Building better communication: An explorative research into system improvements for Dutch public-private construction projects

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ABSTRACT

Research shows that there are promising system developments for the construction industry, but that the sector is slow in adapting new technologies, due to a number of perceived barriers. The purpose of this study is to determine if the improvements can be made to the systems deployed during Dutch public-private construction projects, to increase the communication between stakeholders. The aim is to understand the specific barriers of stakeholders in Dutch public-private construction projects, and determine whether these can be solved by system improvements. The study makes use of semi-structured interviews with project overseers from both the public and private sides. The results of the study are a set of requirements for systems improvements, and considerations about standardization and knowledge retention in the industry. The study concluded that the current systems are underutilised, and that improvements can be made in BIM-maturity, knowledge retention, and information exchange, as well as more standardized communication.

KEYWORDS

Building Information Modelling, Implementation barriers, BIM-maturity, Rijkswaterstaat, Public-private construction

1 INTRODUCTION

The Netherlands is facing a growing issue with its existing infrastructure. Many of the bridges that were built during the 1950s and 1960s were not designed for the traffic load and strain they are currently experiencing. This has accelerated the deterioration of these objects, at a higher rate than was estimated [2]. Maintenance of these bridges is proving difficult and is very costly, due to hidden flaws and scarcity in materials [3]. The Dutch ministry of infrastructure and water management has already pleaded to the Dutch government for an increase in the budget to aid in solving this issue [31]. The different governmental bodies responsible for the infrastructure are now facing the challenge of having to maintain, refurbish and replace thousands of bridges in the next thirty years [1, 3]. In the Netherlands, these bridges are primarily the responsibility of Rijkswaterstaat [1] as an executive entity of the ministry of infrastructure and water management. Additionally, bridges or roads can be owned by provinces and municipalities. These government bodies create tenders that construction companies can bid on. Construction companies are then responsible for creating the infrastructure as requested in the government tender [41].

Due to the fragmented nature of the industry, a lack of qualified workers, and slim margins on construction projects, projects are often exceeding the established time and budget. In public-private construction projects, this is often more prevalent, due to uncertainties, political sensitivities, and the involvement of a larger number of partners [41]. The extra costs in the construction industry are considered failure costs [40]. Failure costs can be mostly attributed to rework, which is the process of revising or redoing a certain task or element due to it being incorrect [27]. Costs of performing rework in construction projects account to around 5% of the total contract value [19], and a total of 7.1% of the work hours [11].

Estimates of the failure costs in the Netherlands range between 5 and 16 billion euros yearly. According to research about failure costs in the Dutch construction industry by the ABN Amro bank [40], all construction companies experience some degree of failure costs. 57% of their respondents claim it is under 5% of the project budget, whereas over 39% of respondents claim that their failure costs are more than 5% of the project budget, with the rest not being able to give an estimation of the share [40]. Failure costs in the Netherlands originate largely during the on-site construction of construction projects. These can be the result of mistakes by the on-site construction staff, mistakes in the work preparation, mistakes in purchasing, but also due to bad planning. To add to that, mistakes made in the design phase and preparation phase only become visible during construction, potentially delaying the project. Many of these problems can be attributed to the time pressure that is on these construction projects. To combat these issues, "planning, communication, and deliberation" are some of the recurring themes [40]. Risks in communication and planning in the construction industry are can be mitigated by the use of information technologies (IT)[18]. The industry however is known to be slow in adopting new technologies, often persisting in employing traditional methods of construction [18, 21].

This study aims to explore what modern communication and project support tools are being used by project overseers to mitigate the risk of failure costs in the Netherlands, focusing on projects in public-private infrastructure. Additionally, the study aims to explore in what ways the current state of the technology can be improved upon to further improve the communication quality between the parties involved in public-private construction. To better understand these concepts, the following research question has been formulated:

[1] https://www.rijkswaterstaat.nl/

To what degree can system improvements be made to improve the communication of sustainable infrastructure construction in Dutch public-private construction projects?

To help answer this question, a set of sub-questions has been formulated to create further understanding of the current situation, the challenges that come with public-private construction projects, and what system or process changes would decrease the challenges. Finally, this work will explore the competencies of people necessary in the making of system changes in the industry. The sub-questions are formulated as follows:

- Sq1: How is the process of realizing sustainable infrastructure currently being done between the Dutch public sector and construction companies?
- Sq2: What challenges can be identified in the Netherlands for building sustainable infrastructure as efficient as possible?
- Sq3: What requirements would be necessary to decrease the challenges for Dutch public-private construction projects?
- Sq4: What human competencies would be necessary to support a change in processes and systems?

To effectively realize the outcome of this research, semi-structured interviews are conducted with stakeholders from both the public and private sides of infrastructure build projects. Following this section, the theoretical background concerning relevant technological developments and the barriers to their implementation in the construction sector are discussed. Next, the research method is explained, after which the results of the interviews are identified. Furthermore, a discussion is provided interpreting the research findings, together with the limitations of the study. Finally, the outcome of the research question will be discussed in the conclusion, along with any recommendations for future research.

2 RELATED WORK

This section will discuss the nature of the construction industry, and the subsequent barriers that are experienced with the adoption of new technologies in the sector. Furthermore, some of the possible technical solutions for the construction industry will be discussed.

2.1 A fragmented industry

The construction industry is considered a fragmented industry. Fragmentation of industries occurs when there is a high number of competitors, and there are no enterprises with a significant market share. The individual companies are unable to influence considerable outcomes for the industry, and there are few intra-firm networks. This fragmentation is increased when the companies compete for the same projects and government tenders [15]. Additionally, this leads to little exchange in knowledge between members in the industry [5].

2.2 Barriers for the implementation of technological solutions in the construction industry

Although newer technologies can greatly improve cooperation, integration, monitoring, and knowledge sharing, the technologies are met with skepticism due to the fragmented nature of the industry [16]. For construction companies, several concerns arise when discussing the possibility of applying new technologies.

The first concern is about security and confidentiality, and the probability of data being leaked or shared unintentionally to outside parties. This is especially true for projects that aim to create a cloud-based working environment between the different parties. This type of online environment enables the documents stored in the environment to act as 'one source of truth'. However, companies have their reservations about this technology due to authorization concerns [23, 38].

Secondly, there is a lack of supporting data and knowledge of benefits, that prevents technologies from being adopted [32]. Especially in the management layers, where the push for newer technology often originates, these weigh heavy. With insufficient commitment or leadership, it is hard to adopt a new technology. One of the reasons that the management layer has trouble committing to drastic changes in technology, is the lack of quantifiable benefits, especially in the early stages of commitment [37]. This also influences the financial ability to adopt new technologies. New technologies often have some form of initial costs, as well as costs for operation. Due to the lack of financial commitment from upper management, it is hard to invest in technologies and adopt them to your core business processes [18, 30].

A third concern that arises is the incompatibility with current systems or interoperability issues between applications and technologies. Due to the fragmented nature of the industry, as well as the different disciplines that are part of the project life cycles, there is a large number of systems that are being used. Applying a new technology would also require interoperability with other core systems [4, 22, 23].

However, the largest concern that arises for the implementation of new technologies is that of the people and culture within organizations. Due to perceived complexity, perceived disadvantages, time pressure, and overall distrust towards the adoption of new technologies, there is little motivation for change. There is also a lack of external motivation if clients do not require the use of certain applications or models [37]. Additionally, there is a need for certain knowledge and skills in the implementation of new technologies. A lack of trained personnel could prevent a company from making the change to new technologies [37].

To overcome these barriers, companies have to make structural changes to their core processes. However, the push for these changes can be hard to find internally, due to the aforementioned reasons. Therefore, some countries have been pushing for a change externally. The UK government for instance has mandated BIM Adoption in all public projects from 2016 onwards. They hope to achieve a reduction in the whole life cost of built assets [10]. Similarly, the New Zealand government has been pushing for the application of Building Information Modelling (BIM) in all building projects by 2025. To encourage this, they have released the BIM Handbook, in which they explain the expectations and regulations regarding the application of Building Information Modelling in construction projects [8].

2.3 Technological solutions

Chowdhury and Adafin et al. [10] have done an extensive literature study of existing research and identified 32 possible technological improvements that can be utilized to improve safety, collaboration, integration, monitoring, and knowledge sharing in construction projects. The most promising among these 32 options are mobile computing, Radio-frequency identification (RFID), Building Information Modelling (BIM), Geographic Information System Mapping (GIS) and Cloud Computing[10]. The focus of this paper will be on the cooperation a between the different parties on a project level and the systems that aid therein. GPS, RFID and mobile computing are beneficial for on-site aid in construction projects and are thus not included further.

2.3.1 BIM - Building Information Modelling. A possible solution to decrease the amount of failure in construction projects is the widespread application of Building Information Modelling (BIM) by all parties involved in the production of infrastructure [33, 37, 42]. BIM aims to support construction during the full life cycle of the project, and has proven beneficial in reducing problems during the design, construction and maintenance phases [39]. It is based on object-oriented IT principles, and allows for more in-depth 2D and 3D representation of objects during design [37]. Additionally, it allows for a more complete overview of additional details, such as the creation of a project schedule (4D-BIM) or costs takeoff (5D-BIM) [9]. As much as the widespread application of BIM is promising, it is not fully used yet. The problem herein is that companies may adopt only some parts of the method, or have no qualified personnel to make use of the BIM principles. Different organizations therefore have different levels of BIM maturity [37].

2.3.2 Geographic Information System Mapping (GIS). GIS is a standard for the mapping and modelling of geo-spatial information that relates to existing topography and man-made objects. GIS-systems provide a means of accessing detailed spatial information on specific locations using coordinates. GIS as such contains data pertaining to the real world, which can give construction companies more detailed information on the construction site, or information on existing builds [13]. GIS can also be applied to aid in different aspects of construction, such as supply chain management (SCM) [20], or in construction safety planning [6].

2.3.3 Cloud-computing. Cloud computing is a broad concept. The definition for cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources [29]. The application of cloud computing to construction is an emerging area, which promises a number of opportunities for the construction industry. These include cost benefits, on-demand scalability of computing resources, secured platforms, massive data storage, as well as the opportunity to facilitate collaborative practices [7, 25]. However, there are also concerns for adopting cloud technology. The first is trust, data privacy and security. Storing construction design and financial information in shared resources understandably gives concerns to stakeholders in the industry. In order to make use of cloud computing solutions, companies would need additional security measures to protect connected devices. Another concern with cloud computing is that of data governance. The question is who owns, who controls and who can make use of the data that is stored in the centralised database. There is need to restrict data depending on roles, as well as agreements on who are allowed to mutate and share data with other parties [7].

3 METHODOLOGY

To answer the research question, it is important to understand what factors are currently impeding projects in the public sector. The sub-questions are aimed to help create this understanding and interpret the findings [35, 36]. The research form of this work is an explorative research, with information-oriented case selection. This case sampling method maximises the utility of the acquired information from a small sample [12]. Additionally, qualitative research approaches can aid in the discovery of requirements and the development of information systems [26].

3.1 Sampling

The sampling method applied is selective sampling, to reflect particular features of groups within the sampled population, specific criteria or purposes [34]. It is important to make a good selection of the experts to increase the value of the findings. As experts, the interviewees are expected to have special knowledge and experiences based on the responsibilities that come with their current or former functions. In order to determine the validity of the acquired results, a survey will be conducted to determine the characteristics and experiences of the actor within the field, thus validating the claims that they might make. The selection of the experts however is also based on their availability and willingness to cooperate within the limited time span of the project, which was under three months. Many companies and governmental bodies were approached, but few were willing to make the time to participate in the project. In table 1, an overview of the experts that have participated is given. Their identity's have been made anonymous, but the organization type they represent and the experience they embody is incorporated.

Respondents			
ID	organization type	organization Size	Experience (years)
I1	Municipality	Small	16
I2	Engineering	Large	30
I3	Engineering	Large	12
I4	Rijkswaterstaat	Large	42

Table 1: An overview of the respondents to the interviews, the organization type they represent, the size of the organization they represent, and the number years of experience they have

3.2 Data collection instrument

For the method of inquiry, interviews have been chosen with people responsible for overseeing construction projects. The respondents are part of engineering firms, municipalities or Rijkswaterstaat. In this, the experts are used as an attempt at representing the larger population [14, 36]. The interviews are in-depth and semi-structured. Semi-structured interviews give the researcher the opportunity to discuss open topics, while the respondents has the opportunity to add their own input and interpretations [17]. The questions were phrased in a way that respondents from both the public and private sector could answer. The interviews were recorded, with permission, and transcribed. The sole focus of the transcription is on the spoken word [28].

3.3 Interview guideline

In order for the interview to remain topical, an interview guide was constructed. The interview guide contains the questions that were derived from the research questions and the related works. The aim of the questions is to provide insight into the possible problems and solutions in the construction of public infrastructure. However, since the interviews are semi-structured, not all questions that have been asked are included in the interview guide. If a respondent provided information on a topic that was not included in the list, further questions to elaborate could be asked. Additionally, the interview guide provided a number of topics that could be discussed in case the interviewee was unable to directly answer a question. For instance, one question discusses possible technological advancements. If they had trouble naming one from the top of their head, a few technological advancements could be mentioned to support the question. The interview guide in full can be found in Appendix A.

3.4 Data collection procedures

3.4.1 Survey. Preceding the interviews, the respondents were asked a few questions through a survey. These questions were used to determine the experience of the interviewee, and to determine some basic information. The questions were as follows:

- 1. What organization (company or governmental body) do you work for?
- 2. Is this organization considered small, medium or large?
- 3. What is your role in the process?
- 4. How many years of experience do you have in the field?
- 5. What is the scale of the projects you have overseen?

The answers of the survey are discussed in result section 4.1.

3.4.2 Interviews. The interviews were held within Microsoft Teams [2], which allows the option for recording and automated transcription during live chats. However, if security policies of certain organizations would have prevented anyone from participating in Microsoft Teams, a Zoom [3] account was also available. Additionally, to make sure there were no mistakes or faulty recordings, the interviews were additionally recorded using OBS [4], a program to record or stream desktop input. In this case, OBS was used only to record the audio. All interviews took place through Microsoft Teams, in June 2022, and lasted between 30 and 40 minutes.

The interviews were held in Dutch, as the experts on the topic are all Dutch residents and use the Dutch language for their day-to-day work. The text was also extracted in Dutch. The transcripts of the interview were then downloaded and cleaned of any unnecessary timestamps and unnecessary small remarks made by listening parties. The transcription software is very sensitive, and had registered many remarks such as 'okay', 'yes' and 'no' when not in direct relation to a question or statement. These remarks were removed to clear up the transcript.

3.5 Data analysis

The transcribed interview documents have been uploaded into Atlas.ti [5], a tool that aids in qualitative analysis. The tool has been used to do the coding of the interview. The first step in the analysis of the data was 'open coding', where the aim is to find all points-of-interest mentioned during the interview. After the open coding, all the resulting codes are compared and checked for synonyms and other similarities, to clean the coding scheme. The resulting lists of codes is grouped into categories, with a process called 'axial coding' [43]. The remaining categories were then allocated under different bigger categories, which are the sub-questions of the paper, as part of the last step of coding. The resulting code tree was used as the basis for the results and is included in the GitHub[6] repository. More information on the GitHub repository can be found in Appendix B.

4 RESULTS

4.1 Survey results

The results of the survey are shown in table 2. However, some valuable information about the experience and type of projects done by the respondents was not fully encapsulated by the questions. Therefore, some additional information will be given below.

Interviewee 1 has not always worked for a municipality. The first 12,5 years of their experience were as a contractor with a large road construction company. In their previous function, they have been part of projects of different sizes. In their current line of work, these are mainly small.

Next, interviewee 2 has stated that they have 30 years experience in the business. They have had roles in all parts of the construction industry, from on-site construction to their current role. They too have overseen projects of all sizes. Although they currently work at an engineering firm, they do not work at the same engineering firm as interviewee 3.

The last interviewed expert, I4, has had 42 years of experience in all parts of the construction industry, starting as an overseer during construction. They too have done projects of differing sizes.

4.2 Semi-structured interview results

4.2.1 Overview of process (Q1). The goal of the first question is to understand how the public-private construction projects are carried out and what parties are involved. The first finding is that there are different type of projects (I2, I4). The first being the creation of new objects, where there was none previously (I2). The second is the creation of objects meant to be coupled or built as part of an existing object (I2). The third is the replacement of an existing build, due to it nearing its end-of-life. Lastly, engineering firms and contractors can be asked to perform management and maintenance

[2]Video Conferencing, Meetings, Calling | Microsoft Teams. https://www.microsoft.com/en-ww/microsoft-teams/group-chat-software
[3]Zoom | Video conferencing, meetings, calling | https://zoom.us/
[4]OBS | Open broadcast software | https://obsproject.com/
[5]Atlast TI | Analyze anything, faster | https://atlasti.com/
[6]Github | Student repository | https://github.com/YannickDogt/ThesisUvA

Survey results					
ID	organization type	organization Size	Experience (years)	Current Role in organization	Scale of projects
I1	Municipality	Small	16	Overseer roads and civil projects	Small
I2	Engineering	Large	30	Head advisory group Asset management infra objects and installations	Large
I3	Engineering	Large	12	Team lead asset information management	Large
I4	Rijkswaterstaat	Large	42	Technical director Asset Management	Large

Table 2: An overview of the results from the survey by the respondents. The number of years of experience denotes their overall years of experience in the sector, not just in the role they currently occupy.

of existing objects, making sure that they are checked and repaired if necessary.

In all cases however, there must be a need to review or create the infrastructure (I4). This can be the result of direct failure, findings during routine maintenance, as part of a scheduled replacement, or during the construction of new buildings (I4). After determining the goal and strategy, a budget is created and a tender is posted, to which different contractors can respond (I1, I2, I4). In small projects, Rijkswaterstaat or a province or municipality can directly hire contractors to carry out the project (I2 - I4). In bigger projects however, Rijkswaterstaat or the contractors cooperate with engineering firms to determine what to do (I2, I4). In all cases, the funds are made available through the government of the Netherlands, which means that the budgets are limited and the margins are slim (I1 - I4). After the contractor finishes the project, the management and maintenance of the bridges is done by the contractor or turned over to the client, depending on what was arranged (I1 - I4). Rijkswaterstaat is putting an increasing amount of maintenance responsibility with the contractors, so that they are responsible for maintaining their own builds (I2, I4).

A followup question was asked about the way the projects take sustainability into account. According to expert 4, sustainability is certainly a factor and they have created a new type of tender to increase the focus on circular principles, but is not a priority for Rijkswaterstaat due to the limited funds available (I4). However, since it is impossible to replace all bridges in the near-future, there is an increasing amount of life-prolonging maintenance carried out, in order to increase the life expectancy of the infrastructure (I2-I4), which in turn can be seen as a sustainability measure (I3).

4.2.2 Problems in public-private construction projects (Q2 - Q4). For questions two and three regarding the excess in time and budget, all experts agreed that it is almost expected for construction projects to exceed the planned time and budget (I1 - I4). Expert 1 however did state that at a small municipality, the risks of projects going over budget are considerably smaller, since they do smaller projects (I1). However, this seems to be more of an exception. In some cases, there is a limited budget, which ensures that there are no excesses (I4). However, under certain circumstances additional funds would have to be made available to finish the project. An example would be the additional costs for materials due to price increases as a result of the corona pandemic and the subsequent war in Ukraine (I4).

Question 4 attempts to better understand what factors contribute to the problems that lead to an excess in time and budget in public-private construction projects. It turns out there is no single reason or problem that explains why these excesses in time and budget happen (I1 - I4). Often, it is a 'domino effect of multiple problems' (I4). The experts gave answers from which a number of issues were derived.

A first issue would be a lack of knowledge in the sector as a whole (I1 - I4). People with experience and knowledge are leaving the sector or retiring (I4), and the amount and quality of young professionals entering the sector is too low (I1, I2). Additionally, young professionals that do enter the sector need time and guidance to learn the trade (I2, I4), as well as "the space to make and learn from their own mistakes' (I4).

A second identified issue in the sector is the general lack of information on existing objects (I2 - I4). The information on the construction of these objects is often stored on paper or in older standards, which can not be used by the current systems and need to be converted (I3, I4). This is a time consuming project, for which Rijkswaterstaat does not have enough people. Instead, it is updated on a risk-based basis, prioritizing the existing builds that need the most immediate attention (I4). Additionally, even though there are regular inspections, existing builds often carry hidden flaws that require additional maintenance, further complicating maintenance and resulting in an increased strain on the budget (I3).

A third issue is the fact that not all parties uses the same standards of design and execution (I2 - I4). All entities that are possibly involved in the project, which include Rijkswaterstaat, provinces, municipalities, engineering firms, contractors and sub-contractors, are autonomous entities (I4). They therefore have different standards and working practices (I2, I4). 3D models created by engineering firms are not always usable by the contractors or government bodies, due to the absence of the system architecture or knowledge to utilize the models (I2). Instead, they are converted or redrawn in different standards, in order for the models to be used in construction or maintenance (I2, I4). With such conversions, information can be lost (I3).

As an extension to the previous issue, a last issue is the high amount of systems in the sector, and the lack of interoperability between them (I2 - I4). These systems may have specific functions within the organization, but they can be lacking when it comes to communicating and cooperating with other parties (I1, I4). Companies are also unwilling to share information on different system architecture strategies they have, because it is also considered a part of their business plan (I2).

There are also a number of issues that were only mentioned by a single expert. These are considered to be of less significance as the ones mentioned above, but they are included in the following list to provide a more complete understanding.

- Projects are becoming too big for contractors to handle (I1).
- Contracts do not foresee all possible problems and these result in unnecessary juridical conflicts (I1).
- Investment costs of new systems (I1).
- Time pressure (I3) and political pressure from local governments or the senate (I4).
- Lack of availability of resources (machines, materials), as well as people (I4).
- Quality loss due to cost effectiveness (I4).

4.2.3 System problems (Q5 - Q6). Question 5 was meant to determine if the current systems were sufficient in their design. All experts agreed that the current systems had their flaws, and that improvements could be made. However, a good use of a BIM-system, a GIS-system or both, combined with a shared cloud computing environment such as SharePoint would already help in avoiding a lot of communication issues (I2, I3) and help in establishing a single source of truth for documents(I3). However, the application of such technology is not widely accepted yet, and in some cases underutilized (I2 - I4).

Another problem with the current systems is the fact that, even though there are exciting technological developments in the sector, they are still in its infancy (I2 - I4) and therefore not always operationally applicable on a wide scale. Examples of such technologies would be clash-detection during the creation of 3D models, or the ability to have robots perform actions based on 3D BIM models (I3).

Question 6 was meant to determine whether there are system issues or flaws that currently impede the ability to properly do their job. Experts 2 through 4 agreed that one of the biggest problems with the current software applications is that everyone uses their own systems, with limited possibilities of exchanging information between these systems (I2 - I4). Parties are reluctant to share what systems they are using, because they do not want to reveal their business plans to competitors (I2). Similarly, there are many system producers that belief that their system could potentially become a market leader (I3). This, in cooperation with the fragmented nature of the industry, leads to the large difference in systems, as well as them being operationally closed (I2 - I4).

Another point of frustration remarked upon by the experts was the high number of systems they need to perform their day-to-day jobs (I1, I2, I4).

4.2.4 Improving upon the current situation (Q7 - Q8). Question 7 was asked do determine what process changes should be made in order to improve the the communication and success in public-private infrastructure projects. All experts agreed that the amount and quality of communication between parties should be better than the current situation. To do so, the experts give different solutions. One solution would be to involve the contractor in the conception of the project to increase the likelihood that the designs are executable (I1). At one of the engineering firms, they have a project team that is connected to every stage of the project in order to make sure that the knowledge is transferred and the success rate is increased (I2). Similarly, such developments are also noticed at larger contractors in an attempt to reduce failure costs (I3). This last change may be due to pressure from Rijkswaterstaat, that have created a new type of tender where they ask contractors to also be responsible for the maintenance of the objects they have build (I4). To mitigate risks, these contracting firms have improved their internal communication processes and have dedicated teams that oversee all the phases of design and construction (I3).

Another improvement would be to create new standards of information gathering and information handover (I3, I4). This would include conforming to international standards, such as of ISO 19650 [7] (I3), as well as possible national information standards. Currently, the information that is available and the information that is transferred is not always up-to-date, or can not be used by certain parties due to a difference in systems and lack of standards. If all parties agree on a set of standards, or if a set of standards is enforced, it would decrease the amount of delays in public-private projects (I3, I4).

A last improvement suggested by expert 2 is to focus more on 'design for maintenance', where the infrastructure is designed in a way that allows for it to be taken apart and repaired more quickly. This would increase the quality of information that can be gathered during inspections, as well as speed up repairs or refurbishing of parts of the infrastructure.

Question 8 was asked to determine what system requirements would be necessary to support the processes related to construction in a public-private collaboration. All experts agreed that a BIM based approach to systems would be the best option for the construction industry. This would include good design features for 3D modelling (I2, I3), clash controlling and resource allocation (I2, I3), as well as doing systematic assurance, a feature that allows clients and other parties to check if the design complies with their expectations (I2, I3).

Another important feature would be to start working with API connections between systems. This would allow for better information exchange between parties (I2 - I4). However, companies would have to agree on what kind of information they would want to exchange, and what kind of interfaces they would expect from each-other (I4).

4.2.5 Competencies of people (Q9). The last question was asked to determine what skills the people need to be able to execute the process of a more ideal and utilize these systems. All the experts agreed that at this moment, there is an incredible gap of knowledge in the sector, at both the public and private side. Rijkswaterstaat, for instance, has lost a significant amount of employees, either starting their own business or retiring. This in turn makes it harder for them to upkeep the quality of their work (I4). This includes technical knowledge, system and data management knowledge, and overall knowledge for on-site construction. An investment needs to be made to ensure that there is more knowledge retention (I4), as well as better opportunities for education (I1, I2, I4).

[7] NEN-EN-ISO ISO 1965 | BIM Loket | https://www.bimloket.nl/p/269/NEN-EN-ISO-19650

When it comes to the competencies of the future, there is an agreement between I1, I2 and I4 that there needs to be an increase in technical knowledge and skills. At the same time, the industry needs people who understand data and systems to increase the utility of the available systems and data (I2, I4). This includes more T-shaped professionals. This means that professionals have to be good at either the technical side, the data management side, or the data analysis side, but understand the other fields to a basic degree. This allows for better communication and cooperation abilities between people and teams (I2).

Lastly, good leadership is identified as a necessity (I3, I4). The sector needs to ensure that some degree of technical knowledge is present in all layers of the organization, because this has not been the case in the last few years (I4). Good managers 'do not need to understand everything at the same level as the engineers', but should have at least basic understanding of what it takes to realise infrastructure projects (I3, I4).

5 DISCUSSION AND LIMITATIONS

The following section discusses the results found during this study. It starts with explaining and describing the principal findings as an answer to the four sub-questions, after which they are compared to existing research. Lastly, the limitations of this study are discussed.

5.1 Principal findings

This research aimed to explore what problems are facing infrastructure construction projects in the Dutch public-private domain, and if these problems can potentially be solved with improved system design. In order to answer this question, four sub-questions were formulated. Below, the results of the sub-questions are discussed and compared to the research.

5.1.1 Sq1: How is the process of realizing sustainable infrastructure currently being done in the Dutch public sector? The first sub-question aims to understand how the process is currently being run, and how possible systems support these efforts. The answer to this question is thoroughly covered in section 4.2.1. Although this process may vary from country to country based on local laws and legislation, it is not uncommon for Governments to post tenders [41]. However, the intricacies of such laws and legislation are not within the scope this paper.

5.1.2 Sq2: What challenges can be identified in the Netherlands for building sustainable infrastructure as efficient as possible? The second sub-question aims to understand what challenges currently complicate the construction of sustainable infrastructure in the Netherlands.The results were that it is incredibly common for construction projects to surpass the expected time and budget. Often, this is the result from multiple problems. The most important issue currently is the lack of knowledge and skill in the sector. The sector is aging and there is a limited influx of young professionals in the scene. This leads to the loss of knowledge and expertise of the sector. This is in line with the finding about the industry by other researchers [40, 41], as reasons for the failure costs in the industry.

Additionally, there is a lack of information on existing builds and construction sites. Gathering this information is time consuming, and existing objects can contain flaws that were not obvious from the outside. This lack of information is often the result of the availability of data. Data on existing bridges that were not recently maintained often have a lot of information in paper records, instead of digital. Rijkswaterstaat has an enormous backlog of project information that needs to be digitized or redrawn, which they can only perform on a risk-estimate basis due to a lack of personnel. There are efforts being taken to encapsulate more knowledge of the built environment with GIS and BIM, but these are often not complete. The specific reasons for the lack of information are not found in the research, but it is clear that the lack of information about building objects is a problem that can lead to project delays [24, 41].

Next, there is a problem with a high amount of systems running alongside each-other, with poor interoperability. Due to the fragmented nature of the industry, all parties have adopted their own systems and their own methods. This has lead to a high amount of different systems, fulfilling different jobs. There is very little opportunity of exchanging information, especially between different organizations. The information needs to be tailored in order to be transferred to another party, which can lead to the loss of information. Although the fragmented nature of the industry [15] and the lack of interoperability between systems [4, 22, 23] are discussed, the lack of information exchange is not explicitly recognized as a direct problem. There has, however, been research into a lack of knowledge sharing [5], which is part of the problem.

Other issues that were mentioned were the fact that materials or people weren't always available in time for projects, leading to delays. Additionally, projects have become increasingly more complex, which makes it harder for especially smaller contractors to handle government tenders. There is also often a lot of time pressure, while the budget has to remain low. This can lead to a loss in construction quality. These are some of the same observations made by van Marrewijk et al. [41] in their case studies on megaprojects in the public-private domain.

5.1.3 Sq3: What (system) requirements would be necessary to decrease the challenges for Dutch public-private construction projects? The third sub-question aims to formulate a set of specific requirements which the industry could implement to decrease the impact of the aforementioned challenges. Below, a list of requirements is given, after which they are discussed.

- R1 - Future applications would benefit from a BIM based approach.
- R2 - The applications must contain enough information about the built environment to act as a reliable digital twin.
- R3 - The applications must be cloud based, and be supported by a common data environment.
- R4 - Applications should have Open API standards for setting up API's for information exchange. organizations that work together should look to define interfaces and determine what information they would want to exchange.
- R4 - Design applications must be able to export design in multiple standards.
- R5 - Information exchange and file handover between systems must be done through ISO 19650 standards.
- R6 - The system must make use of machine learning methods or big data (or both), to make sure that more knowledge

about projects, designs and information is retained within the organization.

- R7 - The system could make use of machine learning approaches to extracting data from hand-drawn designs. This would aid in the conversion of older, paper-based models to the digital environment.

R1 - One thing that became clear from the interviews is that BIM and GIS are very reliable technologies for the construction industry. Systems in the construction industry therefore benefit from being designed with BIM in mind. This includes the options of 3D modelling, clash detection control, systematic insurance, resource allocation and cost takeoff, among others [9]. BIM is seen as one of the biggest gains the industry can make in terms of system improvements [8, 42]. However, various organizations have varying degrees of BIM maturity and adoption [37], which was also remarked upon by the interviewed experts.

R2 - Another frustration was the lack of information about the built environment. Although GIS already aims to be a digital TWIN [13], there is often a lack of information in the Dutch public sector. With more information gathering, a reliable digital TWIN can be constructed, preventing mistakes during design and construction. However, these frustrations were not named as such in the market research by ABN Amro [40]. A possible explanation could be that they spoke mainly with contractors and on-site personnel, and not enough with project overseers, who tend to look at the bigger picture.

R3 - All members of projects should be able to have access to the project data, preferably through a common data environment in which strict document governance is handled. The common data environment acts as a single source of truth for projects, reducing the amount of confusion [25]. Although such standards are already starting to form within certain organizations, cloud computing is not always being used in public-private construction projects. This could be because of the conceived distrust, as discussed by Bello et al. [7], but these were not named specifically by the experts. Instead, they hinted more towards the fragmented nature of the industry [15] and the autonomy of the organizations as a reason for the lack of cloud computing and common data environment solutions.

R4 - Currently, different organizations can work with different standards of design. This can lead to loss of information during conversion. Instead, systems should have knowledge on the different standards and be able to convert designs. This again can relate to different levels of maturity in adopting newer technologies as discussed by Siebelink et al.[37], but it also stems from the fragmented nature of the industry [15] and the different working methods that organizations have adopted.

R5 - Although there are already organization pushing for a more standardized approach through the use of ISO 19650, the construction industry can benefit from a more standardized approach of design and data management overall. If such agreements can be reached, the amount of time and effort it takes to exchange project information can drop significantly. The mention of ISO 19650 or any form of standardization of information exchange was not named as a problem in the Dutch industry. Again, this may be because the research performed by ABN Amro [40] targeted a different audience.

R6 - Currently, a lot of knowledge and skill is contained within the personnel of organizations. These typically work on a project basis, where they jump from one to another. This is also noted by as a trait of the industry [5, 40]. Instead, some of the knowledge they have could be gathered through big data or machine learning approaches. In this way, systems can increase the amount of knowledge that is retained within an organization. This does not mean they can replace the human in the process, but they can support decision making. Chowdury et al.[10] have also identified machine learning and artificial intelligence as possible technologies that could improve productivity in the construction industry. However, they are not mentioned in research that often, and are therefore among the lower ranked results.

R7 - At this moment, Rijkswaterstaat does not have enough personnel to digitize their backlog. They can benefit from data extraction from documentation. Due to the intricacy of such designs and drawings, as well as the possible variety in standards throughout the decades, this may prove a difficult task. This is something that was not covered by any research. This may be a specific task to Rijkswaterstaat, or other government bodies, but it is something that is not reflected within the read literature.

Additionally, opportunities were identified for the use of augmented reality or BIM 3D models as the basis for robotic operations. Robotics and Augmented reality, among others technologies, were also mentioned by Chowdury et al.[10] in their research of technologies that could benefit the industry. However, their research pointed out that these technologies were discussed far less than Radio-frequency identification (RFID), Building Information Modelling (BIM), Geographic Information System Mapping (GIS) and Cloud Computing. Also, robotics and augmented reality are tools that support on-site construction. They are therefore considered as less important solutions to the issues that are currently plaguing the Dutch construction industry.

5.1.4 Sq4: What human competencies would be necessary to support a change in systems and processes? This particular question is underrepresented in the literature. Although a shortage of qualified workers has been identified as a problem in the industry [5, 41], there is little research on the competencies that people in the industry require in the foreseeable future. The experts agree that there will always be a necessity for technical knowledge and skills, but that system thinking, data management, and data analysis will become more prevalent skills in the industry. This is the result of a shift to a more system-based way of working.

5.2 Limitations

A first limitation that will be addressed is the relevance of this study to other countries. Public-private construction projects are issued by the different governmental bodies of the Netherlands. How these operate, and what operations they oversee, is instilled in Dutch law and in agreements between the involved bodies of government. These may vary from country to country, changing the results. This means that the identified challenges and solutions are potentially not useful by other countries, but also may also not apply to public-sector construction projects.

Another limitation has to do with the performed interviews. Semi-structured interviews were chosen as the preferred method of research over other methods such as open interviews or questionnaires. This due to the exploratory nature of the semi-structured interviews, the ability to ask follow-up questions to gain additional insights, and the limited number of subject matter experts available. The total number of interviews however is limited (n=4), and is missing the side of the contractors who accept and execute the tenders offered by the different governmental bodies. Due to the limited time of the project, as well as their limited availability, they are not represented in this work. Including these may give additional insights.

Lastly, the outcome of this qualitative study relies greatly on the interpretation and analysis of a single researcher. While precautions have been taken to mitigate this effect through a strict selection of experts, the degree of validity of this study would be higher if the results would have been analyzed and interpreted by multiple researchers.

6 CONCLUSIONS AND FUTURE WORK

The goal of this work was to identify to what degree system improvements can be made to increase the communication in Dutch public-private infrastructure projects, and thus tried to answer the research question formulated in the introduction of this paper. This paper aimed to do this through interviews with experts overseeing or leading public-private construction projects. The study resulted in the identification of a number of improvements. These mainly consist of the more widespread application of BIM, GIS and cloud-computing solutions, and the retention of knowledge in systems. BIM, GIS, and cloud-computing are already used in different ways in the sector, but these seem to currently be underutilized, especially there is cooperation across organizations. Next, knowledge loss is considered the biggest problem the industry is facing. The retention of knowledge can be aided, but not entirely solved, by big data approaches and machine learning methods. Additionally, systems in the Dutch construction industry should be designed for possible API connections, to improve the exchange of information between organizations. This is currently one of the bigger frustrations that the experts had.

However, some points-of-interest were identified that may not be solved by information systems, but can aid in improving the success-rate in public-private infrastructure projects. These are the improvement of education of young professionals, the recognition of the growing importance of data and system thinking in construction companies, as well as the need for improved standards of information exchange different parties in public-private construction projects.

6.1 Future work

A next step for this research is to include contractor organizations as part of the interviews, as they are also an important link in the public-private construction projects. Their knowledge and experience could help to improve the understanding of the underlying problems that public-private construction projects face. Contractors can also share the insight of the information they need and expect when considering government tenders, as well as provide more insights about problems surfacing during on-site construction.

Additionally, further research can be done in the information needs of different parties in the chain. By taking a closer look at the specific topics and data that the different parties involved expect, standards of information exchange could be derived. The development of such data-standards can help improve the communication and success-rate of public-private construction projects.

Lastly, this work identified the problem of the retention of knowledge in the sector, both in private companies as government bodies. More research could be done in identifying, extracting and grounding key knowledge into the system architecture. By applying big data analytics or machine learning methods to make 'smarter' systems to aid humans, potential mistakes in the modelling and development of infrastructure can be avoided.

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A APPENDIX A

(Translated from Dutch)

Introduction
• Introduction of researcher
• Thank participant for willingness to participate
• Explain the study
• Explain the structure of the interview
• Explain that the results are anonymous
• Ask whether the researcher has permission to record the interview

Main body
A) Question about the current situation
Question 1: How are sustainable infrastructure projects structured? Could you give me an idea of the timeline of these projects?

B) Questions about project challenges
Question 2: Do you have any experience with projects that ran over time?
–> If yes, could you tell me more?

Question 3: Do you have any experience with projects that ran over budget?
–> If yes, could you tell me more?

Question 4: What do you think are the main causes for these increased times and budgets?
Optional topics, to help the conversation:
–> Rework/Doing things again?
–> Communication issues?
–> Else?

C) Questions about systems and their utilisation
Question 5: Are the currently employed system in your opinion good enough to prevent these problems?

Question 6: What are your biggest frustrations when using the current systems?

6.1 Are there technologies or chances you know of that would be an improvement of the current systems?
Optional topics, to help the conversation:
–> BIM
–> Cloud computing
–> GIS
–> RFID, Mobile computing, GPS
6.2 If so, why do you think these are not utilised (properly) yet?

D) Questions about processes and system improvement

Question 7: In an ideal world, how would the process look like according to you?

Question 8: How would the system supporting these processes look like?

E) Questions about people and competencies

Question 9: What competences would employees need to use this system to its fullest potential?

9.1 Would they need extra training, knowledge or skills?
9.2 Would they need training in navigating the system or in skills?

B APPENDIX B

Further information on the project is contained within GitHub. Please use the following link to navigate to the page: https://github.com/YannickDogt/ThesisUvA