BSc Thesis Civil Engineering

Managing technical interfaces in integrated projects during the pre-execution phases

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Preface

This thesis is my final product before I attain my bachelor’s degree in Civil Engineering. I am pleased that I could still perform my bachelor's thesis at an engineering firm after a late cancellation from a different firm. I want to thank Estsaban Döll and Marjolein Oude Groote Beverborg who both made this possible in a short amount of time. I have learned a lot in the past 10 weeks by performing my thesis at Antea Group.

The quality of this thesis would not have been the same without my supervisors. Therefore, I want to thank Steven Reuver from Antea Group and Ruth Sloot from the University of Twente. Their guidance has helped me to deliver my first solo product after many group products during my bachelor's degree.

Furthermore, I want to thank the experts at Antea Group who were easily contactable and content to participate in this thesis.

Sincerely,

Jochem Fortuin
Deventer, July 2024

Abbreviations & terminology

ASC	Autodesk Construction Cloud
BIM	Building Information Modeling
Contract manager	Responsible for the risks between the client and the market, it is also tasked with the contact and contracts between different market parties.
DO	(Definitief Ontwerp) final design
Environment manager	Responsible for engaging with the project's surroundings. Maintaining a balanced relationship with the environment and stakeholders throughout the project.
GWW	Soil, Road and Hydraulic Engineering Sector
IPM	Integrated Project Management
Kunstwerken	Engineering structures
Project controller	Responsible for identifying and handling all the risks in the management aspects of the project, funds, capacity, time, information etc.
Project manager	Responsible for quality assurance and the result, if the other roles perform their job properly the project manager is less burdened.
PVR	(Profiel van Vrije Ruimte) Loading gauge
RWS	Rijkswaterstaat
SE	Systems Engineering
Technical manager	Responsible for providing the technical input into the project, the solution must effectively address the problem that is given.
UO	(Uitvoeringsontwerp) implementation design
VO	(Voorlopig Ontwerp) preliminary design
WBS	Work Breakdown Structure

Management summary

The importance of interface management is well-emphasised throughout this thesis. Currently, interfaces are managed in different ways at Antea Group depending on the client, project size, project leader and disciplines attending the project. This thesis highlights the need for improved management practices aimed at interfaces. The recommendations for conducting this bachelor thesis at Antea Group are shown below. Some recommendations suggest actions close to the described problem and other recommendations try to tackle the problem from a different angle.

1. **Integrated projects require a collaborative start with attention to interfaces.**
With a collaborative start, agreements can be made on how interfaces will be managed during the project. Agreements can be made on interface listing, interface sessions and model sharing between the technical disciplines.
2. **There needs to be a more structured method during the different design phases to manage interfaces.**
By using a more structured method interfaces can be managed more efficiently. Fewer design changes will occur due to interfaces since they are visible in the structured method. This will lead to lower failure costs and more efficient projects. The structured method can be executed by the new version of Relatics which is more user-friendly. Here interfaces can be linked to objects and objects can be linked to client requirements giving more structure to the project between the different phases.
3. **Use the structured method in as many projects as possible.**
By using the structured method in non-integrated or smaller projects, employees of Antea Group become familiar with this uniform way of working. This creates efficiency among all projects and leads to lower failure costs in smaller projects. The step for project managers from small-scale to larger integrated projects will be less abrupt.
4. **Apply standardisation where possible throughout the design process.**
Standardisation action should be performed more frequently during the design process. This can include standardising certain customer requirements and common interfaces. This can be linked to the structured method, where libraries can be created that hold these standardised requirements and interfaces. These libraries can be extended after the completion of each integrated project.
5. **Aim for working in more stable teams to be able to use knowledge from past projects.**
By working in stable teams, people will learn what each other's weaknesses and strengths are. It is easier to learn from missed interfaces gathered in similar projects.
6. **Share information on the current and past activities of the employees.**
Sharing what employees of Antea Group are working on or have worked on, will increase knowledge transfer among employees. This can be integrated into the SharePoint of Antea Group specifically the who is who page.

Content

1 Introduction

In the construction sector project management plays an important role. Large-scale infrastructure projects need to be precisely planned and executed, this ensures that resources are efficiently used, deadlines are met, risks are controlled and quality can be assured for the complete lifetime of the infrastructure (Shah et al, 2023). The performance of construction projects today is under pressure due to environmental and sustainable demand, highlighting the need for effective project management (Trtílek & Hanák, 2021).

Construction projects in the infrastructure sector have evolved significantly over the past decades. Transitioning from relatively straightforward projects, such as lane expansions on the A1 in the sixties, to more complex projects such as the construction of the North-South metro line in Amsterdam. This can be seen as area infrastructure where in the case of a new metro line, the project comprises various sub-projects such as the construction of stations, tunnels, viaducts and crossings that collectively contribute to the completion of the entire project.

Infrastructure projects have transitioned from a linear workflow to more integrated methodologies, where different disciplines need to work together to deliver a product that satisfies the client's requirements (Voeller, 2019). During integrated projects interfaces can occur, if these interfaces are poorly managed this will affect the project outcome (Piantanida et al, 2014). Actions can be taken to manage and secure the interfaces during an integrated project which can benefit the profitability and project quality (Chen et al, 2007).

This thesis is performed at the engineering consultancy firm Antea Group, where attention is given to four technical disciplines. This thesis focuses on the management of interfaces during the pre-execution phases of integrated projects. Antea Group benefits from the findings of this thesis, as it will improve securing and managing interfaces throughout the pre-execution phases.

This chapter continues by presenting the *Problem description,* where the problem Antea Group phases will be stated and the *Theoretical framework*, where specific concepts will be further explained. The *Research aim* will present the research gap, main research question and sub-research questions, where each is described with a summary. Attention will be given to the current literature in the domain of the research questions with a *Literature study*. This thesis will rely on company literature and expert interviews and these research methods and the interview guide are given in the *Research methodology*. The findings are presented in the *Results* chapter, addressing sub-questions in separate subchapters. The thesis is then concluded with a *Discussion* and *Conclusion* where the recommendations are presented with limitations.

1.1 Problem description

At Antea Group technical disciplines work on integrated infrastructure projects. These projects contain interfaces, where interactions and information exchanges between disciplines play a crucial role in managing interfaces. Integrated projects require an integrated design approach by different technical disciplines that need specifications from the actual site and each other. In an integrated project, disciplines must collaborate in a way that is not always needed in less complex projects. Interfaces among disciplines can occur during the design process, which may be identified beforehand or during the design phase. When interfaces are not properly managed and secured this can result in conflicts and inefficiencies, in turn delaying the project (Chen, 2007).

This thesis will include the following technical disciplines: Kunstwerken, Rail, Road and Soil which are often involved in integrated infrastructure projects. At Antea Group, Interfaces are currently managed in different ways depending on the client, project size, project manager and attending disciplines. It can be stated that there is no uniform method for managing interfaces, which results in inefficiencies during the pre-execution phases.

1.1.1 Project goal

This thesis wants to give Antea Group guidance on how to manage interfaces during an integrated infrastructure project. Attention will be given to interfaces that take place during the plan & design phase. Furthermore, current working methods used in managing interfaces will be evaluated together with the experience of employees. The findings of this thesis will help Antea Group in managing interfaces, which will improve project efficiency.

1.2 Theoretical framework

1.2.1 GWW sector

The Ground, Road, and Hydraulic Engineering Sector (GWW) is a large construction sector in the Netherlands. The sector covers a wide range of disciplines such as the construction of dikes, bridges, canals, civil engineering earthworks, dredging, hydraulic engineering and infrastructure projects. The government is one of the largest clients in this sector, placing billions of euros worth of contracts on the market each year (Pianoo, 2024). With the largest client being Rijkswaterstaat (RWS), there are also special sector companies who publish their contracts such as ProRail which is responsible for the majority of the train tracks throughout the Netherlands.

During large integrated projects, Integrated Project Management (IPM) is used. This management model is developed by RWS and is used in the public sector by RWS itself, ProRail, provinces and in the private sector by large contractors. Five roles are defined in an IPM team: project manager, project controller, environment manager, contract manager and technical manager (Rijkswaterstaat, 2024). The four disciplines included in this thesis fall under the technical manager. These disciplines are all present at the Deventer office of Antea Group and are often involved in infrastructure projects in the GWW sector, they are presented below.

Kunstwerken
The discipline of Kunstwerken encompasses a wide range of critical infrastructure, including bridges, tunnels, viaducts, quay walls, locks, and pumping stations. The majority of the structures are constructed from concrete, although alternative materials such as wood and steel are also used, for example in the construction of pedestrian and cyclist bridges.

Rail
The discipline of Rail is involved in rail projects with the largest client being ProRail. The majority of the rail projects are maintenance-related. The Dutch railway dates from after World War II and lasts for around forty years. Eighty years later a second round of significant maintenance is required (ProRail, 2024). Other projects include converting unguarded crossings into guarded crossings or eliminating a crossing by building a viaduct or bridge.

Road
The discipline of Road is involved in the development, improvement, and management of road infrastructure challenges. The main clientele includes municipalities, provinces, central government, and contractors. The projects can be related to existing roads or designing new ones.

Soil
The Soil discipline plays a crucial role during any GWW project conducting essential ground research that supports various disciplines. This work ensures the success of projects across domains, without creating visible structures. By providing accurate soil information, this discipline contributes to the stability, safety, and longevity of infrastructure projects. In one recent rail infrastructure project the

Kamperlijn, trains were limited to reduced speeds due to soil conditions, which was not known during the plan and construction phase of the railway line (ProRail, 2017). This indicates the importance of the soil discipline during construction projects.

1.2.2 Project phases

Construction projects include different phases which can be seen in *Figure 1*. During the pre-project phase, the project's feasibility is considered. The project is only a vision of the client that needs to be realised. Activities during the planning phase consist of forming a technical team, outlining the design and securing operational permits.

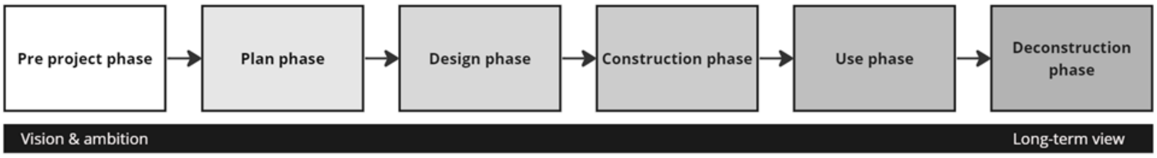

Figure 1: Phases in construction project

During the design phase, the structures are designed that will be built during the construction phase. Different designs are made, this is an iterative process where deviations are unavoidable (Aslam et al, 2019). There are three major designs made during this phase, the preliminary design (VO), the final design (DO) and the implementation design (UO). With each design step, the design becomes more detailed. Finally, after completing the implementation design the construction phase can start. The use phase covers the time that the designed structure is in use. During this phase the structure can be monitored and if required maintenance activities can take place. The deconstruction phase covers the end-of-life phase of the structure where it is demolished and recycled.

1.2.3 Fragmented industry

The construction industry has fragmented throughout the years. This fragmentation, often called specialisation, has led to the emergence of new disciplines, each with a distinct role in the project lifecycle, resulting in complicated organisational structures. The extensive specialisation during the design and construction phases requires input from various technical disciplines, such as mechanical, electrical, IT, and civil, as well as financial and regulatory bodies (Fellows & Liu, 2012). Adam Smith, an early advocate for the division of labour into distinct roles, stated that fragmentation could enhance productivity. However, the modern construction industry faces challenges due to this fragmentation.

Over time the industry fragmented vertically into phases, first 'design' then 'build' then 'operate' with different teams at each phase (Voeller, 2019). This vertical fragmentation began to extend horizontally and complexity led to specialisation where in each phase multiple disciplines are involved (Voeller, 2019). This also occurred in the infrastructure sector. Currently, projects are often integrated projects with multiple disciplines needed to realise the project. Before defining integrated projects, understanding the workflow in traditional construction projects is necessary. Within traditional projects, a set of work activities are performed linearly, task by task. One discipline works on its task until it is finished then information is shared with the next discipline. This workflow is inefficient when multiple disciplines are involved in the design process. There is a lack of communication between disciplines which can lead to errors requiring disciplines to readjust their design (Matthews et al, 2018). Redesign work is costly and time-consuming, often resulting in delays and increased project expenses. Lack of interaction among disciplines can compromise the overall quality of the design. Without input from all relevant disciplines, the final design may fail to meet the desired standards or requirements set by the client (Matthews et al, 2018).

1.2.4 Integrated projects

During an integrated project disciplines work together in the different phases. By performing cross-functional interactions and interdisciplinary exchanges, professionals gain better insights from diverse fields. This collaborative approach helps address complex challenges and results in a more integrated design, optimising both performance and value (Hooimeijer, 2022). Research on interdisciplinary interactions or knowledge transfer among disciplines is performed in a wide range of fields. These fields include the collaboration between engineers and architects, as well as the interaction between environmental experts and decision-makers. The conclusions from these research projects remain quite general (Hooimeijer, 2022).

Information transfer between technical disciplines is especially vital during interfaces (Chen et al, 2007). During integrated projects, interfaces can take place which makes the project more complex. Interfaces occur at project points where scope boundaries between different technical disciplines intersect (Ascerta, 2024). Interfaces define the scope of work under the responsibility of a discipline that may affect or be affected by the scope of work of another discipline working on a similar part of the project. Each layer of complexity adds a layer of additional risk, the greater the number of disciplines and interfaces, the higher the ambiguity and uncertainty (Ascerta, 2024). Taking these interfaces in an engineering context, Kunstwerken is involved in the design of a railway viaduct and is responsible for the structural elements, which must seamlessly integrate with the transportation infrastructure provided by the disciplines of Rail and Road. The Soil discipline is focused on the geotechnical and environmental state of the soil providing information which is needed to design the foundation for the structural and transportation elements that are built on the soil. Effective management of interfaces between these disciplines is especially crucial during the pre-execution phase. A well-controlled interface between designers helps incorporate customer requirements into design and increases output value and flexibility (Chen et al, 2007). Interdisciplinary exchanges, foster a deeper understanding of the project’s challenges. Interface management strategies such as interdisciplinary exchanges will work when the scope of work for each discipline is clearly defined and the potential impacts it will have on other areas are considered (Piantanida et al, 2014). As projects grow the complexity and risk associated with interfaces increase, highlighting the importance of robust interface management.

2 Research aim

This bachelor's thesis aims to provide specific recommendations on how technical disciplines should manage interfaces within an integrated project. This will ultimately lead to more successful project outcomes, benefiting both the client and Antea Group. While interfaces can occur during different phases of a project, this thesis will specifically focus on interfaces that take place during the plan & design phase.

2.1 Research gap

The necessity of interface management in complex integrated projects is well-recognised. The absence of effective management can lead to a decline in the final design quality, resulting in a final product that fails to meet the client's requirements, which calls for expensive redesigns. The specifics of how interface management should be implemented to secure the interfaces remain general. The current research does not provide detailed guidance on the intensity and extent of the cooperation between technical disciplines. Furthermore, it is unclear when these interactions must occur during the design phases. This gap in research shows that more research is needed on how to secure interfaces during the pre-execution phases. By concentrating on integrated projects in the infrastructure sector, it is possible to provide more valuable recommendations regarding the problem that Antea Group faces. By filling this research gap, this thesis will contribute to the existing body of knowledge on interface management in integrated projects, providing valuable insights for experts in the field.

2.2 Main research question

How can managing interfaces between technical disciplines in an integrated project be improved during the pre-execution phases?

The main question is answered based on the findings of this thesis, with these findings recommendations are made, which aim for better-managed interfaces. All disciplines ultimately work towards the same goal, a successful project where the client's requirements are realised.

The main research question is subdivided into sub-questions. This has been done to make answering the main question easier. The required information is organised into different topics, which creates a proper foundation for identifying areas of improvement and giving recommendations.

2.3 Sub-research questions

1. **What are the different interfaces between the technical disciplines during the pre-execution phases of an integrated project?**

   By examining the processes that take place and the products that are made by the different disciplines. When looking at the common practices of each discipline insights can be gained in the different approaches. The difference in processes can indicate interfaces among the disciplines.

2. **What are the experiences of the discipline members when they work within an interface between disciplines during the pre-execution phases?**

   By investigating the current state of interaction among the members of the different disciplines, insights can be found in the current strengths, weaknesses, challenges and opportunities of this interaction.

3. **When there is a substantial change in project specifications does this hamper the insight into the interfaces between disciplines, how do the various disciplines react to these circumstances?**

By examining how the disciplines react to substantial changes more information can be found about the interactions that take place during an interface. A change in project specification will create more complexity, and working in interfaces will most likely be more challenging.

4. **How do the literature insights and expert interview outcomes inform the understanding of interfaces during the pre-execution phases of an integrated project?**

This subquestion aims to bridge the gap between theoretical knowledge and practical experiences found by interviewing experts, by comparing the literature with insights gathered from expert interviews. Identifying commonalities and discrepancies will result in a better insight into the complexity of this problem.

2.4 Research scope

The information gathered to answer the research questions will be formed during two phases of a project, the plan phase and the design phase. These phases can be referred to as the pre-execution phases, as construction has not yet started. *Figure 2* illustrates the two phases and other common phases of an infrastructure project in a timeline.

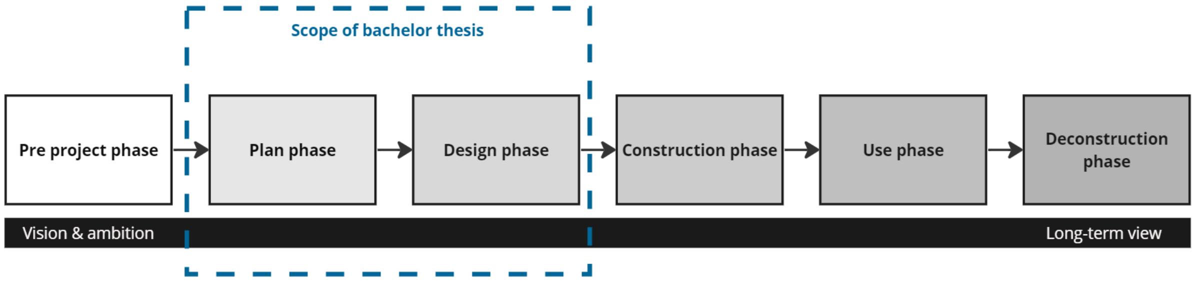

Figure 2: Scope of the thesis

Technical management is responsible for the content of a project. During the two phases, a design process takes place where the structures are designed, that need to be built. During this design process, interfaces between disciplines are managed. This process needs to be investigated regarding where interaction and information sharing among disciplines take place. Interactions can take all kinds of forms from dedicated interface meetings to messages between designers. Projects can experience periods where interactions are more frequent, due to more interfaces among the disciplines. The disciplines and experts interviewed need to have worked on projects in an integrated form where interfaces among other disciplines take place. If other technical disciplines or non-technical disciplines will cause interfaces with these four disciplines this will not be excluded, However, the main focus of this thesis is on how interfaces are managed between Kunstwerken, Rail, Road and Soil during an interface.

The thesis will investigate this problem in a general context instead of a case study associated with one ongoing project. This will result in broader recommendations and findings into the interfaces that take place between the disciplines. This decision creates a large group of employees who can be asked for an expert interview. The findings of this thesis are valuable to more employees within Antea Group who work on integrated infrastructure projects.

3 Literature study

The challenges formed by the fragmented construction industry are an important factor when addressing interfaces. This separation results in poor communication and a lack of understanding of dependencies between phases, contributing to inefficiencies and failures (Nawi et al, 2014). The challenges found by Lawrence and Scanlon which affect interfaces are mentioned here, supported by other researchers who have the same findings. Outdated project management tools struggle to represent the complexities of integrated projects, especially in capturing iterative design processes. The existing planning tools fail to adequately represent detailed information flows and iterative dependencies, leading to unrealistic resource requirements which can lead to project delays. These two challenges are created by the combined effects of dependence and variation in construction as well as the project's complexity (Howell 1999). To manage these issues new forms of planning and management tools are required, which is key for enhancing workflow reliability (Howell, 1999). In construction projects, the actual progress of the project can be slower than the planned project speed. This results in teams who work on the project being unwilling to update the plans as the project evolves (Lawrence & Scanlon, 2007). This could be tackled by changing how work is structured at the start of a design phase and regulating the workflow throughout the design phase (Chen et al, 2007). The last challenge that affects interfaces is the poor reuse of knowledge between projects. This means that between projects, design teams can encounter the same interfaces and work out the same interface, which could be prevented by sharing past project knowledge. To mitigate these issues, there is a need for improved management practices that offer better integration and cooperation among the various stakeholders. This management model must also tackle the challenges created by the vertical and horizontal fragmentation that takes place in the construction sector. Fragmentation extends further to the bid/tender process, where new project teams are created for each project, which creates longitudinal fragmentation, where new teams are repeated over and over (Voeller, 2019).

It is important to use management tools that can handle iterative design processes. If iterative design processes are not performed and the design eventually does not fulfil the client requirements design changes need to be made at the end of the design phase. Design changes during the design phase can have a large impact on the cost of a project, even in well-managed projects the cost can be impacted by 2.1% to 21.5% of the total construction cost (Han et al, 2013). Next to the need for project management and planning tools which can handle dependencies between disciplines and iterative processes. The different disciplines must secure the interfaces during the design phases, this is vital to having an efficient project (Chen, 2007). Research shows that multiple interactions can be set up to navigate an interface between disciplines. Formal collaboration and coordination between disciplines is a crucial aspect of successful integrated construction projects, as it encourages teamwork, information sharing, and effective communication (Mahame, et al, 2018). There are different forms of interactions disciplines can take such as co-designing elements, information sharing and proper communication among disciplines.

There was an emerging need for a platform where interfaces could be coordinated, where interface problems should be addressed and information shared. In 2006 Roshani already highlighted the importance of using emerging technologies to facilitate collaboration. It focussed on the development of a collaborative online environment where multi-disciplinary collaboration is possible. These environments exist today, Building Information Modelling also known as BIM is essential in today's design process. BIM functions as a platform where information is shared among different disciplines. The various models of the disciplines are integrated into one operating environment (Olatunji, 2014). Within this environment, disciplines can find specifications of elements designed by another discipline. The result of this environment is that the ownership of the information is shared, in an integrated platform, enabling all participants to collaborate openly (Olatunji, 2014). During the design phase, different design iterations are made by the discipline. Managing these iterative changes is challenging as it usually requires long transition times between each design step (Shafiq, et al, 2012). Disciplines can also work in different tempos, with one discipline advancing further into the design phase and working on a more detailed design. In these cases, interoperability is compromised, even when the different disciplines use BIM. (Love et al, 2015). This highlights the importance of making strict agreements at the beginning of the design phase.

BIM techniques are regularly used in construction but more actions need to be taken to secure the interfaces during the design process. The benefits of interface management are researched by Chen et al (2007), it can have a positive impact on the whole construction process. The most important benefits of Interface management for this thesis are mentioned in *Figure 3*.

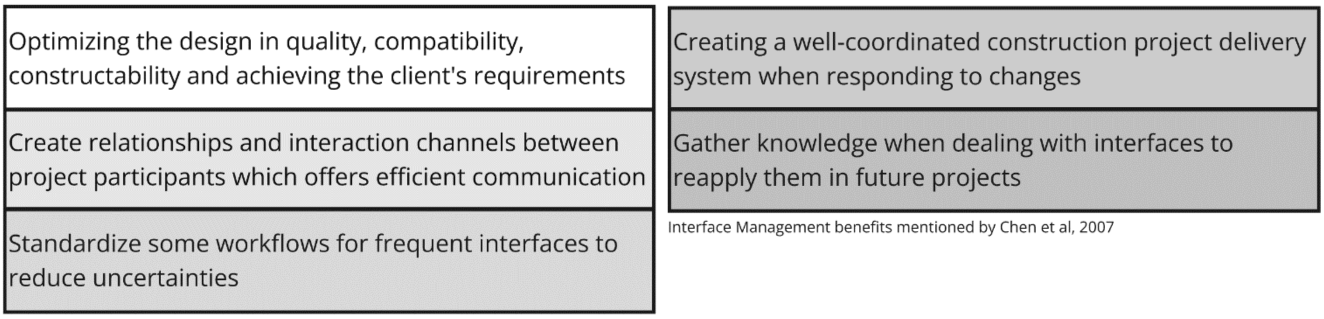

Figure 3: Interface management benefits

Interface management must reduce the number of physical interfaces through component integration and standardising common interfaces (Chen et al, 2007). This decreases the number of steps that need to be taken in the design process and therefore simplifies this process. This emphasises the importance of a structured project. This can be done by using functional-based work breakdown structures. Work Breakdown Structure (WBS) are work packages that are separated into different disciplines or even separate contractors. Inappropriate work packages result in excessive interdependencies and enlarge the number of interfaces in a project, increasing the likelihood of delays (Chen et al, 2007). A more interface management approach uses functional-based WBS, which is based on creating subsystems in a project, that results in allocating work packages to different disciplines without breaking complex interfaces. Rawsthorne (2004) states that using functional WBS in a construction project can provide visibility and control for the project manager and the client. Furthermore, it is important to control boundary conditions between disciplines to better understand the project complexity (Chen et al, 2007). This information can again be useful in future projects which have the same objectives.

The management of knowledge gathered from past projects within the organisation allows it to be reused on other projects, reducing the time spent recreating what has already been learned (Owen, 2006). Knowledge can also be transferred more practically by working in stable teams during integrated projects. Team members who stay in the same team learn how to work together well (de Graaf & Loonen, 2018). In stable teams, team members get to know each other and recognize each other's strengths and weaknesses. Actively exchanging and using team member's knowledge and skills can have a positive effect on the effectiveness of the project (de Graaf & Loonen, 2018).

4 Research methodology

In this chapter, the different research methodologies are described. This is done for each research question. The output which is expected of each question is also given. This bachelor thesis uses academic literature, company literature and expert interviews.

4.1 Main research question

To be able to answer the main research question fundamental knowledge is gathered. This is done by answering the sub-questions where more insight is found into the current situation of the problem.

A literature study has been performed which focused on the current methods used to manage interfaces. This study has given a proper explanation of the need for interface management during integrated projects. By comparing these findings with the case of Antea Group effective recommendations can be given.

4.2 Sub-research questions

Company literature is used to find the interfaces between disciplines, standardised working plans and manuals are requested from the different disciplines. Processes and products that occur during the plan and design phase are investigated for each discipline.

Expert interviews are used for all sub-questions to investigate experiences and perspectives on the described problem. Qualitative interviews can be used to give a better understanding of the social reality that is at play (Edwards & Holland, 2013). The experts at Antea Group have valuable information on the problem and translating this knowledge is the focus of this thesis. Information that was found by performing expert interviews consists of interfaces, interactions, working methods and the effect that substantial changes have on a project. Especially past experiences of employees played a vital role in understanding the challenges associated with interfaces. Experts were also asked on the topic of stable teams since the academic literature mentioned this as a solution.

The interviews are held with 11 experts who come from different disciplines and have diverse functions, this information can be found in *Appendix: A1.* The sequence of the table directly displays the interview order in which the experts are interviewed. Their function can affect how they answer the question.

Next to the experts from the four disciplines, an environmental manager is interviewed on the topics of conditioning surveys and client requirements. For the topic of stable teams, a PhD candidate from the University of Twente is interviewed who specialises in programmatic projects. Before the start of the interviews with experts 4 until 11 an interview guide was made. The interview guide has been reviewed by an assistant professor in Social Sciences from the University of Twente. The process of making this guide is described in *Appendix: A.2* and the final guide can be found in *Appendix: A.3*.

In the last sub-research question the literature and expert interview findings are compared. The difference in findings will be analysed which helps in forming recommendations for the main research question.

5 Results

This chapter presents the findings of this thesis. Information related to the project organization and project phases within Antea Group is found in the *Deelmanagementplan, Technisch Management*. Subsequently, the expert interview findings are analysed per sub-research question. Different theories on interface management are formed with the opinion of the experts. To finalise this chapter similarities and differences between the literature study and the case of Antea Group are highlighted.

5.1 Processes & common interfaces

The design processes within Antea Group are aligned with the processes of large clients in the GWW sector. For projects related to lane extension attention is given to phases used by RWS. For rail projects processes used by ProRail are taken into account. This results in a design process with 6 steps for each discipline. In *Figure 4* the different design phases that Antea Group uses can be seen, it is shown that these phases fall within the scope of the thesis.

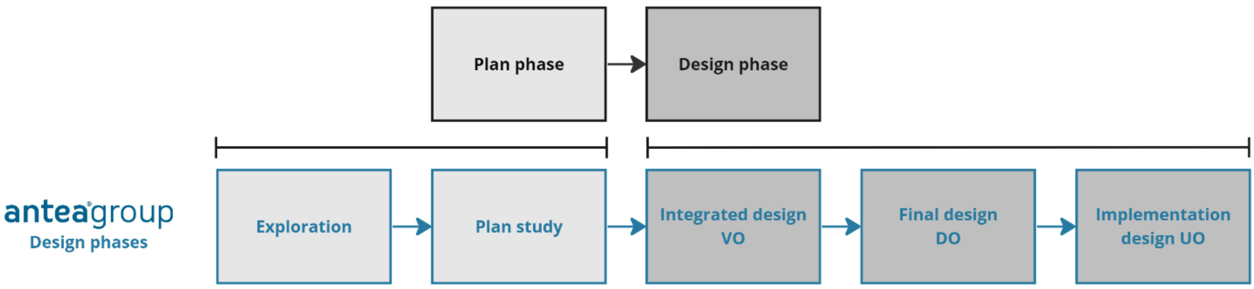

Figure 4: Antea group design phases

The first phase is not presented in this figure, this is the initiating phase. This phase is mainly performed by the client, Antea Group does not yet have a role in this phase. The phases will be addressed below assisted with the experiences of the experts, first for the plan phases and then for the design phases.

5.1.1 Plan phases

Exploration

This phase focuses on the use of the structure, the client needs to have a specific need for which the structure is designed. The client shares information regarding their needs, this can be information regarding the users, lifetime, safety aspects and environmental goals. This is referred to as the client requirements these can also originate from stakeholders, common requirements from stakeholders in infrastructure projects are limiting the noise pollution and delay caused by the realisation phase of a construction project. In a large integrated project, the environmental manager plays a large role in gathering customer requirements, with technical management playing a supporting role. The technical specialist is important in formulating functional requirements which can be used in the design process. Customer requirements undergo a process in which the requirements are honoured. If a requirement is honoured this means that the requirement must also be fulfilled in the project. Not all requirements can be honoured, for example in the case of unrealistic requests which fall outside the project scope. This process can be managed with an SE approach where functional requirements are linked to objects that need to be designed.

I think we need to move more towards an SE solution, we need to be more aware of what is happening at the beginning of a project, attention should be given to the final product and associated requirements which come from client requirements. Then you can see with your own eyes what needs to be done before you start designing. [Expert 7]

This belief has been supported by the majority of the experts. The intensity in which these tools must be used and during which phases, is up for discussion among the experts. There also is a possibility to standardise certain steps in gathering customer requirements. The requirements for a bridge or tunnel are typically 70% the same, as they are largely derived from legislation, standards, and guidelines. In one case Antea Group has encountered a project where the client requirements were made up by the design team. The client stated similar projects were carried out and found it unnecessary to set up new client requirements.

At the end of the exploration phase, design alternatives are made which are not fully worked out, these are compared against each other. Eventually, a preferred design alternative is chosen. Which holds the needs and functions of the client's requirements and stakeholders who are present in the project. It is possible to already look at interfaces that can take place between disciplins, the focus is on identifying interfaces and seeing if they are solvable in one of the next phases.

Plan study:
The main goal of this phase is to develop an alternative design that can be supported by all stakeholders. The chosen design variant needs to be designed in more detail in the coming phases. When an SE approach is used, the client requirements can be linked to functions. This can take place in a very structured method where functions are divided into systems. Eventually, objects are created, if a road needs to have a function that prevents drivers from colliding with opposing traffic, this function will be linked to a guardrail between the two lanes.

During the plan study surveys are performed at the preferred project location. Surveys can act as a pre-condition for design teams as they directly influence design, planning, fasciation and work plans that eventually acquire a contractual status. Multiple experts from different disciplines mentioned the importance of the timeframe in which surveys are performed. 'You schedule the conditioning surveys so that information is available for technical management at a useful point in the project' [Expert 3]. Obtaining this information at the right time in the design process is important to avoid unnecessary work. The Soil discipline performs their own surveys, this discipline is seen as a facilitating discipline. The information this discipline gathers can be seen as the input value for the design phase.

I hope to finish the soil surveys when the other disciplines are designing the VO since it can have an impact on how structures are designed. [Expert 1]

During the plan study desk research can be performed by the Soil discipline here geotechnical and environmental conditions of the soil can be researched. The most accurate information is found when the Soil discipline performs tests at the actual project location. There was one expert that mentioned surveys can also be performed too early during the plan study.

If you are exploring three alternatives, It is unnecessary to test the soil at three locations, this will only increase project costs. At the beginning of the project, it is important to know when information needs to be provided by the different disciplines. [Expert 10]

A clear distinction between internal and external interfaces must be made in this phase. External interfaces are found by surveying the project location, this can bring limitations which need to be taken into account. Examples of external interfaces can be the existing cables and pipes at the project location or neighbouring Natura 2000 areas that have strict environmental requirements. External interfaces can have a large effect on design choices, if environment management states that a train station needs to be operational during a maintenance project, different design options and techniques will be used due to this request.

The project location can impose certain conditions on the method of execution, these methods of execution can in turn affect the choices you make in your design. [Expert 7]

Securing and managing the external interfaces is a continuous process, which extends beyond the pre-execution phases. Internal interfaces are the interfaces throughout the project within and among disciplines. These interfaces are mainly revolved around the design and placement of objects.

5.1.2 Design phases

Preliminary design (VO):
After the plan study, the preferred alternative is made into a preliminary design. If there is only one object that needs to be designed a preliminary design can be made immediately. If several disciplines are involved in the design process an integrated design should be established at the end of this phase. This integrated design is used to check if there are any interfaces between the designed objects. These interfaces must be resolved before the design is further worked out.

Individual plans are merged to ensure that they work together, this requires an overarching view that looks across disciplines rather than thinking in separate disciplines. [Expert 10]

An integrated design approach is needed during the different design phases, the largest interfaces are tackled at the start of the VO. The axis of the road or train track ultimately decides where structures are built. Next to the axis of these transportation infrastructures, the loading gauge (PVR) is an important test to perform between disciplines. The PVR is a 2D profile which describes the profile of free space on a road, train track, cycle path, pavement and bodies of water. In this profile, no object can be placed this test determines the height at which the bottom of a structure could start, or how far down a road should be laid under a viaduct.

A risk during this phase is that the different disciplines do not have the same working speed. This can result in the leading discipline creating bottlenecks for other disciplines that are not as far along in the design phase. The leading discipline can also suffer consequences from this risk such as needing to readjust their design because other disciplines request adjustments, resulting in extra work for the leading discipline. The technical manager may require the disciplines to work parallel throughout the design.

Kunstwerken starts first because they have a permit deadline of six months before construction, the other disciplines often have not started yet. This results in limited design freedom for the other disciplines, it is more practical when the disciplines work parallel. [Expert 4]

The integrated VO design should allow the different disciplines to continue designing their structures in the coming phases independently. The designs of the disciplines in the next phases should be comparable to the VO in which the main dimensions have been established. Between the different disciplines, the design aspects must be known which the various disciplines deliver. The disciplines must also indicate the interfaces that will arise in the coming phases between each other.

Final design (DO):
After the Preliminary design, each discipline makes an independent final design. The objects are further designed and are location-specific depending on where they will be placed. With the amount of detail

in this design, it is possible to apply for the environmental permit which is needed to start the realisation phase. The design is an actual representation of the structure that will be built. The dimensions are specified as well as the material choices, performance and internal interfaces.

A DO can be made individually, you have to manage the resolved interfaces. Small things can arise such as a drainage, it cannot be the case that during the DO you find out that there is a sewage pipe running through your project, you should have known that before. [Expert 4]

Implementation design (UO):
In the UO phase activities are developed for the construction phase, this is done for each object from the final design. The phase starts with creating the WBS. Objects are bundled by location or object type this depends on the order in which the structures are built. It is advised to create bundles which can be constructed by a single contractor, this is more efficient. The UO must ensure that the structure is built in such a way that it acquires the qualities of the DO.

It is vital to manage and check the resolved interfaces during the UO. The design of a moveable bridge was given as an example of this importance. During the design of a moveable bridge, a lot of interfaces take place between the steel, concrete and moveable parts. 'Only when the bridge is built you are sure that all interfaces are secured, this is done by testing the bridge after the construction phase' [Expert 7].
Information needs to be known at a certain detail level to properly secure the different interfaces, this makes securing the interfaces more complicated. During the design of the basement of a movable bridge, dimensions need to be determined without knowing the size of the installation that is going to be installed in the basement.

Dimensioning the basement of a movable bridge is a rather large interface which needs to be managed from the start of the VO phase. Eventually, the installations in the basement need to have access points for pipes and cables, this is something you want to know in the DO phase Then during the UO phase, you secure this interface by taking these pipes and cables into account when designing the concrete reinforcement. [Expert 8]

Difference in detail
The VO, DO and UO designs have a difference in detail. It is common practice for the Rail discipline to make a VO and allow the contractor responsible for that project to work towards an UO. To give a visualisation of what the differences are between the different design products. An example of a VO, DO and UO design of a project from Kunstwerken is shown in *Figure 5*.

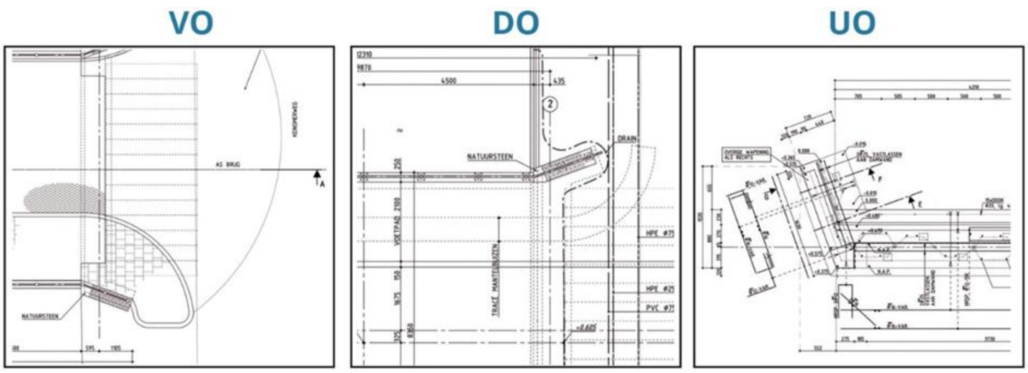

Figure 5: Difference between design products

In this particular example, it is possible to see that the axis of the bridge has already been determined in the VO, in the DO the dimensions of the structure are specified. Kunstwerken only starts with the concrete reinforcement design during the UO. The difference in detail can depend on the project, when working with multiple disciplines the technical manager can determine the amount of detail of the design products per discipline. This can be useful since the output of one discipline can be the input value for another discipline.

5.1.3 Funnel & loop theory

Funnel theory

The effect interfaces should have on the different design phases can be explained by comparing it to a funnel. The first interfaces are very broad and abstract and the amount of detail in the plan is limited. The decision to relocate a road or construct a bridge can simply be a line on a map. With more information a preferred alternative can be chosen and more specific interfaces can be identified.

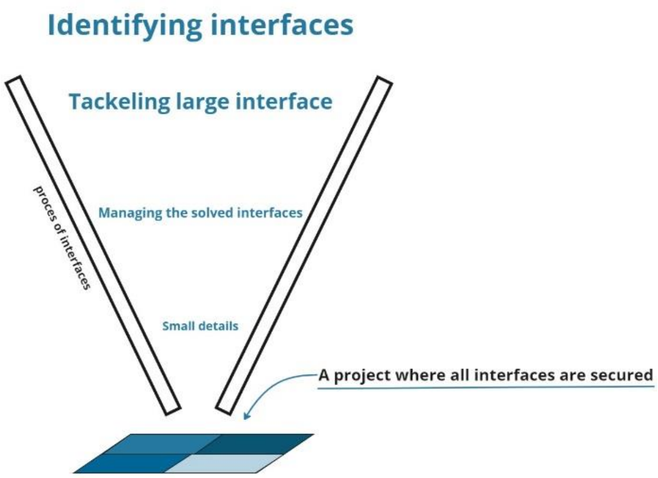

Figure 6: Funnel theory

In *Figure 6* the funnel theory is shown, starting with a high level of abstraction that becomes increasingly more specific as the project progresses. When more information is added you can funnel more and more towards the solution. Towards the end of the design process, the focus shifts to examining interfaces in greater detail. This should always be the case since design products get more detailed over time.

Loop theory

Interfaces have a constant influence on all design phases, regardless of the phase the project is in. Identifying and securing the interfaces is an ongoing process throughout the design phases, but the interfaces are smaller over time. This can be visualized with loops that get smaller when the design holds more detail, this is shown in *Figure 7*.

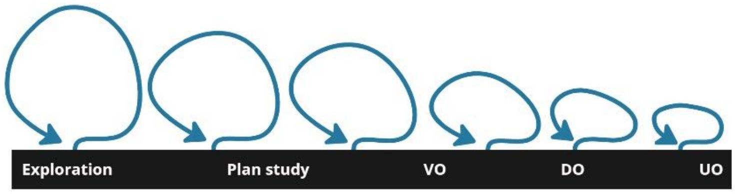

Figure 7: Loop theory

In each loop, alternatives are assessed by going back through the process to see if there is a better solution that comes closer to the objectives of the project. At the beginning of a project, a structure across a body of water can be a tunnel or a bridge the best alternative depending on the environment and future users must be chosen. These alternatives get smaller with each step from the dimensions of the structure to different light plans. The same accounts for the interfaces which get more specific during the design phases.

5.2 Interfaces vs interactions

There is a clear difference in how quickly projects are started or when they start designing when comparing integrated projects with traditional projects. Experts agree that design tasks start sooner during a project where only one discipline is needed. There is a preference for a collaborative start in integrated projects. Integrated projects require a more thoughtful approach focusing on interfaces at the start of the design phase. However, opinions differ in the level of detail and timing in identifying interfaces throughout the project and how interactions between disciplines should look like. This becomes more apparent when diving deeper into listing interfaces and interactions that disciplines have when managing interfaces.

5.2.1 Listing interfaces

Listing interfaces is under the responsibility of the technical manager, when this is too much work it is possible to appoint someone to help manage the interface register. Opinions differ on listing interfaces, some experts recommend listing interfaces as soon as possible, while others believe this should be done during the design phase.

The systematic work which we perform during integrated projects ensures that you keep an overview during the project. The difficult thing is that everyone has their preferences, one likes the process the other likes the design part yet they are both technical manager. [Expert 10]

All experts agree that it is beneficial to address interfaces as soon as possible, this can save costs. This process can start during the plan study where large interfaces between the disciplines can be named based on expert knowledge. Some experts take identifying and listing interfaces very seriously before starting the design phase. This would create a VO phase in which the interfaces are secured and a DO phase where only minor adjustments in the interfaces would be needed. Experts stress the importance of managing interfaces that have been resolved in the VO and DO phases. Failure to adequately identify and manage interfaces can lead to costly redesigns, especially if major aspects are overlooked.

I*n an integrated project you first list 80% of the interfaces, then come up with a rough idea of how you're going to solve it. The large interfaces can all be listed before you start designing.* [Expert 4]

Two different systems have been found which are regularly used by technical managers for listing interfaces, Relatics and the BIM environment.

Relatics

Relatics is a SE tool which focuses on presenting project information in a structured method, this is done throughout the life cycle of a project. This tool is used by various technical managers to get better insight into the interfaces. The interfaces can be linked to objects which come from client requirements. Experts mention that experienced employees can play a large role in identifying interfaces by using knowledge gathered in past projects. Experts who use Relatics mention that there is resistance to using SE-focused systems.

People have cold feet about doing everything through Relatics. They find it difficult to work with and like the easier old-fashioned way. They also find this to be a lot of extra work, but it ends up delivering a lot of benefits. [Expert 4]

Experts question if everybody knows that such tools exist and if they know how to use them. Working in such a systematic way can provide guidance throughout the design phases. It will eventually lower failure costs, which include potential redesign when interfaces are missed or not properly secured.

BIM

Within the BIM environment in which the structures are designed, it is also possible to list and manage interfaces. Antea Group uses the Autodesk Construction Cloud (ASC) where models of the different disciplines are merged and clashes between two objects can be pinned. Clashes are directly displayed in the 3D program, where experts point out that Relatics is an extra step. Clashing is performed throughout the different design phases with large interfaces being tackled at the beginning. Interfaces can be noted before designing by creating a BIM execution plan here it is written down which objects will clash and that it is possible to perform a clash check on them.

In recent years you can see a shift, BIM is becoming more mature within the market. Today a 3D model is already created within the VO phase, this allows for early identification and clashing of interfaces, which saves time in later phases. [Expert 5]

Some experts indicate that Relatics is only used in very large projects where the interfaces can be copied from the ASC. Interfaces can easily be shown on 2D and 3D plans an example is given in *Figure 8*, where interfaces are listed for the design of a new viaduct.

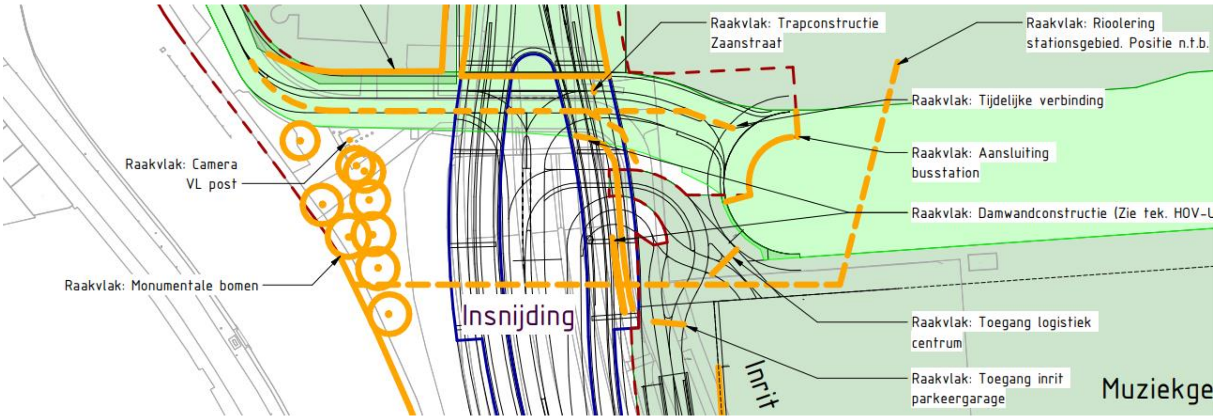

Figure 8: Interface map (Emmaviaduct Groningen)

Although there are different opinions from the experts in listing interfaces all experts agree that by addressing interfaces earlier in the process, valuable time and resources can be saved. Designers should closely consider the list of interfaces, failing to do so may necessitate design adjustments. Listing interfaces is not the only topic in which differences were found one expert stated that a more uniform design process could benefit project outcomes.

Design notes, design justification, all those kinds of documents I see in different variants some in better quality than others. This calls for the importance of a uniform method of working during a project. When there is uniformity in the way that work is performed, interfaces will be better secured. [Expert 7]

5.2.2 Interactions

Interactions among the disciplines are vital in securing interfaces. The experts agree that there must be one person who manages the interfaces. This person determines which discipline needs to solve the interface, this can be a collaborative and iterative process. Who this role performs depends on the project it could be the technical manager, BIM coordinator or a designer from the discipline that is most dominant in the project. This integrated design leader is responsible for merging the various designs and managing the interfaces. The leader must emphasise the need for collaboration and communication between disciplines to ensure an efficient and effective design process.

When this person points to someone to work out the interface, he will receive input from the other disciplines, the designer is then responsible for that piece of design. He will present his solutions in a dedicated interface meeting. [Expert 8]

The experts mention different forms of interface meetings but all recognize the importance of these meetings. One expert suggests organising interface sessions where representatives from two disciplines come together under the guidance of a chairperson. During these sessions, the interfaces are presented systematically, solutions are made by the disciplines together. During these sessions inputs, outputs, agreements and certain dimensions are discussed. 'From my own experience as a discipline leader, I can indicate a lot of interfaces but I do not know what each discipline needs or where all interfaces lay' [Expert 8]. It is important to maintain a structured approach, focusing on efficiency and effectiveness in resolving interfaces.

At Antea interaction between designers is quite good. I do notice that it becomes more difficult when an external party is involved. These parties can work differently which does not align with the way Antea Group works, or they simply do not see the need to collaborate. [Expert 4]

It is always a risk when certain expertise is not found in-house. There is knowledge about it but Antea Group is not allowed to make decisions in these fields. To give a particular example Antea Group does not specialise in overhead line construction for railways. Experts indicate that overhead lines often create an interface because of the location of the catenary poles and the forces this exerts on structures such as viaducts.

It is possible to just invite these people to your design meetings, for the importance of both parties. They must not feel that they are there for only the progress of your project. [Expert 9]

Interactions between designers can also take place outside of dedicated meetings. Some technical managers prefer to have all designers in one office, whereas other managers disagree. These managers focus on making effective agreements between designers at the start of the project, this means designers from different offices work as well together as designers from the same office.

In my experience, young designers frequently message and call each other. The older employees are more old school and prefer to see each other physically. I don't believe that solutions are just solved by putting everyone in one room. [Expert 4]

Some experts prefer working on the design in the same office because the communication lines between designers are shorter. It is easier to ask questions, especially during the phases where large steps need to be made in the design. When designers from two different disciplines frequently work together they will know each other's needs and co-design throughout the project. While there are contrasting opinions on interactions between designers. Experts empathize that working out the interfaces is an intensive task in managing interfaces. A manager should not put too much pressure on using as little time on the design, it is important to stimulate the designers to come up with solutions that will pay out in the quality of the design.

5.2.3 Postage-stamp projects

In both the topics listing interfaces and interactions with interfaces working systematically proves to be an important aspect when managing interfaces. Experts have pointed out that working systematically is necessary in each project independent of the size of the project. Common questions in construction projects are what is the scope of the project, where are the risks and the opportunities these aspects are present in all projects and must be managed systematically. Currently, there is a difference in interface management between large and small projects, where large projects receive more attention because of the higher potential failure costs.

On a postage stamp-sized project a lot of disciplines can be involved. Perhaps that is also the risk of a very small project. We take these kinds of projects too lightly, there is a lot of room for improvement. [Expert 4]

A project manager who starts on a relatively small integrated project can end the project with a loss since he forgot to include one discipline in the project. [Expert 10]

In smaller projects designers tend to start designing sooner, interfaces are found along the way. If not all disciplines are known at the start of the project, there may be insufficient room for each discipline to achieve the customer requirements. Even in small projects, it is possible to use a systematic approach. An interface list could be made in a couple of hours and provides guidance throughout the design phases.

5.2.4 Theory 1-2-3

A theory will be presented on how it is possible to manage interfaces throughout an integrated project, this theory is formed with the opinion of different experts. The theory is described by placing the numbers 1, 2 and 3 underneath the different design phases, this can be seen in *Figure 9*.

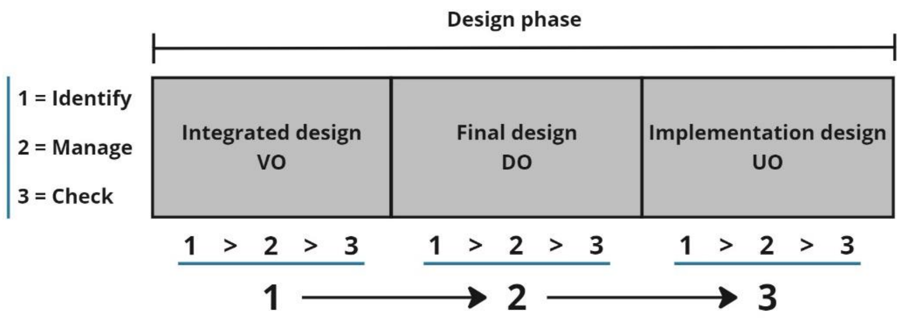

Figure 9: Securing interfaces throughout the project

Number 1 represents identifying interfaces, during each design phase. It is crucial to identify interfaces upfront to prevent unexpected issues from arising during the design phase. Number 2 represents managing the interfaces here the interfaces are worked out between the disciplines. Number 3 represents that each interface which is identified during the design phase must be checked to ensure that it is secured. It is also possible that an interface could be identified in the VO phase, worked out in the DO phase and then checked in the UO phase. This is represented by the lower sequence of numbers. The numbers indicate the importance of each step, with the most important step being Identify, then Manage and finally Check. It can be argued that the most crucial step is checking if an interface is secured. However, this is only possible if the interface in question has been identified in the first place.

5.3 Substantial changes & stable teams

5.3.1 Substantial changes

Different opinions are found when substantial changes take place during the design process. This can be justified by the roles that the experts hold during an integrated project. Project managers and design leaders are critical of their work when a client points out that the design lacks quality. When this is the case the project can incur significant extra costs depending on how far along the project is in the design phase. Designers tend to point more at each other when the design does not have the intended quality. When changes need to be made a new set of interfaces needs to be assessed. All experts agree that it is better to prevent substantial changes since they involve a lot of work, preventing this turns out to be more difficult.

During the design process, the client comes up with new requirements or adjusts their requirements so your project scope changes again. You certainly do not want that to happen, but 9 times out of 10 it just does and you have to be aware of that possibility. You may have collected all client requirements but then you start designing and the client realises he wants certain aspects differently. [Expert 11]

Experts indicate the importance of progress discussion with the client throughout the design phase, to prevent these substantial changes. Clients can give their opinions on the design throughout the VO phase, this can then be taken into account during the DO phase. All experts prefer that adjustments are made as early as possible in the design phase as this can reduce the complexity of finding a solution. A well-structured process before the design phase shows the client that you followed his requirements throughout the design. Some clients demand these structured practices such as ProRail which demands an SE approach. These structured processes help to ensure that when adjustments are required, previous design decisions are clearly stated and previously resolved interfaces can be taken into account, making it easier to perform design adjustments.

If I start changing anything in the UO, everyone will have long forgotten what was important in the VO. Designers may have left the company or joined a new project. If you then start adjusting something that was designed for a certain reason, you find out that it has a function and you created a bigger problem, you should always keep the design at rest. [Expert 4]

When substantial changes need to be made during the UO phase experts have alternating opinions. Some experts think it brings together all the experts and that the additional time pressure is beneficial but other experts highlight the complexity during this phase. At the end of a design phase, design teams tend to be smaller, the will to collaborate is there but there is limited time left. It can be the case that unforeseen objects in the ground surface during the implementation phase, creating new challenges. These challenges can go as far as the need to readjust the design of a particular object on the VO level.

5.3.2 Stable teams

Working in Stable teams specifically programmatic projects can give an efficiency gain to the project. The largest reason for this gain is that it is easier to learn between projects. This leads to interfaces that are better secured when working programmatically, as it primarily involves the same interfaces across the bundled projects. Furthermore, the communication lines among designers become shorter, this also accounts for stakeholders involved in the project.

After a few projects, it is known which person to contact. Things go more smoothly, and the communication lines between the project teams and external stakeholders are formed. Another factor is the learning curve that persists during programmatic work. Working in stable teams sounds logical but in this sector, it is difficult because everything revolves around projects. [Expert 2]

The opinion of the experts aligned in some areas but critical points in working with stable teams were mentioned. Project managers who are familiar with working in stable teams mentioned that it is easier to learn from past projects, communication lines are shorter and an increase in efficiency and quality can be monitored. This ultimately helps in being able to better manage interfaces between similar projects.

Working on projects with different disciplines is an experience trade, a well-balanced team is needed with attention to knowledge, skills and experience. Do not only look at the disciplines but at the different people in a team. When people frequently work with each other, they learn each other's needs, what does another person need to do their job well? [Expert 10]

There are multiple challenges and limitations when working in stable teams. With the logical explanation that people change jobs, retire or become ill this means the team must be well-balanced and team members must be flexible to take on different roles. Then there is a chance that working in the same team limits the design options by not looking at new possibly better options. Due to this reason, experts call for a good balance between the number of stable people in a team and newcomers to limit this issue. Some experts fear work will become too repetitive, while other experts state that repetition is a fundamental design principle when working project-based. There are specialists, who are not burdened to perform the same tasks and generalists, who rather work on diverse topics. The most important limitation could hamper the project and decrease efficiency something which project-based working tries to improve.

When you work programmatically you may make more verbal agreements, it becomes a more friendly relationship that you have with the client. This can result in scenarios where the design team follows verbal agreement and the client eventually argues that this was never stated since the result does not benefit them. [Expert 8]

It is essential to prevent this by following a systematic approach, ensuring that client requirements are met and that binding agreements are in place. This was highlighted by some experts as a key aspect of the design process.

5.3.3 Final theory

In this last theory section, the three past theories are combined. Highlighting the most important points made by the experts on interface management in one theory, the final theory is visualised in *Figure 10.*

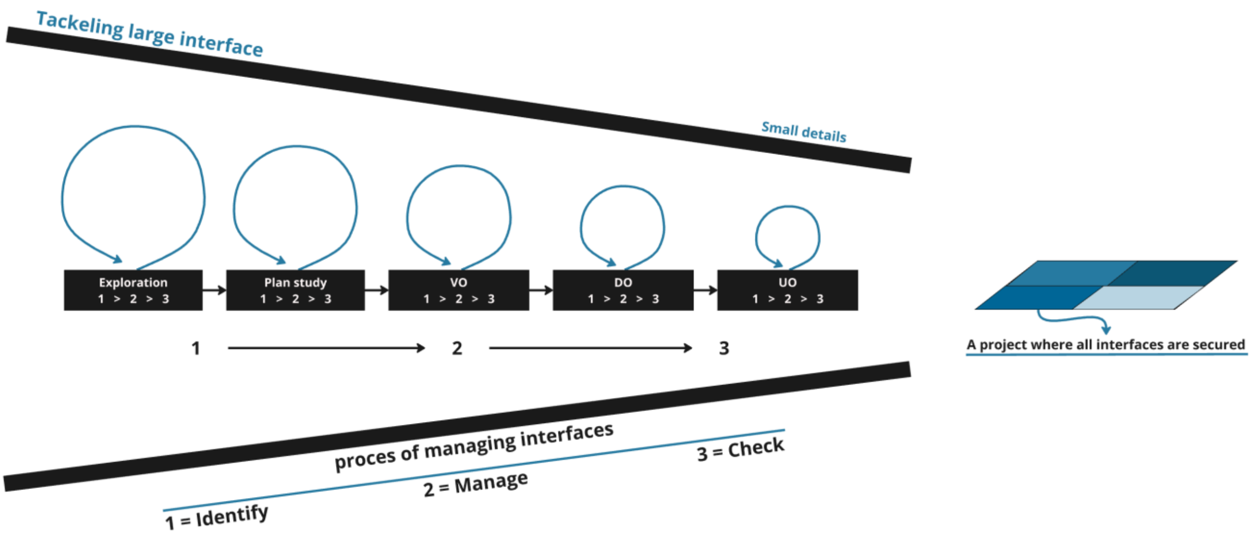

Figure 10: Final theory

The funnel from the first theory describes the amount of detail throughout the design process. This highlights the importance of tackling large interfaces at the beginning of the design process and discussing only small details during the UO phase. The loops indicate the importance of looking for different solutions than the solutions that are already found. This makes sure that the disciplines look for unique solutions rather than using the most obvious solution. The obvious solution may have been used in previous projects but solutions need to fit the environment in which they are placed. The loops also prevent tunnel vision within a project, which is even more important when projects are carried out by a stable team. The sequence of numbers indicates the importance of identifying, managing and checking interfaces. The larger numbers represent the majority of the experts who find it important to start as soon as possible with identifying interfaces. Then during the VO phase securing and managing the majority of the interfaces. In the end, the interfaces can be checked by using the structured approach throughout the design phases where all interfaces secured or unresolved can be found in a list.

5.4 Comparing findings with literature

In this chapter, a comparison will be made between the information which is found in the literature study and the expert interviews. If common opinions are found this can emphasise the importance of these aspects, conflicting opinions can give an alternative view.

Common findings

Both the literature study and expert interviews emphasize the importance of interface management in integrated construction projects. The literature study indicates this importance due to the fragmented nature of the construction industry and the experts look at this from a more practical approach, poorly secured interfaces can affect the project outcome. The sources agree with the need for disciplines to secure the interfaces during the design phases. Both sources highlight the need for improved management practices that offer better integration and cooperation among the disciplines. The use of BIM as a platform for information sharing among different disciplines is also a common point in both sources. This is taken even further by the experts since developments in this field take place quickly. The literature study discusses poor knowledge reuse between projects, experts agree with these findings and state that it is easier to learn from past projects when working in stable teams but this is not common in this field.

Conflicting findings

Where the literature study emphasizes the need for new forms of planning and management tools, which can be used in integrated projects. Indicate some experts the existence of these tools but highlight that some managers prefer the familiar methods. The expert interviews primarily emphasized practical aspects related to interface management, filling gaps in the current research. When comparing company literature with expert interview findings, some experts manage projects more with their expertise than the systematical approach described int the *Technisch Deelmanagement Plan.*

6 Discussion

The problem this thesis wanted to address was the effect that interfaces have on integrated projects. By looking at the interfaces that take place between Kunstwerken, Rail, Road and Soil lessons can be learned on how to manage interfaces during these projects. The thesis has put attention on the effects that poorly managed interfaces can have on the project outcome and profitability. Expert knowledge was used to gain insight into the different opinions at Antea Group surrounding interfaces. This thesis can be useful for Antea Group as a reflective purpose to see how interfaces are currently managed. The outcome of this thesis can give Antea Group guidance into which direction steps need to be made, to better manage the interfaces in the future which will have a positive effect on project outcomes.

This research used different forms of Literature and expert interviews to form a conclusion. During the thesis, it became clear that it was difficult to identify specific interfaces between the four disciplines. Interfaces depend on the type of project, location and customer requirements. Large interfaces such as transportation infrastructure axis, project boundaries and PVRs were found since these will always play a role in integrated infrastructure projects. More interfaces could have been found if this thesis was a case study where a past project or ongoing design phase was researched. Another shortcoming of this thesis was that the results could not be discussed per discipline. Contrasting opinions between discipline experts were found making it difficult to write the opinion on interfaces for each discipline. It may have been possible to prevent this by using surveys where the opinions of more experts could have been gathered. In the end, the expert interviews provided a lot of valuable information about how experts think about interfaces. Including information on how interfaces are currently managed and the limitations this provides. It could be argued that the most valuable information was found by asking follow-up questions during the semi-structured interviews. Something that would not have been possible if surveys were chosen as the research method. Experts were not bothered to give examples of past projects both positive and negative or share their vision on how to secure interfaces.

The thesis needed to be performed in 10 weeks, although this was a short period, 11 interviews from approximately 45 minutes were held. This was possible by planning the major activities and setting milestones, this proved to be a learning curve. The experts were selected on their knowledge and invited two weeks before the interview phase. All experts were easily contactable and were interested in the topic. When looking at the information that was found by interviewing 10 employees and comparing it to the size of Antea Group, there must be more employees with a vision on this topic. This thesis can initiate the creation of a systematic design process within Antea Group which should bring uniformity and increase project efficiency.

7 Conclusion

In this chapter, the research questions will be answered, this is done by using the information presented in the result chapter. This bachelor thesis aimed to improve the management of interfaces between four technical disciplines in integrated projects during the pre-execution phases.

This thesis found that integrated projects require more attention at the beginning of a project, with a focus on interfaces. There is a difference among the experts in using a systematic approach to managing interfaces, this carries on during the design phases where interfaces are identified, managed and checked. There is also a difference in the type of interactions that need to take place between designers. Where some technical managers prefer binding agreements over physically working together. Substantial changes must always be prevented since this can hamper project efficiency. This is possible with a more systematic approach throughout the entire pre-execution phase. This thesis has well-emphasised the importance of interface management in integrated projects. A proper foundation has been formed by answering the sub-research questions, the main research question can be answered.

How can managing interfaces between technical disciplines in an integrated project be improved during the pre-execution phases?

Recommendations will be given which can improve the management of interfaces. Some recommendations suggest actions close to the problem, while other recommendations try to tackle the problem from a different angle.

1. **Integrated projects require a collaborative start with attention to interfaces.**

2. **There needs to be a more structured method during the different design phases to manage interfaces.**

3. **Use the structured method in as many projects as possible.**

4. **Apply standardisation where possible throughout the design process.**

5. **Aim for working in more stable teams to be able to use knowledge from past projects.**

6. **Share information on the current and past activities of the employees.**

7.1 Limitations

The recommendations are based on information found by interviewing 10 employees of Antea Group. Some recommendations require drastic change and should be further researched to be certain that the correct effect will take place after implementation. The recommendation will influence other disciplines excluded from this thesis. This calls for more research on the topic of interfaces between technical disciplines, where all disciplines involved in integrated projects must be included.

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9 Appendix

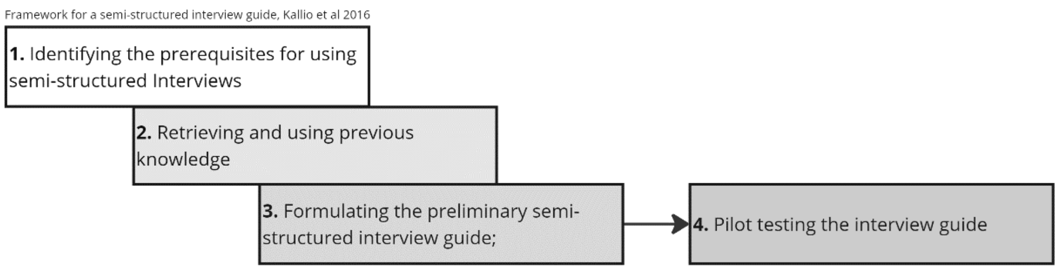
A: Expert interviews

A.1 Experts

	Anonymous name	Discipline	Function	Interview date
1	Expert 1	Environment & energy	Project engineer	24-5-2024
2	Expert 2	Utwente	PhD candidate	4-6-2024
3	Expert 3	Permits & Procedures	Senior advisor	5-6-2024
4	Expert 4	Kunstwerken	Stategic advisor	6-6-2024
5	Expert 5	Road	Project engineer	6-6-2024
6	Expert 6	Kunstwerken	Advisor	10-6-2024
7	Expert 7	Contracts	Project manager	10-6-2024
8	Expert 8	Kunstwerken	Senior advisor	11-6-2024
9	Expert 9	Rail	Senior advisor	11-6-2024
10	Expert 10	Road	Senior advisor	11-6-2024
11	Expert 11	Rail	Advisor	14-6-2024

A.2 Making interview guide

The expert interviews are the main source of information for this thesis. Semi-structured interviews are used which allow experts to mention past experiences accumulated in previous integrated infrastructure projects. The interviewer asks open-ended questions, allowing the experts to say something of value where follow-up questions can be asked. An interview guide will be made that will form the main structure of the discussion during the interview. With this structure, the interviewer will explore the research area by collecting similar types of information from each participant (Kallio et al, 2016). By guiding the experts on what to talk about comparisons can be made between the disciplines after answering similar questions. The researcher needs to be able to determine some areas of the phenomenon based on previous knowledge before the interview (Turner, 2010). The framework made by Kallio and other researchers is used to create an interview guide, the framework is shown below.



The prerequisites for using semi-structured interviews are well stated in the chapter Research Methodology. The previous knowledge on this topic is found through academic and company literature. With this information and the research questions, the interview questions are formed. The Social Sciences professor suggested using three broad questions to extract the opinions on interfaces from the experts without sending them directly in one direction. The broad questions are then assisted with less broad questions regarding the same topic, which will allow the comparison of opinions between experts & disciplines. The professor pointed out that it is possible to adjust the interview after the initial interviews have been conducted, which is also stated in the interview framework. The same can be said of the topics raised by experts in their respective fields. This information is used to create new interview questions to gather the opinions of other experts on that topic. At the top of the interview guide a summary which describes the aim of the expert interview is given.

A.3 Interview guide

Expert interview with ___________

(Discipline)

(Function)

Duration:

It is made clear to the expert that the interview will be recorded

Introduce yourself, state that you are performing a bachelor thesis at Antea Group.

During the interview, information must be found that describes the experiences when working within an interface between disciplines. The most attention needs to be laid on the interfaces between Kunstwerken, Rail and Road. The interfaces need to take place during the plan & design phase of an integrated project this is been made clear to the expert and the expert has been chosen on this criterium.

Questions

Introductie:

1. Wat is jou ervaring met het werken aan integrale infrastructuur projecten? (hoelang werk jij al in deze sector?, zijn de meeste projecten waar aan je werkt integraal?)
2. Zit er een verschil tussen het opstarten van een integraal project en een niet integraal project? (word er bij een integraal project aandacht gegeven aan het werken met andere disciplines?)
3. Welke voornaamste raakvlakken met andere disciplines zie jij vanuit jouw rol binnen een integraal project?

Wat is jou ervaring met raakvlakken tussen technische disciplines gedurende een integraal project in de plan en ontwerp fase?

4. Zijn er raakvlakken gedurende de plan studie met de andere drie disciplines? (Kunstwerken, Rail & Road) of zijn er alleen maar externe raakvlakken gedurende deze fase? (Met de omgeving van het project, bebouwde omgeving, OM)
5. Worden de raakvlakken verdeeld onder de disciplines waarbij een discipline de leidende ontwerprol krijgt voor dat raakvlak? (Of is dit meer een iteratief proces waar bij ontwerpen meerdere keren worden over gedragen tussen de disciplines?)
6. Hoe worden de bekende raakvlakken gedurende de VO fase opgeslagen? (Is dit op een centrale locatie waar alle disciplines toegang tot hebben?)

Hoe hebben de raakvlakken een effect op de verschillende ontwerp fases?

7. Word er een integraal ontwerp ontwikkeld wanneer alle disciplines een VO hebben gemaakt?
8. Wacht jou discipline met het maken van een DO, nadat alle disciplines klaar zijn met hun VO en wanneer er een integraal ontwerp vast staat?
9. Zijn voor de start van de DO fase 80% van de raakvlakken uitgewerkt?
10. Komt het voor dat raakvlakken nog steeds niet geborgd zijn wanneer de disciplines starten met het maken van de UO?

Wat zijn de interacties tussen de technische disciplines wanneer er in een raakvlak word gewerkt?

11. Hoe intensief zijn de interacties tussen de disciplines wanneer het VO word gemaakt?
12. Welke methode word er gebruikt om de raakvlakken gedurende verschillende ontwerp fase te managen? (Relatics, alleen gemanaged bij de technische manager, Mail/Teams chat, lijst van raakvlakken)
13. Wat gebeurd er met de interacties tussen de disciplines wanneer er substantiële ontwerp veranderingen plaats vinden?
14. Wat gebeurd er met de raakvlakken als de client grote aanpassingen wil toepassen nadat het VO is gemaakt?

Afsluitend:

15. Duid aan gedurende welke periode in een integraal project de raakvlakken het intensiefst zijn? Geef een top 3