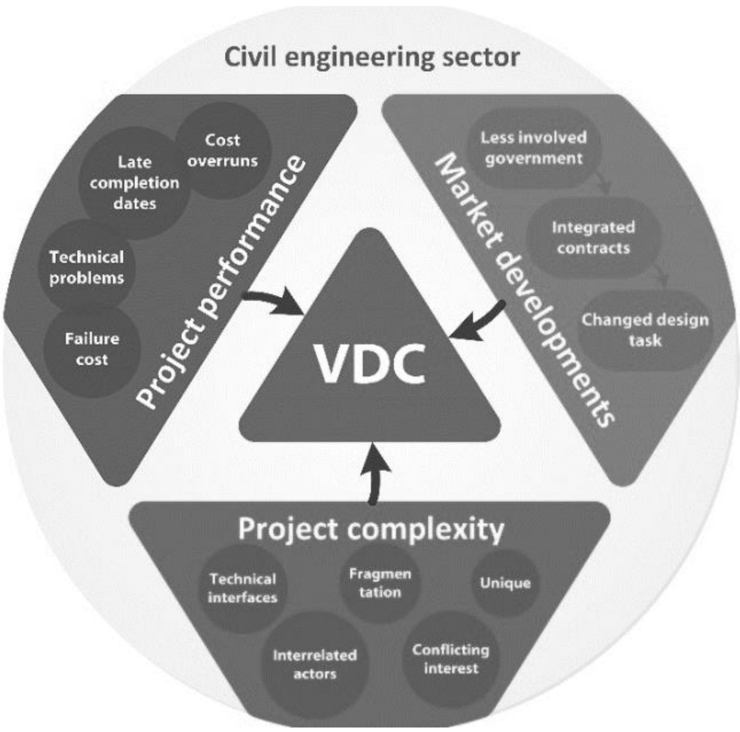

Figure 9: VDC applications in Dutch civil engineering (source: (Rijsbergen, 2013))

According to (Rijsbergen, 2013): the application of VDC can be described by three drivers. The first one is poor performance of civil engineering projects, as can be concluded from the research by Dutch infrastructure projects and their large number of cost overruns, failure costs, and failing completion deadline (Cantarelli et al., 2012). For this reason, VDC can be used to identify interfaces in the early stages of a project to minimise problems later on. The second driver is the changing market developments that result in changed designs tasks for contractors. Again, in this different environment with multiple stakeholders, VDC can be used to streamline the process and tasks. The third driver is project complexity of civil engineering projects. This driver deals with not only the technical difficulty but also the organisational difficulties encountered in the civil projects. VDC responds to these difficulties by focusing on both the product as well as the organisation and process, With the use of visualisations and metrics structural complexity can be quantified, measured and prepared during iRoom sessions. An iRoom is a room equipped with multi-screens to allow stakeholders to simultaneously describe, present and evaluate projects. Dynamic complexities that result from interaction between stakeholders can occur during iRoom sessions. These types of complexities can be managed with the use of VDC in iRoom sessions. In theory the application of VDC can be of added value reasoned from these drivers (Rijsbergen, 2013).

3.4 Chapter conclusion

This chapter is a literature study and has elaborated on the challenges and possible solutions in the AEC industry. It seems that quickly assessing built objects against their design intent is one of the greatest challenges in this industry from a theoretical standpoint. According to the literature study this challenge increases due to more complex designs. As construction projects have a high risk high impact profile, adding extra risks by implementing experimental tools and technologies in projects seems irrational. However, the AEC industry must anticipate on increasing challenges and the modern visualisation technologies reviewed in this chapter do seem to have potential to address this issue. The reviewed technologies, tools and methods seem to have a potential for increasing the level of spatial information in projects. The next chapter elaborates on the case selection procedure and the in-depth interview to obtain deeper insights in the challenges faced in the execution phase.

4. Case studies

This chapter elaborates on the selection procedure for the project cases in section 4.1. Afterwards the project cases are briefly discussed with general background information in section 4.2. Section 4.3 elaborates on the interview process, topics, and the selection of interviewees. Lastly in section 4.4 the chapter conclusion is provided.

4.1 Case selection

As mentioned earlier, due to limited time three cases are selected from a pool of past and present projects from the construction company Dura Vermeer. The company's projects can be categorised into three groups, see the table below.

Category	*Financial bandwidth*
Small local projects	<€ 1.000.000
Midsize projects	€ 1.000.000 - € 10.000.000
Super projects	> € 10.000.000

Tabel 3: Project categories

First there are small local projects below € 1.000.000. These projects may have their problems at any given time, but the related costs are not of great magnitude as they are quite small in size. It should be mentioned that these types of projects do not encounter complex problems most of the time and the problems that do occur are often easily solved.

Then there are the midsize projects who fall in the order of € 1.000.000 - € 10.000.000. These projects form the bulk of all the total projects within a company. This category contains a wide variety of projects such as tunnels, viaducts, bridges, sluices etc. The majority of all projects falls in this category, that is also why the most problems occur in this category. Since the bandwidth can vary strongly among the projects, the errors that occur can have a high impact on the profits of the related project but also the company as a whole. Financially seen, this category has the highest impact on the company, it can be either positive or negative depending on how the occurring errors are being handled.

Lastly there are so called super projects above € 10.000.000. These types of projects are essentially a few midsize projects clumped together. For instance, there could be such a super project which develops a new urban area including houses, bridges, tunnels and other infrastructural objects. These super projects do not occur that frequently and therefore do not have a high impact on the financial situation of a company compared to the previous category.

The three cases are selected from the midsize project category since they have the highest impact on the financial situation of the company. The selection criteria for these cases will be: either a renovation project or a project where the new object had to be constructed in connection with an already existing object. Also, in these projects there should be cost overruns due to errors in the execution phase of the project. Preferably cost overruns originated from construction errors related to a lack of spatial information. For instance, not building within predetermined limits.

4.2 Case description

This section elaborates on the chosen projects as preparation for the in-depth interviews. For this research three cases are selected.

Het Atrium Amsterdam

The Atrium building is located on the Zuidas which is a business district in Amsterdam. This business district is located next to the motorway A10 and also connected with a public transportation hub with direct access to Schiphol airport. The area surface of the Zuidas is approximately 225 ha. A lot of companies are established in office buildings like the Atrium building. The Atrium building renovation and upgrade has started in the summer of 2016.

Figure 10: Impression new building (source: https://www.amsterdam.nl/zuidas/bouwprojecten/uitbreiding-atrium/)

The building renovations and upgrade works include:

- thorough upgrade of the garden
- the restaurant
- the central lobby and reception
- other common areas
- the climate installation

Next to renovating the building is also being upgraded with two towers which brings the total office area to 54.000 m^2 (was 20.000 m^2). A parking garage is also constructed which will be able to facilitate 525 vehicles over 2 parking levels alongside the renovated building.

The project clients are GNS-bouw and GNS- vastgoed. The uniqueness/complexness of this project lies in the rotation of new project team members during the project. To begin with the organisation of the project phases, the entire project is split up in three phases currently the project is in phase 2. The initial plan was to construct the parking garage first and then the towers next to it. However, the parking garage is not constructed in time which leads to both the towers and the garage being constructed at the same time. These parallel construction activities made the entire project more complex.

Figure 11: Impression Atrium entrance (source: https://atrium-amsterdam.nl/news/)

At the start of the project the documents and design were there, but they were far from complete and also the time planning was unrealistic due to this fact. When the construction planners started their activities, they discovered a whole lot of open ends which needed to be addressed if they were to continue. For instance, the design traffic load unexpectedly changed for the last parking garage floor. But the most common problems with the design was the overall lacking of a practical, executable design which translated into tons of stress and complexity for the project teams in order to even start building. The combination of a tiny construction site in the middle of a business district, the lacking design and the garage and the tower being constructed simultaneously, made this project extremely complex and time demanding.

Phase 1 started by placing sheet piles and draining the construction site and problems occurred immediately. First the sheet piles did not reach their desired depth. Also, the construction pit was filling up with water which showed that the preliminary research for the water management in the area was wrong and measures had to be taken right on the spot to solve this issue. The remainder of this phase dealt with a lot of delays and other obstructions during construction, this resulted in another delay for the start of phase 2. However, since the project team of phase 1 was swamped with their work it was impossible for them to also prepare the work for phase 2. The decision was then made to introduce a new project team for the second phase of the project and let the first project team finish their phase 1.

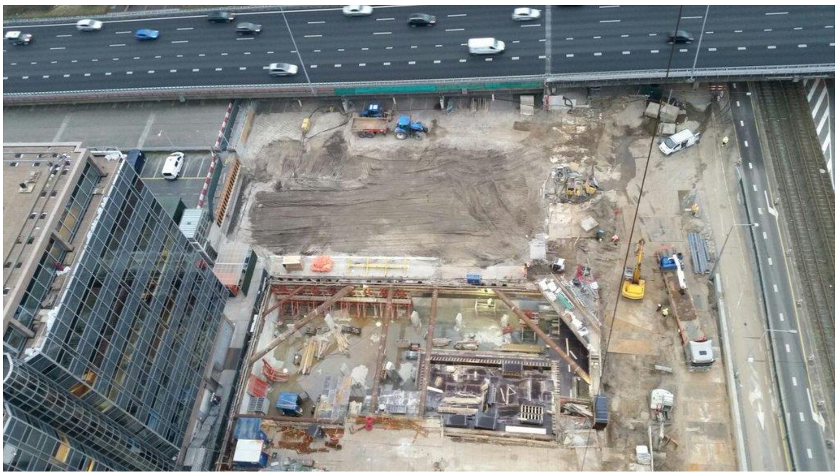

Figure 12: Construction site Atrium Amsterdam (source: https://twitter.com/LooijenTweet/status/692656289172865024)

During phase 2 the project team had to deal, almost fight, for space to construct their work. In this phase of the project there was a huge amount of activity on the tiny construction phase. With a lot of parties and suppliers this meant a nightmare for the logistics (spatial information) part of the project since parties were also working above and beneath each other. For instance, when the contractor above needed to place windows in the towers, the contractors beneath them working on the parking garage had to stop their work and move.

In general, this project was very complex and demanding, the communication among the parties was even more terrible, for example, proposed plans to the client did not always get a response or approval. Also, the impact of the environment is taken too lightly which is why this project makes a perfect example for the lack of spatial information during the execution phase.

OV SAAL Almere centrum

Keeping a future perspective in mind for the accessibility among Amsterdam and the northern parts of the Netherlands, it is important to have a proper and reliable train connection between Almere – Amsterdam Centraal and between Almere – Schiphol and Lelystad. In 2030, it is expected that 80.000 commuters will use this trace, in 2010 the number of users was 40.000[6]. The current public transportation network is not able to sustain this growth that is why the public transportation hub in Almere is expanded to facilitate more trains and more space for the tracks and their different functions.

This project can be split into 2 phases:

- The short-term phase (2010 – 2016)
- The semi-long term phase (>2020)

During the first phase the tracks between Schiphol – Amsterdam – Almere – Lelystad have been improved with an allocated budget of € 900 million. The condition here is to be able to have a train every 10 minutes between Amsterdam and Flevoland. Then there have also been some smaller measures which allow for a better utilisation of the new tracks. Also, these smaller measures are cheap, quickly installable and provide less construction hindrance. Some examples of these smaller measures are:

- Smaller changes to the track for better use of the track (additions or replacements of signal posts and installations)
- Installations and use of new technologies
- Adaptation of new legislation

Some of the adjustments after 2016 are:

- Two additional rail tracks in Weesp (from 6 to 8)
- Implementation of European Rail Traffic Management System (ERTMS) security system
- Extra space for commuters on platforms
- Measures to improve railway crossing security

For the adjustments after 2016 a budget of € 500 million is available. This budget is for the implementation measures, especially for the municipal of Weesp. Also after ERTMS is active the frequency of trains can be increased.

For this thesis, the section of this project that is researched is the SAAL Almere centre project. See figure 13 for an overview of the entire OV SAAL rail trace highlighted with red.

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6 https://www.rijksoverheid.nl/onderwerpen/spoor/betere-bereikbaarheid-spoor-schiphol-amsterdam-almere-lelystad-ov-saal

Figure 13: OV SAAL situation (source: https://www.rijksoverheid.nl/onderwerpen/spoor/betere-bereikbaarheid-spoor-schiphol-amsterdam-almere-lelystad-ov-saal)

Just east outside Almere centre two reverse tracks (keersporen) have been realised and multiple change complexes (wisselcomplexen). Furthermore, the bulk of the civil work consists of modifying multiple viaducts for the construction of the revers tracks and the construction of sound screens. Since the amount of trains on this route will increase over the upcoming years and therefore the noise pollution will increase, sound screens are constructed to keep the amount of noise within legal limits. Over a length of 24 km. the track will have sound screens on both sides of the tracks. Normally these construction activities are not technically difficult but since the project is in the middle of the city, the available space is limited and proper project planning is mandatory.

This project started with a project team consisting of a project leader, construction planners from infra and civil and a chief construction executor. This setup resulted in a very positive and pleasant project experience. The team delivered the project on time and also within budget even though challenges occurred during the project due to some poor choices and decisions in the preparation phase of the project. Most of the challenges encountered in the execution phase of the project originated from limited space for construction, that was not anticipated or neglected by some of the construction planners.

Tournooiveld Den Haag

This project is placed within the heart of Den Haag city centre. The project is a good example for this research project since this environment deals with many stakeholders, interfaces, traffic and limited working space. See figure beneath for the project location.

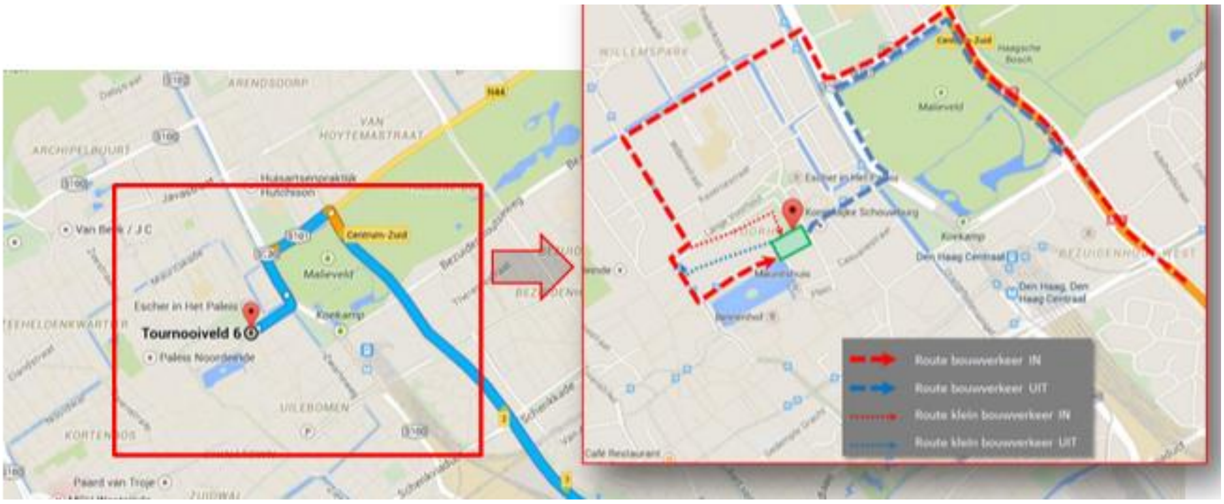

Figure 14: Project location (source: Dura Vermeer project informatieboekje).

The project is a private initiative from SENS real estate, a small project developer based in Den Haag. SENS real estate wanted a parking garage in the west area of the centre of Den Haag, not because there is a lack of parking space, but because there is an unequal balance of parking garages in the centre. Also, the municipality desires cleaner and open ground levels. SENS real estate managed the political procedures and afterwards together with Dura Vermeer they designed the parking garage and sold it to the Belgian parking manager Interparking who is attempting to expand their activities to the Netherlands. Over three levels 320 parking spots have been realised, see the figure below for the floor plan.

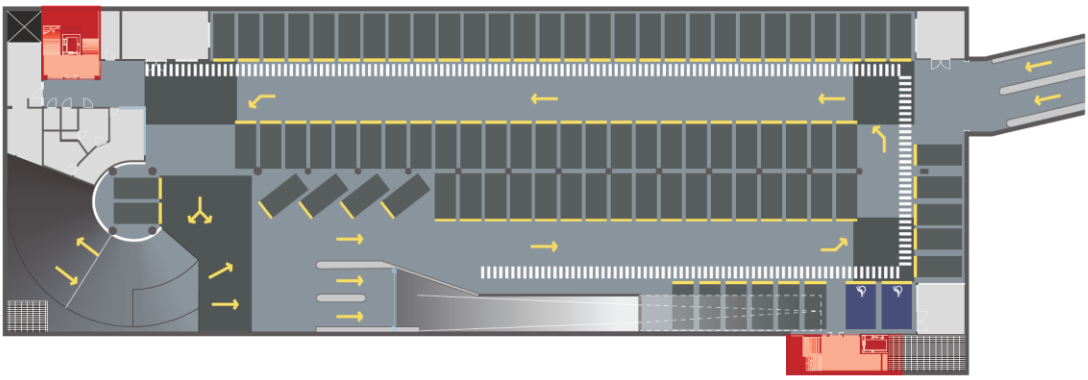

Figure 15: floor plan parking garage (source: Dura Vermeer project informatieboekje).

As can be seen from the project location, the construction site is located in the centre of Den Haag and surrounded by historical buildings, the American embassy, public transportation routes, monumental trees and traffic. The environment had a serious impact on this project since it was a private and not municipal initiative to develop the parking garage. Therefore, the municipality had no interest in this project being developed and that was noticeable in the way they stuck to their conditions (damages to historical buildings, monumental trees, east-west traffic passage at all times).

In September 2014, they started moving the cables and pipelines and was finished in July 2015, which was also when the design for the construction pit was finished. Afterwards the location was prepared for the execution phase of the project. The main guidelines for the execution was:

- Preparation work
    - Moving cables and pipelines
    - Archaeological research
    - Site preparation
- Project execution phase
    - Construction pit
        - CSM wall & grout anchors
        - Underwater concrete & grout anchors
    - Concrete construction
        - Construction floor
        - Walls
        - Prefab columns and floors
    - Finishing construction
        - Architectural
        - Installations
- Redesign Tournooiveld
    - Rebuilding tram tracks and roads

The project was finished in January 2017 and opened a few months later for exploitation. With the start of the exploitation the parking garage also got a new name; Museumkwartier. The intention in changing the name of the garage was to promote the surrounding museums in effort to also attract more visitors to these museums.

4.3 In-depth interviews

The research method for diving deeper into the level of spatial information used in this thesis is in-depth interviews. Prior to the interview a list of general subjects and themes are formatted into a list of interview questions. The interviewer uses this list as a guideline during the interviews and assures the subjects discussed during the interview are relevant for the research project. Appendix B contains the list of interview questions that is structured to ensure a clear and logical line of thoughts. Starting with some general questions followed by defining a clear starting point for the interviewee in the project. The latter deals with the moment in time but also the available spatial information and topics like project organisation. Afterwards the questions dive deeper into subjects like describing which challenges they encountered with spatial information in the project and how they solved it. The list closes with more general approach related to equivalent experiences in different projects with spatial information. Lastly a number of reflective questions are asked about the positive and negative experience the interviewee had in the project.

As mentioned in the first section of this chapter, three project cases are selected. Within each case two different employees are interviewed, a construction planner (werkvoorbereider) and a construction executor (uitvoerder). Both of these roles are involved in the execution phase but operate in a different manner. The goal is to dive deeper in the experience and knowledge of the interviewees on the topic of spatial information and try to clearly define the challenges they encountered with spatial information and how they managed it. Lastly a BIM manager is interviewed who also participated in one of the selected projects. His input is valuable for this research project since preliminary interviews showed that

BIM is not a standard method in Dura Vermeer. The BIM manager can provide information and the challenges with the implementation of BIM.

4.4 Chapter conclusion

This chapter elaborates on the selection procedure for the project cases and the interviewees. Due to time constraints three projects are reviewed and selected on the following criteria. The project cases are from the midsize project category and are either a renovation project or a project where the new object had to be constructed in connection with an already existing object. Cost overruns should have been made in these projects, preferably due to errors related to a lack of spatial information in the execution phase. Based on these criteria the following cases are selected; Het Atrium Amsterdam, OV SAAL Almere centrum and Tournooiveld Den Haag. A construction planner and a construction executor are interviewed from each of the three cases. The interview questions consist of a list of general subjects and themes designed to provide precise and descriptive data. These questions aim to explore the challenges and solutions related to a lack of spatial information as experienced by the interviewees. The next chapter provides the results from the in-depth interviews and co creation session.

5. Results

This chapter contains the results of both research steps. First the results of the interviews and a summary of the key findings of each interview is given in section 5.1. Next the results of the expert review co creation session are given in section 5.2. Both results are evaluated and the sub questions are answered in section 5.3. Lastly in section 5.4 the chapter conclusion is provided.

5.1 In-depth interviews

[Confidential information]

5.2 Expert review co creation

[Confidential information]

5.3 Results evaluation

In the previous sections the results from the interviews and co creation session are given. In this section, the sub questions are answered based on the findings in this chapter. See the tables below for a recap of the interview results and the co creation results. The interview results are given in the table below. General results are in the left column and the results specifically related to the lack of spatial information are in the right column.

	Results	***Results related to lack of spatial information:***
OV SAAL Almere	• Great start, best approach to begin a project • Design lacked in terms of execution • Limited work space, underestimated in preparation	• Deviation supplied information and reality • Corrections not documented/updated
Tournooiveld	• Tough contracting process, only 6 months left for construction • Intensive cooperation with subcontractors resulted in integral approach and planning optimisation • Limited work space, site located in city centre	• Incomplete design • Unclear subjective requirements structural outfitting
Atrium Amsterdam	• Project divided in three phases, currently in phase two with a separate project team • No logistics plan and design with lots of loose/open ends in terms of practicality • Environment impact is heavily underestimated	• Tiny construction site with many parties and tight planning • Constant effort to create space to actually construct the project
BIM-manager	• Currently on-site paper remains the best medium for information transfer • In the design phase practical information from construction planners and executors is missing • People in the construction industry are not ready to implement innovative technologies to improve information flow	• Technology to represent data on site is not practical • Working with old versions of drawings • Potential to combine gaming industry aspects with BIM aspects for better project results

Table 13: Overview results interview

5.3.1 Sub question 1

With the interview results the sub research question 1 and 2 are answered. These research sub question have been formulated as follows:

1. *What spatial information is missing in the execution phase?*
2. *What are the implications of lacking spatial information, during the execution phase, in terms of project end results?*

By interviewing project team members and diving deeper into the lack of spatial information over three different projects, a broad bandwidth of answers was found. This is mainly because the term spatial information in and of itself is very broad. In the right column in the table above the examples of the lacking spatial information in these projects is given. They vary from lacking spatial information on drawings and in designs to aspects from the construction site and dealing with the environment and parties involved in the projects. The last two, environment and parties, seem to be more common in the execution phase. However, the lack of spatial information in drawings and designs also showed up in the execution phase in these projects. In these specific projects the lack seemed to be a ripple effect originating from design phase.

5.3.2 Sub question 2

The second sub question, *what are the implications of lacking spatial information, during the execution phase, in terms of project end results,* seemed to be quite constant over the three different cases. According to the interviewees the most important implications are time and cost. The time aspect differed from a few weeks to months in the researched projects which had a duration of 1 to 2 years. It is noticeable that these delays are more related to the specific construction activities or processes in the project and not so much the date of project delivery. The OV SAAL Almere and Tournooiveld projects were both delivered on time even with challenges and delays through the projects.

Increased costs are considered a direct effect of lacking spatial information. According to the interviewees it can either originate from a lack of spatial information in design and drawings like in the Tournooiveld and Atrium Amsterdam projects. But it can also be a result of poor logistics and practicality and environmental impact like in all three projects.

Considering the triple constraint (time, cost, quality) the last factor; quality, seems to be a complex variable to measure. It was a reoccurring topic in the interviews as some of the interviewees stated, they, the construction planners and executors, always find a way to construct the object but how efficient, in time and cost, can it be realised is the challenge. However, even though a built object complies with its design and structural demands have been reached in terms of quality, during a project challenges will occur which could influence the quality. According to the interviewees every project will face its challenges and the project team will eventually find a solution. In the process of solving the challenges, the team must quickly make choices in solving these challenges which could lead the built object to differ from its design intent. This difference is not included in the initial project design and it is often questionable if these differences are beneficial for the quality of objects on the long term. It is not unimaginable that in solving the challenges, project teams could also negatively impact the quality over time.

The last implication was mentioned as most negatively impacting the project team members on various levels. It is the stress and uneasiness from high workloads because of lacking spatial information. If there is a lack in either design, drawings, logistics or practicality then project team members must come up with solutions. In the three projects the project team members were faced with finding solutions for these types of issues while keeping up with the regular deadlines and planning. Especially in the execution phase there seems to be a sense of urgency for these issues which demands fast solutions and therefore impacting the project team members with stress and uneasiness since there rhythm of work processes is disturbed.

5.3.3 Sub question 3

See the table below for the results of the co creation session. With these results the last sub question can be answered:

3. *Which technologies or other means can help improve the lacking spatial information?*

	Greatest challenge	*Solution*
1. Unclear requirements by the client and a design with loose/open ends	Having a proper execution design in time	Engaging with client in a conversation, while diving deeper in his wishes, desires expectations and objectively stating them in the contract
2. Supplied/obtained information does not match with the reality on site	Knowing on paper what the current situation is on site and how it impacts the project and activities	Depends on contract, as a contractor conducts own measurements prior to construction so they can control it
3. Corrections have been made on site but is not updated on drawings	Maintaining the processes through the entire project	Keep checking if the processes are executed and if the project team members are sticking to them
4. Subcontractor falls behind with his designs (installations)	Knowing who you are collaboration with and guarding the process	Choosing competent partners whom can be trusted and not the cheapest like usual, Design leader who keeps parties accountable
5. Very small construction site in busy city centre with many parties, high workload and little space	Contractors and parties who you can trust and know that you can complete the project with	This is a task for the managing board of the company, project team members are too busy with deadlines

Table 14: Overview co creation results

The purpose of the interviews was to determine the problems encountered in Dutch infrastructural projects related to a lack of spatial information and what their implications are for the project result. Over three different projects the results show overlapping on certain topics. The topics and results formed the basis for the expert review co creation session in the form of five scenarios. With the purpose of gauging the construction planners and executors with their ability and resourcefulness to determine the greatest challenge and more importantly how they would solve that challenge.

In the literature study (section 3.3) potential modern visualisation technologies and options are mentioned in dealing with a lack of spatial information. For a recap see the list below:

- BIM
- Virtual reality, Augmented reality
- 3D Laser scanning
- Photo/video grammetry
- Serious gaming

- Virtual Design and Construction

From the table above, it can be seen that the results hardly correspond with the potential modern technologies. During the co creation session the participants assessed the scenarios and formulated solutions which hardly included modern technologies or methods. Most of the solutions are in line with managing human errors and minimising its negative impact in the scenarios. The BIM manager (appendix H) also said that people in the construction industry are not ready yet to implement innovative, modern technologies and that is exactly what these co creation results show. Currently the best answer in dealing with the lack of spatial information seems to be making sure the project team members and other parties involved, stick to procedures and processes. In general, keeping human error and negligence to a minimal which can be achieved in numerous ways depending on the situation. According to the participants, the modern technologies at the moment are just not practical enough and people do not see the added value of it. The latter should be addressed by the managing board of the company to incentivise the adoption of modern technologies.

5.4 Chapter conclusion

The results from the in-depth interviews show the variety in examples of lacking spatial information. This variety could be explained due to the term spatial information being very broad itself. The common categories in the results from the in-depth interviews are lacking spatial information in drawings and designs and dealing with aspects from the construction site, environment and parties. Regarding the implications of a lack of spatial information they seem to be quite constant. According to the interviewees delays and cost increases seem to be the most important factors. The delays are relative small in these reviewed projects. Delays differed from weeks to months in the projects with durations of 1 to 2 years. Also, these delays did not impact the project delivery date but rather specific construction activities and processes. According to the interviewees the cost increases also seem to be a direct effect of lacking spatial information. The increases seem to result from lacking spatial information in designs and drawings, poor logistics, poor practicality and environmental impacts. Stress and uneasiness experienced by project team was also mentioned by interviewees as a result of lacking spatial information. Lacking spatial information in designs, drawings, logistics or practicality causes urgency among project team members to come up with solutions. This results in a high workload since project team members also have to keep up with regular deadlines and planning. The results from the co creation session show the greatest challenges and respective solutions as described by the participants. In their solution description, the participants hardly included any modern visualisation technology apart from BIM. According to the participants the solutions to deal with these challenges are management of human errors. They think modern technologies currently are not practical enough and people do not see the added value of it. The next chapter answers the main research question with the results from this chapter. Afterwards the answer is discussed, and limitations and recommendations based on this thesis are provided.

6. Conclusion

In this chapter, the main research question is answered in section 6.1. In section 6.2 the answer is validated and discussed. Section 6.3 elaborates on the research limitations. Lastly section 6.4 elaborates on the recommendations for the scientific field and Dura Vermeer.

6.1 Answering the main research question

This thesis provides insights into project cost overruns of the construction industry and specifically the infrastructure sector. It shows how project cost overruns are not decreasing over time while budget forecasting techniques are becoming increasingly more accurate. The construction industry seems to be known as a conservative industry which translates into working with suboptimal methods, tools and technologies. Preliminary interviews show the challenge this industry is facing in quality assessment of constructed objects in the execution phase of projects due to lacking spatial information. The literature study shows many potential solutions for a lack of spatial information and revealed the necessity of additional research to obtain practical information on the implications of lacking spatial information. The sub questions have been answered to answer the main research question:

What are the implications of lacking spatial information during the execution phase of Dutch infrastructural projects and how can they be tackled?

Interviews have been conducted to pinpoint sources of lacking spatial information in infrastructure projects. The in-depth interview results show a broad spectrum of examples of lacking spatial information, varying from lacking spatial information on drawings and designs to aspects from construction site to environmental impacts and dealing with parties involved in the project. The latter two do seem to occur more frequently in the execution phase of projects.

The impact of the lacking spatial information is considered regarding the triple constraint; time, cost and quality. According to the interviewees quality seems to be rarely compromised in projects. Multiple interviewees state that they, the construction planners and executors, always find a solution to the challenges they encounter. According to the interviewees every project faces challenges and the project team must quickly produce solutions. In the process of finding and producing solutions a built object could differ from its initial design and it is often questionable if these differences are beneficial for the quality of the object on the long term. As these differences are not included in the initial design it is not unimaginable that in solving the challenges during the construction phase, the project team could also negatively impact the quality of the objects on the long term. Even if these solutions do comply with the client's structural requirements and design. According to the interviewees and participants it seems to be the efficiency in time and costs that matters the most. Hence time delays and cost increases seem to be direct effect of lacking spatial information. Although compared to the entire project the time delays and cost increases seem to be rather modest. Both Tournooiveld and OV SAAL Almere finished on time and within budget while they did encounter delays and cost increases during the project as a result from lacking spatial information.

For time, it shows to vary from weeks to months depending on the challenges encountered in the reviewed projects. These delays do seem to be related to specific construction activities or processes in the project and not so much the date of project completion. According to the interviewees, increases in costs occur from a lack of spatial information in designs and drawings or because of poor logistics, poor practicality and environmental impacts. The most important effect of lacking spatial information, according to the interviewees, seems to be project team members experiencing stress and uneasiness from a high workload. Especially in the execution phase of projects there seems to be a sense of urgency for solutions to unexpected challenges.

The literature research shows the theoretical challenges in the construction industry with potential solutions for a lack of spatial information. Results from the in-depth interviews formed a practical understanding of the challenges encountered in projects. To provide a deeper understanding in dealing with spatial information the co creation session is conducted. The results show a difference in the solutions mentioned by participants and the potential solutions from the literature research. Most solutions from the participants are related to managing human errors and their negative impact on the project and not so much implementing modern technologies or methods to deal with a lack of spatial information. These results are in line with a specific statement from the interviews, stating that professionals in the construction industry are not ready yet to implement modern technologies. From a practical viewpoint, the answers of the participants are understandable as they are focussed on reaching deadlines within the project. Dealing with stress and high workloads could lead these participants to think in concrete solutions that can be implemented quickly to achieve quick results. It is understandable that the majority of these quick results come from the employees (human errors) and their influence in the project. On the short term these participants could be right and quick results could come from dealing with human errors. However, on the long term the literature study has concluded that the challenge of quickly assessing the construction quality of built objects will increase.

The literature study shows a number of possible solutions to solve the quality assessment challenges. The preliminary interviews and the in-depth interviews result show the majority of the interviewees as open to implementing modern technologies that increases project insights, early detection of errors, misalignments and other problems. As the construction industry has a high risk high impact profile, early detection seems to be key in dealing with lacking spatial information and avoiding project cost overruns. The literature study shows modern visualisation techniques as BIM, AR, VR but also, SG and VDC as potential solutions to the quality assessment challenge. However, according to the interviewees these technologies do not seem to be accurate enough and more importantly practical enough. Practical application and accuracy seem to be the biggest barriers for the implementation of these technologies in the construction industry.

This research project shows the difference in theoretical and practical challenges and related solutions in the construction industry. The interview results show that the implications of the lacking spatial information are substantial in terms of quality, time, costs and stressed project team members. To ensure the greatest advancement in dealing with the lack of spatial information in the Dutch infrastructure sector, it currently seems to be most beneficial to deal with the management of human interference in project processes related to the lack of spatial information. Project team members do not give project processes such as updating drawings, working with most up-to-date documentation and sticking to the initial plan, the attention it perhaps requires. These issues seem to be most frequent among the different parties within a project and not so much within the same party or company. People seem to be the key when it comes to dealing with lacking spatial information since this research project shows how in most cases they themselves are the cause. However, on the long-term, implementation of innovative and modern technologies seems to be necessary and companies should start incentivising the implementation of these technologies and methods to prepare for the increasing quality assessment challenge.

6.2 Discussion

This research project started with the objective to contribute to the implementation and modernisation of visualisation techniques and tools in the Dutch infrastructure construction industry. With the literature research and interviews the causes and implications of lacking spatial information are mapped and hereafter tested with practical knowledge and expertise during the co creation session to determine a practical solution.

Recent advancements in technologies provided architects and engineers the option to design increasingly more complex objects. While at the same time implementation of technologies for checking constructed objects against their design intent did not advance that quickly. This lack of spatial information in the execution phase made it challenging to check constructed objects for correctness. This research project provides insights in lacking spatial information in construction projects and how they affect the project. It provides a better understanding in the causations of lacking spatial information and how they contribute to delays, increased costs and stressed project members.

The combination of literature study and interviews showed the broad spectrum of the examples of spatial information. At first spatial information was defined to add focus but the results from the interviews showed the variation in interpretation of spatial information among the construction planners and executors. This was to be expected and anticipating on it showed many reoccurring topics in the results like designs and drawings, construction site- and environmental aspects. Also, the difference in theoretical and practical challenges and solutions was expected to some extent. The co creation session results show solutions leaning to the management of human errors and interference. Since the literature study described such behaviour, the conservative nature of the construction industry, these co creation result would have been expected. However, the gap between theoretical and practical solutions was larger than expected. Since BIM and virtual reality gain more popularity, an expectance for these options as possible solution is normal. All the results combined show how these modern technologies seem to be lacking in practicality and accuracy which seems to be the main reasons why it is not implemented in construction projects. For instance, according to the interviewees the Google Glass and HoloLens are far from user-friendly compared to simple paper drawings. Then there is also the issue of inaccuracy from several technologies. The experience some of the interviewees had with these technologies were not satisfying in contrast with what the literature study described as these modern technologies being an asset. The difference could be explained by projects in the infrastructure sector having a more complex nature than anticipated.

As stated in the introduction, the construction industry tends to have a conservative nature and working with traditional methods. The results from this thesis also show that the construction industry indeed seems to be somewhat conservative. The question remains why this industry is conservative. With a high risk, high impact, high workload profile construction projects do not seem to take additional risks. Working with familiar and proven methods and tools does seem to be the priority instead of experimental innovative methods and tools like modern visualisation techniques. With susceptible profit margins and high time pressures there seems to be no room for innovation and experimentation. Also, no incentives from clients for implementation of these modern technologies does seem to play a role as the client eventually has to pay for these tools and methods. Clients could also demand certain specific tools and methods, leaving no room for innovation and implementation of modern technologies.

Professionals in the construction sector, specifically in the infrastructure sector must adopt and implement a new way of working. This includes more modern technologies and transparency that can cause fear to some people. Fear of change in their functions and responsibilities causes these people to reject implementation of modern technologies for instance. Then there is also a group of people, mainly the older generation, that needs extra instructions and education on adapting to a new way of working. This issue could be solved by pairing older and younger generations of engineers together. This way the older generation can learn to adapt to modern technologies from the younger engineers since they generally progress faster through a learning curve. The younger generation learns from the experience and knowledge of the older generation. This group of professionals in fear and resistance have to be educated and accustomed to a new way of working. This process starts in the tender phase where changes must be explained and implemented. For instance, including a construction executor in the design phase to increase the practicability of a design. But also during the project searching for interaction and beneficial experiences of project team members. One example of increasing interaction is to improve documentation and communication among team members with images or video clips. Sharing images when challenges occur in a project can also quickly place responsibility where it belongs in the project team or organisation. This way the WE-culture is also stimulated as people must accept responsibility as they can be held accountable but are also supported when challenges do occur. For some people it takes a mindset shift to adapt to a new way of working and it could require an expansion of project teams with individuals who supervise these changes. Modern technologies seem to evolve faster than professionals in the infrastructure sector, that is way the emphasize should be on adaptation and education of these people.

6.3 Research limitations

The research and results have several limitations which are elaborated below.

1. **The validity, reliability and accuracy of the results could be questioned since it is based on a very small set of experts and projects.** A larger set of projects and interviews could have been used, however this will take more time to conduct the research. Due to time constraints, this research had to be limited to three project cases with six interviews.

2. **The co creation session was conducted with two participants**. With a group of five participants the results from such a session will provide more insights in the underlying thoughts of the participants. More people will provide more input, discussion and building on each other's thoughts.

3. **The generalised results should be used with caution**. Since the conclusion is based on a small set of data from one specific company. The result can be questioned as they are extracted from one company. The company culture could influence the results. Which could be very different when compared to another company in the same sector.

4. **The broad research area**, specifically the broad definition of spatial information. During the interviews the definition was given to focus the results. However, this could lead to framing of the answers given by the interviewees. The definition was given with some example and the clear statement to also think about other examples of spatial information than was given.

5. **The individuals** who participated in either the interviews or co creation session have the greatest influence on the results. Therefore, their opinion on this research topic also plays a key role. How these individuals think about the innovative, modern technologies is key. They could be open to new possibilities or stick with their current tools and methods.

6. **The interviewees are all employees from the same company**. It could be very beneficial to interview project team members from other companies who worked on those same projects. This will definitely provide more insights and understanding in the interactions in those projects.

6.4 Recommendation

With the main research question answered and the results have been discussed in the previous paragraph, recommendations can be made. First recommendations are given for future research which are related to the research limitations. Then recommendations are given for the company Dura Vermeer.

6.4.1 Future research

The recommendations for future research are given below and are related to the research limitations from the previous paragraph.

1. **Scaling input data of this research to include more projects and more interviews could lead to more accurate and reliable results**. Due to time constraints, a limited number of projects could be reviewed, and limited interviews were conducted. Further research needs to be conducted with a larger set of data for a more complete representation. This could include longer and deeper interviews to produce more accurate results. More projects need to be researched to identify the causations and implications of lacking spatial information over a larger set of data which could provide more reliable results.

2. **Conducting the co creation session with more participants.** This will lead to a better and deeper exploration of the spatial information issues encountered in projects as perceived by the construction planners and executors. Further research should focus on exploring how construction planners and executors deal with these issues. With more participants, there could be more discussion and interaction with each other, which can lead to more substantial results.

3. **Using quantitative methods, or a combination of quantitative and qualitative methods to identify the implications of lacking spatial information.** Quantitative research on lacking spatial information could provide more insights on the implications and effects of a lack of spatial information. This research project used qualitative methods to identify the causations and implications. However, a quantitative method would improve the validity and reliability of these results. For a completer understanding of lacking spatial information, tangible results are necessary which can be achieved through quantitative methods.

4. **Test the modern technologies in real projects.** Further research needs to examine the accuracy and practicality of modern technologies more closely. This could be in the form of testing the technologies in real projects and see how they preform against normal project processes. This could be performed by two different project teams in the same project. If construction companies quickly want to check the constructed objects against their design intent, these modern technologies are necessary and could result in greater efficiency and less costs increases.

5. **Narrowing the research area further**. As spatial information is a very broad term and includes lots of aspects from a construction project, further research should focus on one area to produce more accurate and reliable results. For instance, only include the start, mid or end of the execution phase or only the transition from design to execution. In these phases, there are many activities and procedures going on which makes it challenging to pinpoint the source of lacking spatial information. Another option is to focus on one specific area of spatial information. This could be only looking at how the environment is influencing the projects, or only how the design is realised. Exclusively looking at only one area could provide more accurate and reliable results.

6. **Conducting interviews and co creation sessions at other companies.** Since the research is conducted at one company Dura Vermeer, the results could be influenced by the company's

culture. Further research should examine how other companies deal with the issues of lacking spatial information and more importantly conducting the co creation session at other companies. Preforming both methods at different companies could provide a better understanding of this issue in the Dutch construction industry.

7. **Investigating how stress affects the people in the construction industry.** The results show how a lack of spatial information can cause stress for the project team members. While at the same time the causes of lacking spatial information are mostly by human error. Further research should investigate how these two are linked. Stress from one project could snowball and could cause errors in a new project. Following individuals over several projects could provide insights into why people in this industry seem so negligent.

6.4.2 Dura Vermeer

[Confidential information]

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Appendix A.1: Preliminary interview

[Confidential information]

Appendix A.2: Preliminary interview

[Confidential information]

Appendix B: Interview questions

1. Wat is jouw huidige functie? En tijdens het project?
2. Kan je een korte beschrijving geven van het project?
3. Wie is de opdrachtgever?
4. Hoe was het project georganiseerd en wie zijn erbij betrokken?
5. Waren er bijzonderheden in het project? (Nieuwe software, technieken gebruikt)
6. Welke informatie had je tot je beschikking?
7. Welke tools en middelen had je tot je beschikking?
8. Was dit voldoende naar jouw mening?
9. Waren er momenten waar je ruimtelijke informatie te kort kwam?
10. Welke problemen/onvoorziene zaken hebben zich voorgedaan als gevolg van een tekort aan ruimtelijke informatie?
11. Wat was hiervan de oorzaak?
12. Hoe is dit tekort aan informatie gedetecteerd?
13. Hoe is dit opgelost?
14. Wat waren de gevolgen hiervan?
15. Wat heeft dit tekort uiteindelijk gekost?
16. Tot welke (ruimtelijk) informatie zou je graag eerder toegang gehad hebben, gezien vanuit jouw functie?
17. Hoe zou dit tekort aan ruimtelijke informatie volgens jou voorkomen kunnen worden?
18. Wat heeft uiteindelijk tot de meeste onvoorziene kosten geleid?
19. Ben je deze problemen eerder tegengekomen in andere projecten?
20. Wat zijn volgens jou, de meest voorkomende fouten op de bouwplaats qua ruimtelijke informatie?
21. Wat zijn jouw positieve ervaringen met dit project?
22. Welke les haal je uit dit project voor toekomstige projecten?

Appendix C: Interview OV SAAL Almere centrum

[Confidential information]

Appendix D: Interview Tournooiveld 1

[Confidential information]

Appendix E: Interview Tournooiveld 2

[Confidential information]

Appendix F: Interview Atrium Amsterdam 1

[Confidential information]

Appendix G: Interview Atrium Amsterdam 2

[Confidential information]

Appendix H: Interview OV SAAL Almere centrum/BIM

[Confidential information]

Appendix I: Expert review co creation

[Confidential information]