Engineering in the planning discipline

Systems Engineering for area-oriented redevelopment of ageing infrastructure

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Colophon

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Preface

At first, writing the master thesis was something that I initially was not very enthusiastic about. It was not necessarily the amount of time I would have to spend. The main question for me was: am I well-equipped to write a master thesis? But as you will see in the coming 50 pages, everything turned out fine in the end.

Of course, this would never have been possible without supervision. I had the luxury of three people willing to help me out on this journey, and for that, I am very grateful. First of all, I would like to thank Jorian Wals for the opportunity to write this thesis at Witteveen+Bos. The opportunity to write a thesis at an organization directly involved with the practice gave me the motivation to get the most out of it. You being always open to helping me with both organizational practicalities as well as getting to know how practice works have been a valuable part of my study!

Secondly, I would like to thank Jos Arts for his supervision at the University of Groningen. Being in your classes already was inspiring, and I was happy to hear that you were going to be my supervisor. Your enthusiasm and fascination with respect to the topic (and specifically one case) were contagious. What I respect is that you did not 'beat around the bush' when it came to giving me feedback, it was always very direct, but fair.

Last but not least I would like to thank Wim Leendertse for his additional views on my thesis. At one point in time Jos, Jorian and I were stuck with respect to the theoretical basis of this study. Your suggestion to include systems theory into this study really helped to push me forward. Even while you were not my initial supervisor you chose to keep on joining the meetings and kept asking the overarching questions: "how do you define your system?"

This thesis also would not be here if it weren't for all the interviewees. What still strikes me the most is that everyone that I emailed with the request for an interview responded positively. It shows that the field of spatial planning is a working environment in which people *want* to communicate and collaborate with each other, really trying to make our environments better.

This thesis marks the end of 6 years of studying in which I made great friends and had much fun (also outside of studying, of course). I am looking forward to a new challenge in which I can contribute to making this world a better place.

Abstract

Ageing infrastructure results in opportunities to rethink contemporary objects, as well as their functionalities and their aesthetics. The context of the infrastructure that was built in the thirties, fifties, and sixties has changed over time. To successfully adjust our infrastructure to the current and future context, area-oriented planning approaches are needed. But even though this is a major challenge for planning practitioners, it does not seem to get enough attention from both academics as well as policy makers.

The dominant approach for infrastructure development is systems engineering, an approach that finds its origin in the aviation industry. Systems engineering is a linear approach based on an engineering philosophy that is currently being applied in the planning practice to structure projects. Systems engineering is also predominantly focused on the development of new infrastructure and may benefit from further insight into the redevelopment practice. The aim of this research is to find out how system engineering can be applied at redevelopment projects as opposed to new development and how systems engineering can support area-oriented (re)development of infrastructure.

In order to answer this question, a literature review was conducted. The literature review showed that one way of engaging in area-oriented planning practices is to get a thorough understanding of the context of a project by identifying the functional interrelatedness and the institutional interdependencies between the object and its context. Increasing interrelations and interdependencies result in increasing complexity of projects. Systems theory is used to better understand complexity.

Based on these findings, the loosely coupled systems theory could be used to better understand the nature of interrelations and interdependencies between object and context. A differentiation between tight couplings and loose couplings could be made. Tight couplings are inevitably related to a project and result in reciprocal relationships, while loose couplings can be decoupled from a project without major consequences.

Based on the findings in the literature review, ten expert interviews and one focus group were conducted with planners, engineers, and project managers. Two cases were chosen: a simple development case and a complex redevelopment case. The case selection resulted in the possibility of comparing both the ability of systems engineering to support area-oriented planning between development and redevelopment as well as simple and complex cases.

Results show that the actual process of systems engineering at redevelopment projects does not necessarily differ from development projects. However, while the steps remain the same, the content of the steps does differ. The complexity debate shows that in a simple development case, interrelations and interdependencies can be decoupled from the project. A linear systems engineering process in which the scope of the project is predetermined is very suitable here.

The second case showed that in complex cases, interrelations and interdependencies cannot be decoupled from the project without major consequences for project planning and management. However, engaging loose couplings that seem to be outside the project scope may help to better cope with the project’s complexity by widening opportunities for that project. A prerequisite for this is that the scope of the project should not be fixed beforehand.

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List of abbreviations

CS	Complex System
EC	European Commission
ECMT	European Conference of Ministers of Transport
GKB	Gerrit Krolbrug
GWW-sector	Grond, Weg en Waterbouwsector (Ground, Road, and Water-construction-sector)
HLD	Hoofdvaarweg Lemmer-Delfzijl (main waterway connection Lemmer-Delfzijl)
I&W	Ministry of Infrastructure and Water management
MIRT	Meerjarenprogramma Infrastructuur, Ruimte en Transport (Long-term program for infrastructure, spatial planning, and transport)
NNN	Nature Network Netherlands
NPM	New Public Management
PSB	Pieter Smitbrug
PVM	Public Value Management
RHDHV	Royal Haskoning DHV
ROK	Richtlijn Ontwerp Kunstwerken (Guidelines Design for Works)
RWS	Rijkswaterstaat
SE	Systems Engineering
VONK	Vervangingsopgave Natte Kunstwerken (Redevelopment strategy waterworks)
UNECE	United Nations Economic Commission for Europe

1 Introduction

1.1 Problem statement

Infrastructure redevelopment is a challenge that is being faced by many western countries, think of the USA's 'Infrastructure Investment and Jobs Act' or the redevelopment of many 'autobahnbrücke' in Germany. Much of the infrastructure has been built in the sixties, fifties or even earlier (Willems et al., 2016). From its initial development up until now, the spatial and societal context of a certain infrastructure development has drastically changed. The question becomes whether infrastructure that is at the end of its lifecycle should be replaced one on one, or that redevelopment of infrastructure should be more focused on how it fits in contemporary societal and spatial contexts.

Similarly to Germany and the USA, the Netherlands is also facing the redevelopment challenge, especially when it comes to redevelopment of ageing water infrastructure (Hijdra et al., 2014; Willems et al., 2018). The focus on water infrastructure in the Netherlands has its origins in the past. Verbong and Vleuten (2004) extensively researched the development of infrastructure networks in the Netherlands and point out that prior to world war two, the main way to transport goods was via water infrastructure. This was facilitated both by the geographical features as well as economic aspirations of the Netherlands. To create more land to live on the Dutch had to dig canals, build dykes, and create polders, which resulted in a very dense network of smaller bodies of water. And for economical purposes the Dutch waterway system had to be very well connected to the German system. The result of this is an extremely dense network of regional, national, and international waterways, which is confirmed by the Central Intelligence Agency (2011) who finds that the Netherlands has the most dense waterway network of all the countries with major waterway networks, among which are countries such as the USA, China and India.

Consequently, the redevelopment of ageing water infrastructure in the Netherlands is a challenge which is high on the political agenda. Minister of Infrastructure and Water Management Cora van Nieuwenhuizen stated that the redevelopment of ageing infrastructure is one of the biggest 'maintenance' challenges the Netherlands has ever faced (Trouw, 2018a). However, within the challenge of redevelopment ageing waterway infrastructure in the Netherlands, recent literature shows that there seems to be a considerable misalignment between the nature of existing institutions and the goals and opportunities that present themselves through this redevelopment challenge (Hijdra et al., 2014; Willems et al., 2018). While the redevelopment of ageing water infrastructure presents an excellent *opportunity* to re-think its functionalities for its contemporary and future context, water management in the Netherlands is still predominantly object oriented, which may result in missing opportunities. On top of that 'redevelopment' is simply sounds less interesting that new developments. It is not unlikely that due to political ambition and administrative pressures, the redevelopment projects are put lower on the agenda.

One of the major parties when it comes to redevelopment is Rijkswaterstaat (RWS). Rijkswaterstaat is the executing body of the Ministry of Infrastructure and Water Management and has operational and managerial responsibility over the entire waterway network. Typically, RWS is described as a risk-averse and conservative party, which is reflected by the main objective for RWS in the redevelopment of the waterway network. Their main concern with regard to redevelopment is that the waterway network itself, should remain operating just as good, or even better than it currently does (Willems, 2018). This technical engineering focus has been successful in contemporary Dutch water management and is thus deeply embedded in day to day practice of parties such as RWS (Jong and van den Brink, 2017). Rijkswaterstaat is not the only operator for infrastructure in the Netherlands, regional and local governments such as provinces and municipalities are responsible for regional infrastructure.

To (re)develop infrastructure, RWS and, engineering and construction firms work with systems engineering (SE) as an approach for developing infrastructure (LeidraadSE, 2013). Typically, SE has two characteristics that are of importance in this redevelopment challenge. First of all, SE is predominantly used in the development of *new* infrastructure as opposed to the redevelopment of ageing infrastructure. Second of all, in most cases, SE is very object oriented, making it a very suitable method for solving complicated problems such as the (re)development of a single bridge or lock within broader network in a very systematic and cost-efficient way (efficiency). A prerequisite for this is that an object is treated as if it is functionally and institutionally stable, meaning that before the project starts the functional and institutional context is determined and shouldn't change. Which in fact is in line with traditional water management practices, as mentioned before.

However, if we want to use the redevelopment challenge as an opportunity to rethink functionalities of infrastructure in its contemporary context, we might need more than an object oriented approach. In this research the concept of area-oriented planning is used to conceptualize the way opportunities can be seized in the redevelopment challenge (Heeres et al., 2012). In area-oriented approaches, an object cannot be isolated from its context. This has an influence on the way SE is being applied in infrastructure planning projects. Systems engineering will not only be used to redevelop a single object, but will have to find a way to actively include a dynamic context.

Area-oriented planning explicitly acknowledges functional interrelatedness and institutional interdependencies within and between projects (Heeres et al., 2016). Simply put, area-oriented approaches emphasize the integration of the socio-political realm into infrastructure (re)development. Which raises the question in what way SE can be applied for projects in which it is not only about a technical object, but also about its socio-political context.

At first glance this seems to be especially true for infrastructure objects that are situated in complex contexts, such as bridges or locks in urban areas. Functionally, such an object maybe related to many local infrastructure networks such as cycling and walking infrastructure or local car traffic infrastructure (and thereby linked to other spatial functions such as housing, businesses, facilities for shopping, education, health care etc.). Institutionally wise, a complex case simply means more stakeholders to deal with, which brings along challenges with regard to for example decision-making among formal institutions and citizen participation. Therefor an SE approach which facilitates these links between institutions would be very beneficial for overall project management.

The acknowledgement of the complexity of such redevelopment cases may require a more area-oriented approach to water management in the Netherlands. This research will explore how this can be done while making use of SE as a management and planning tool for infrastructure redevelopment.

1.2 Research questions and aim of the research

Based on this problem statement this research has two main objectives: 1) finding out how to apply SE in *redevelopment* projects rather than new infrastructure development and, 2) how SE can be applied in *area-oriented* planning activities.

1.2.1 Primary research question

How can systems engineering support area-oriented planning for the redevelopment of ageing water infrastructure in the Netherlands?

1.2.2 Secondary research questions

1. In what way can area-oriented planning lead to more integrated planning for redevelopment of ageing water infrastructure?

2. What is the role of 'systems theory' in planning for redevelopment of ageing water infrastructure?

3. How is systems engineering currently being applied in the redevelopment of ageing water infrastructure?

4. How can increasing functional interrelatedness and institutional interdependency be included in systems engineering practices?

5. What are barriers, success factors, and conditions for the application of system engineering at infrastructure redevelopment projects?

1.3 Scientific and social relevance

This thesis tries bridge between theoretical work mostly found in the literature and actual practice, something which is missing according to recent literature (Hijdra et al., 2014; Willems et al., 2018; Leendertse, 2015). Secondary research questions one and two will be answered in the theoretical framework while three, four, and five will be answered by the empirical data.

As this thesis is written in a collaborative setting between the 'Rijksuniversiteit Groningen' and engineering firm 'Witteveen+Bos', the output of the research has to be scientifically as well as socially relevant, which will be further elaborated on in the next sections. The final chapter of this thesis will consist of practical recommendations with respect to SE which can be taken into account in real practice and will also contain recommendations for further research down this particular path. The second output goal is especially relevant because this thesis will be of explorative nature, and will not be able to provide full strategies and frameworks to tackle the redevelopment of ageing water infrastructure in an integrative way.

1.3.1 Scientific relevance

Expected results for academia in the planning sector will mainly focus on increasing detailed empirical information available in a debate that has been mainly theoretical until now. Case studies have been conducted by authors such as Hijdra (2017), Willems (2018), and van Geet et al. (2021) but these mainly focus on identifying the problems that occur (the 'what' issues), and/or state that there is no sufficient research with regard to actual practices that cause mis-alignment. This research will explore more in-depth the planning process for re-development and, specifically, what role the planning tool of SE can have in creating more alignment between area-oriented planning ambitions by local and national governments and the technical nature of parties such as RWS. As such, it will add more in-depth data analysis on the reasons of mis-alignment, explore 'how' to apply SE in redevelopment planning processes, and will thereby help to fill the knowledge gap acknowledged by both Willems (2018) and van Geet et al. (2021).

As briefly touched upon in the problem statement, SE is a technical approach which is does not necessarily match the goals of area-oriented planning. While *current application* of SE is predominantly focused on the infrastructure object itself, area-oriented infrastructure planning is much more focused on the integration of a certain infrastructure object into its wider surroundings. Therefor, current application of SE can be characterized as having a technical rationale planning philosophy while on the other hand area-oriented planning is much more related to having a collaborative rationale planning philosophy.

One can imagine that once these two philosophies meet in real practice tensions may arise. Here, it is however good to realize, that SE itself cannot be the *cause* of mis-alignment. As SE is merely a tool for infrastructure (re)development, the suitability of SE for area-oriented development is rather dependent on the practitioners of SE and how they apply SE. Thus, the real questions are much more focused on *how* SE can actively

System engineering and (area-oriented) planning literature do have something in common, their focus on the development of new infrastructure, as opposed to the redevelopment of ageing infrastructure (Geels, 2007). Largely, a reason for this is the high investment of time and financial resources in operations with regard to development, which results in high sunk costs.

Put differently, much time and effort has to be put into the understanding of the redevelopment challenge even though there are still many uncertainties to cope with in this field of interest (Willems et al., 2016). However, this study will address the importance of research on redevelopment as this is becoming increasingly important in real practice, which consequently requires attention from academics in the planning discipline. As Willems et al. (2016) argued, the maturity of Dutch infrastructure networks requires a re-focus on redevelopment rather than development.

1.3.2 Social relevance

Much of the infrastructure that has to be replaced has been built in the 1950's and 1960's or even earlier. The spatial and societal context that this infrastructure is situated in has changed dramatically. As a result of this, redevelopment of bridges, locks and weirs provide an excellent opportunity to rethink their functions in the region by creating more integrative redevelopment plans (Hijdra et al., 2014). For this study, the basis of this aspiration is area-oriented planning.

Next to integration of different functionalities, area-oriented development also has potential for achieving sustainability, the careful integration between different land uses, as well as its ability to bring different stakeholder together creates a basis for long term relationships and innovation, when applied appropriately (Heeres et al., 2012). While attention for sustainability has become such common practice in contemporary planning, this research will not address sustainability as a concept as such, but the study will assume that this is automatically incorporated when choosing for area-oriented planning as an approach for the redevelopment challenge. The focus is rather on how to redevelop ageing infrastructure following area-oriented approaches.

Secondly, when redeveloping infrastructure, we now facing additional challenges as opposed to the infrastructure's initial development. It is known that during its initial development much of the infrastructure was developed as if it was situated in a isolation from its local context, and only part of its network (Hijdra et al., 2014). On top of that, the current spatial functions around infrastructure objects have become dependent on the contemporary function of that object, resulting in vested interests. Therefor, we have seen an increase in public and political interest for more area-oriented planning in the redevelopment challenge (Willems, 2018). There is still considerable debate among different stakeholders, such as RWS and regional and national governments, on how this integration must be incorporated.

Systems Engineering is a dominant approach for RWS and engineering and construction firms for delivering infrastructure projects (LeidraadSE, 2013). This research will explore how this approach is currently being applied in the redevelopment challenge, and will try to identify what role it can play in creating more integration between the waterway network and its surrounding area. Systems engineering is common practice in a technical context, but is now being placed in a more collaborative setting, which as mentioned before, may result in frictions. Exploring these tensions is not only scientifically interesting, but it also gives an opportunity to investigate how a dominant approach within infrastructure development can adapt to a new discourse on how such infrastructure should be (re)developed. It is rather undesirable to portray SE as an approach that only disables integration because of its technical nature. As SE is an approach that contains multiple tools to work with, it may very well be the case that there is potential for SE to contribute to increased integration. This research will explore under what conditions certain tools of SE can be suitable to reach more area-oriented redevelopment.

This study focuses specifically on the redevelopment challenge in the Netherlands. As mentioned before, the Netherlands is a country with a vast waterway network, hosting many infrastructure object that are in need of redevelopment. Rijkswaterstaat is one of the biggest stakeholders for this challenge and often has to work together with local governments in which these infrastructure objects are situated, also highlighting the importance of institutional relations between different governmental layers.

1.4 Thesis guide

From this point onwards the thesis will start of by answering the first two sub research questions. The theoretical framework will give the reader a broad understanding of the main concepts such as SE, area-oriented planning, and systems theory. This will be followed by a methodology section (chapter 3) in which the data collection approach is being outlined. After that the results will follow (chapter 4), giving extensive descriptions of two chosen cases, including quotes from interviewees. The results section will also include a first glance towards the discussion in chapter 5. Finally chapter 6 will give a definitive answer to the sub-questions as well as the main question, but will also outline shortcomings, future research options, and will give advice for the practice.

2 Theoretical Framework

Concepts such as SE and area-oriented planning require in-depth knowledge in order to actively engage with them in the data collection. Secondary research questions 1 and 2 are formulated to better understand the aforementioned concepts. However, the first section of the theoretical framework will be used to outline what this study regards as a redevelopment project. What does a redevelopment project look like, and what elements of it are relevant when it comes to SE and area-oriented planning.

Sections 2.2 and 2.3 will then be used to further operationalize area-oriented planning by exploring functional interrelatedness and institutional interdependency. The functional interestedness will concern a general trend in public administration regarding the shift from new public management (NPM) towards public value management (PVM). It will address the impact this has on infrastructure planning by making use of the concept area-oriented planning. Functional interrelatedness will resolve in institutional interdependency which will be explored in section 2.3 It will serve as a basic understanding of the interdependencies between different (governmental) organizations. Finally, part 2.4 will elaborate on the role of systems theory in the redevelopment challenge. The focus on *systems* engineering requires this study to dive deeper into the different kinds of systems one can define.

The theoretical framework will follow a specific rhythm to create coherence between the different sub-chapters. Each sub-chapter will start from a simple perspective on the specific subject, and will move towards a complexity perspective on that same subject. On top of that, each sub-chapter conclude with a resume which will provide a short summary. The answers to sub-questions 1 and 2 will lead to the conceptual model which will be the bases of the data collection.

2.1 Infrastructure development

2.1.1 Object, context, and network

Object, context and network are all part of a certain scope, what exactly is the scope of a redevelopment project? Figure 1 provides a model that gives a simplified overview of the scope. Each category (object, context, and network) stand in relation to each other, interactions take place in and between them. Both the individual categories as well as the relationships between them represent a system of some sort. An infrastructure object is part of a transport network on a high scale level, but also situated in a local context, representing a much lower scale level.

The interaction between object and context in the redevelopment challenge will be the main focus of this research. To explain the different interactions between object and context, this thesis will make use of two categories on which interaction takes place: functional interrelatedness and institutional interdependency. The functional interrelatedness will focus on the physical interactions between object and context, while the institutional interdependency will mostly concern governance and policy that represent functionalities. However, before going into depth on this, it is good to know how infrastructure is currently being developed. An understanding of current practices in the infrastructure sector will help determine the origins of the tensions that we find in the redevelopment challenge.

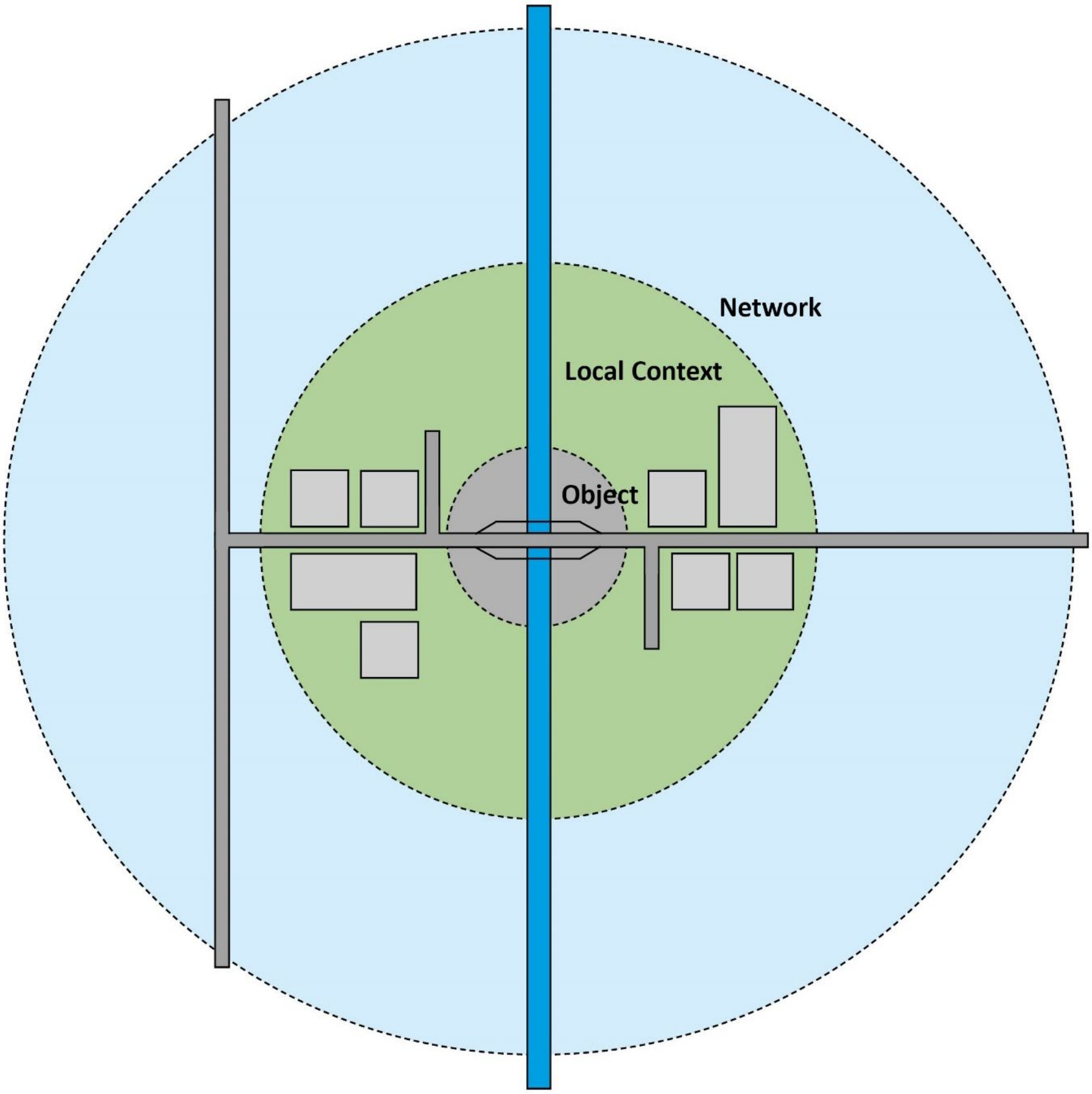

Figure 1: Simple representation of the scope of the redevelopment challenge

2.1.2 Contemporary infrastructure development

Infrastructure development is typically seen as a sectoral and object oriented discipline (Eriksson et al., 2017). The water infrastructure sector is no exception to this (Brown et al., 2011; Willems, 2018; Willems and Busscher, 2019). Especially in countries such as the Netherlands, a country which has successfully applied technocratic measures to provide security against water, the technical discourse in the water infrastructure sector prevails (Willems, 2018). Dutch infrastructure development has highly invested in SE, a design approach which, in its current application, fits well within its sectoral and object oriented character.

The role of SE in specifically the redevelopment challenge will be addressed later. However, at this point it is good to know some of the basics of SE. Systems engineering is used to design and engineer technical systems based on customer-requirements. In infrastructure (re)development these customer-requirements are acquired from the stakeholders in the direct context of an object. These requirements are documented in databases in which each effect of each customer-requirement on the system as well as on each other can be analysed.

Rijkswaterstaat is responsible for the development (and redevelopment) of the national water and road infrastructure network. Over the years the role of RWS has changed from an agency that was able to completely develop infrastructure (construction excluded) within their own organization towards a public agency that works together with the market to also develop infrastructure (Leendertse, 2015). Following new public administration philosophies, elaborated on later, RWS started to outsource proceedings such as design and contracting.

In the Netherlands the infrastructure development sector is called the *grond, weg en waterbouwsector* (ground, road, and water-construction-sector) (GWW-sector). The GWW-sector consists of public agencies such as RWS and Prorail (the national rail infrastructure provider) but also includes all construction and engineering firms that often collaborate with those public agencies (Leendertse, 2015). The GWW-sector is categorized as a technical and object-oriented sector. The public agencies in the GWW-sector have been criticized by authors such as Jong and van den Brink (2017) for their inability to engage in planning disciplines outside their own sector. The result of the sectoral approach (focussed on infrastructure) leads to missed opportunities to extra societal value for the public through infrastructure planning. To illustrate what this means in practice van den Brink (2009) observed that at projects in which the GWW-sector actively engages with the public, the discourse still remains of technical nature. This results in the public not being able to participate in many of the discussions, something which was already known to be problematic for public participation in the literature (Forester, 1989; Healey, 1996).

In contemporary planning, public agencies tend to specify procurements into much detail to ensure the creation of public value due to their public responsibility (Leendertse and Arts, 2020). However the more one specifies, the less room there is for actual interaction between public agencies and for example citizens. How can public value be added without the possibility of real interaction between a government and its citizens?

In essence, increasing public value cannot be accomplished without active participation by the public (Healey, 1996). As it is currently organized creating public value through the planning process then solely belongs to the public client. For the explicit case of redevelopment of ageing water infrastructure it means that this responsibility lies at Rijkswaterstaat, a party who is known to struggle with social and political engagement (van den Brink, 2009; Willems, 2018). Increasing interactions between object and context result in a challenge for Rijkswaterstaat with regard to engaging in planning disciplines outside their comfort zone.

2.1.3 From development to redevelopment

Geels (2007) concluded that literature and practice in infrastructure planning predominantly regards new infrastructure, this was later confirmed by Willems et al. (2016) and based on the findings of this research, there is reason to believe that this is still the case. According to Willems et al. (2016) one of the primary reasons for this is that both science and practice highly invested in researching and developing new infrastructure. As such, shifting to a 'new' planning paradigm such as infrastructure redevelopment may consume additional resources and will create more uncertainty. Based on the risk aversiveness of the GWW-sector, one may conclude that the process from a development paradigm towards a redevelopment paradigm will be a challenge on its own.

However, when is something redevelopment instead of development and, in what way are redevelopment and development different from each other with respect to the actual process? Currently, the way SE is being used in the GWW-sector does not specifically distinguish between development and redevelopment.

Chapter 1 (The problem statement) already pointed out a difference between development and redevelopment with regard to the infrastructure objects' relation to the functional context. In many cases, the object in need for redevelopment was built in a completely different functional *and* institutional context. In essence this means that the object remained the same, while the context changed. With this in mind, one on one replacement does not make sense anymore. There is a need to redevelop the object fitting its current functional and institutional context, in other words, area-oriented planning. 2.2 will elaborate on the changed functional interrelatedness of the redevelopment challenge, which will be followed by chapter 2.3, with a focus on institutional interdependency.

2.2 Area-oriented planning – Functional interrelatedness

2.2.1 A shift from New Public Management to Public Value Management

The increasing interest in creating public value as described in section 2.1.2 is a reflection of a broader trend in public administration: a shift from New Public Management (NPM) towards Public Value Management (Stoker, 2006). Spatial development which is based on NPM follows market philosophies, at which development has to be as efficient and cost friendly as possible (Stoker, 2006). This is very much in line with the conventional way the GWW-sector approaches the redevelopment challenge, the network has to remain its current functionality as good as possible (Willems, 2018) and proceedings such as design, contracting and constructing are outsourced to market parties.

However, a general shift from NPM towards PVM can be observed in recent planning practices. PVM has an increased focus on the value a certain development has for the general (Hijdra, 2017; Stoker, 2006). This shift from NPM towards PVM can also be observed in the political interest with regard to the redevelopment challenge. Political and public interest are much more focused on (seizing) the opportunities that arise during this redevelopment challenge rather than the redevelopment of a single object (Hijdra et al., 2014; Willems, 2018). The increasing need for public value in the physical world and the increasing interest of politics and citizens in the planning process are typical for the increasing functional interrelatedness and institutional interdependency (Heeres et al., 2016, 2017)

Redevelopment of ageing water infrastructure provide an opportunity to revisit the purpose of a set piece of infrastructure to increase its value for the public. To increase value to the public, careful integration between different sectors is needed. Whereas Rijkswaterstaat incorporated the shift from traditional public administration towards NPM by privatizing specific activities, the PVM philosophy seems yet to be anticipated. Only redeveloping water infrastructure based on the NPM philosophy, purely focused on the waterway system, is simply not sufficient to create more value for the public.

2.2.2 From line towards area-oriented development

Area-oriented planning is gaining popularity in Dutch infrastructure planning to create more public value (Heeres et al., 2018). It is representative for the increased functional interrelatedness between object and context. But even though it is gaining in popularity, it is not common practice. In reality, infrastructure development of any kind is often pursued in a line-oriented approach (Heeres et al., 2012), as can be read in section 2.1.2. Area-oriented and line-oriented approaches are to be seen as extreme opposites of planning philosophies (Heeres et al., 2012).

When developing using a purely line-oriented approach, the scope of the project will be only the object itself (figure). The focus of the development is based on the notion that if every object fulfils its proposed option, the network should function perfectly. Figure 4a schematically shows that in this approach the object only dictates demands towards the direct context, but does not receive feedback on it. In this case the functional interrelatedness as described by Heeres et al., (2017) is hardly present, as interrelatedness implies a reciprocal relationship between the object and its context.

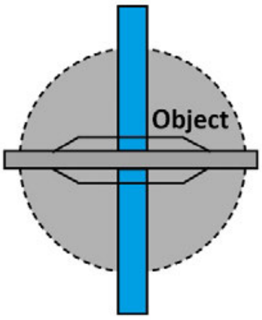

Figure 2: The object is being redeveloped in isolation

Figure 3 represents the development of an object in a broader network context, first and foremost based on its functioning for its main network (for example the functioning of a lock on the waterway network) (Heeres et al., 2012). The context of the development might have increased, but that does not directly lead to much more functional interrelatedness. As stated before, the network-object relation is a relatively simple one. In the case of the redevelopment challenge we find that the network does give prerequisites to object in terms of minimum dimensions for objects due to for example, increasing usage of class Va vessels (RWS, 2020). Incorporating this feedback however, remains a relatively simple task because of its technical nature. The blue one-way arrows represent the 'simple', one way relation between the object and its network (figure 3). In essence this is still line-oriented development as the object does not give and receive feedback to such an extent that it leads to increased public value for the local context.

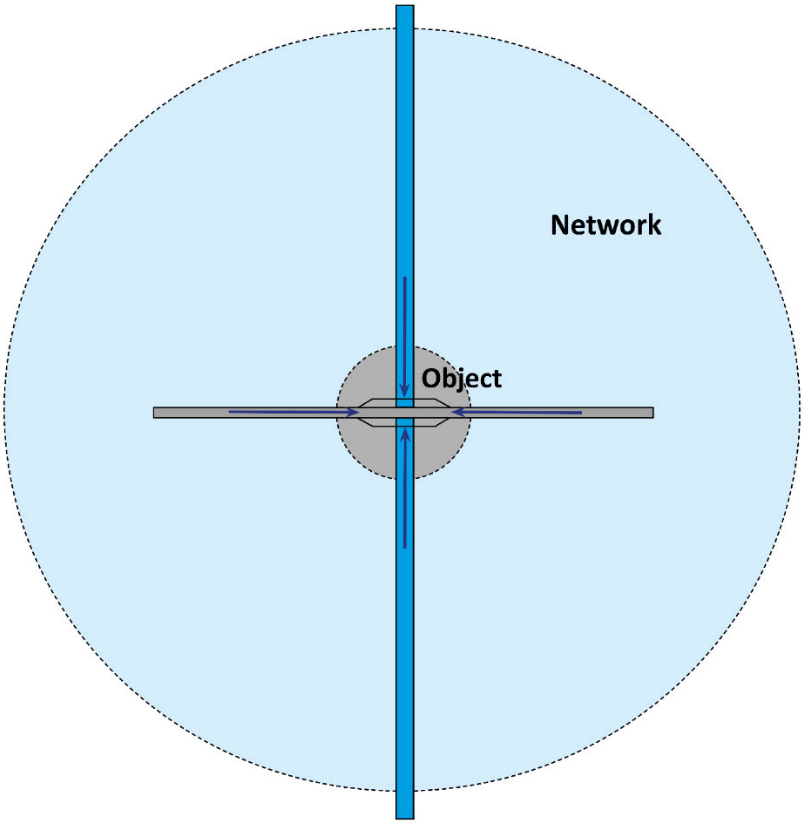

Figure 3: Object being developed in a network

The shift from NPM towards PVM as a spatial planning philosophy can be seen as the basis for an increase in interest in area-oriented planning approaches. Similarly to the NPM philosophy, line-oriented approaches are sectoral, and concentrated on efficiency. Area-oriented approaches resonate much more with the PVM planning philosophy, in which the creation of value for the public is a central goal (Stoker, 2006). Area-oriented approaches may be a fitting means to create more public value in infrastructure planning. Hence, exploring area-oriented approaches can be an appropriate way to find openings for seizing the functional opportunities that the redevelopment challenge presents.

Figure 4 is a simple model to explain the difference between line and area-oriented approaches. The basic logic is that in line-oriented approaches, surroundings need to adapt to changes made to the infrastructure. The interaction between infrastructure and its surroundings is a one way relation, reflected by figure 2 and 3. Area-oriented approaches consist of two-way relationships in which, on top of object-context interaction the context also influences the object. These are the interactions that cause increased functional interrelatedness, and make redevelopment a complex challenge.

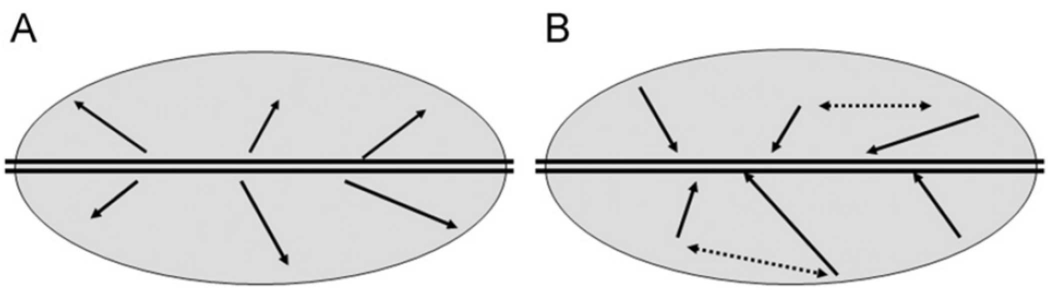

Figure 4: Simplification of relations of infrastructure. A represents a singular relationship, in which information and feedback only flows from the infrastructure to its surroundings (Line-oriented). B shows that there is also feedback and information flowing from its surroundings to the piece of infrastructure (Area-oriented) (Heeres et al., 2012).

This is the point where we arrive at a similar overview of the case study as figure 1. In this study, area-oriented planning and functional interrelatedness are at their climax when the object is being developed by incorporating the local context in the planning process (Figure 5). Due to an area-oriented planning approach the functional interrelatedness within the system increases (Heeres et al. 2017). Put even stronger, even if one would choose a line-oriented approach at a complex project, the functional interrelations would still be there, they are then simply being ignored. The goal of area-oriented planning is to create more value for the public in the broader context. In other words, when an object is being (re-)developed, one should be looking for how this object can be (re-)developed to increase value for its surroundings.

The blue functional arrows are now two-way and green institutional arrows are added to represent stakeholders (figure 5). This results in increased complexity in the planning process due to the increasing number of stakeholders and the necessary adaptive planning process. These stakeholders all represent different norms and values, and are looking out for their own interest, which will be reflected in the final overall spatial design. In area-oriented planning, it is not only the object that will be redeveloped. The object can function as a trigger to engage new projects in its proximity (Arts et al., 2016; Heeres et al., 2017, 2018), which is in line with Willems' (2018) findings on perceived (functional) opportunities in the redevelopment challenge.

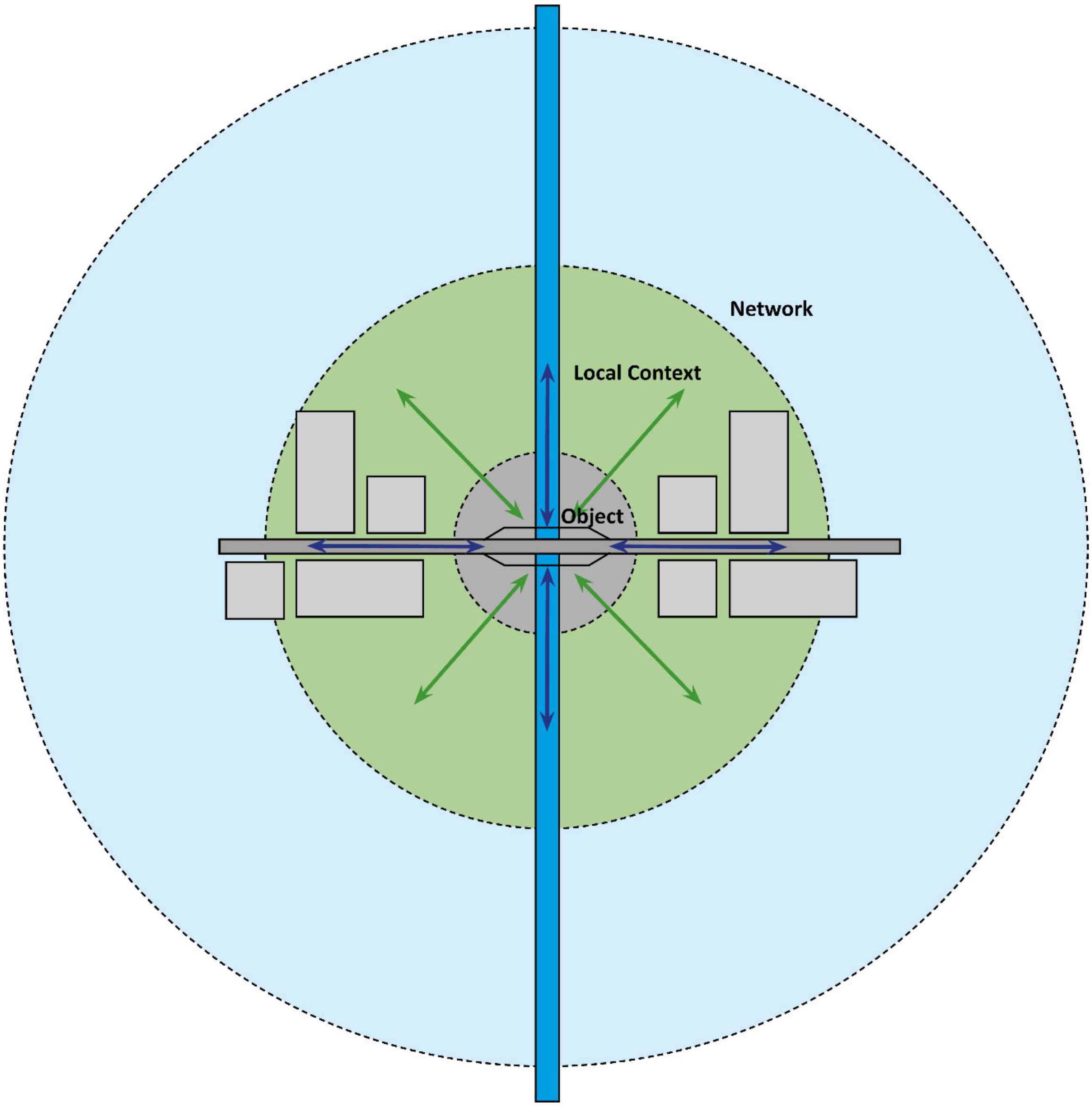

Figure 5: The scope of the redevelopment challenge in which object, context, and network all interact with each other

Arts et al. (2016) state that area and line oriented planning do not exclude each other, they rather complement one another. They acknowledge that a singular focus on the functioning of the infrastructure network does not help to create more value for its surroundings, but also point out that the core premise of an infrastructure development will always be a better infrastructure network. The difference is that in line-oriented planning *compromises* are made for the surrounding functionalities and area-oriented planning is looking for *synergies* between object and context (Heeres et al., 2017).

The introduction of area-oriented approaches into the GWW-sector is however not self-evident. Both the public as well as the private parties in the GWW-sector are not experienced in debating in a social political context (Leendertse and Arts, 2020; Willems, 2018; Willems and Busscher, 2019). Their technical knowledge is effective in a setting in which all parties speak the same (technical) language, but with increasing socio-political interest in infrastructure development, technical parties are asked to perform outside their comfort zone. This determination may hint towards one of the reasons for mis-alignment of goals and means in the redevelopment challenge, of which the applicability of conventional SE methods is of special interest for this study.

Area-oriented approaches itself are not without its fallacies, Arts et al. (2016) for example point out that in area-oriented planning creating ownership of the project can be challenging. In more traditional line-oriented approaches ownership of the project is straightforward, which is usually the case with infrastructure providers. In reality this means that actors may have difficulties in progressing the planning process towards concrete project realisation (complex decision making). According to Brown and Farrelly (2009) Integrated planning, closely related to area-oriented planning, suffers from fragmented institutions and stakeholders, which can potentially be an explanation for lack of ownership and responsibility. Arts et al. (2016), Busscher and Willems (2019), and Heeres et al., (2017) all find that institutional fragmentation keeps on being a barrier for integrated, area-oriented planning.

Arts et al. (2016) conclude that line-oriented planning and area-oriented planning can be combined to create a best of both worlds situation. The challenge then becomes, where and how do we find an equilibrium between them? Institutional and organizational learning literature may give a sense of direction on how to find the right balance between line and area oriented planning (Busscher et al., 2019; Eriksson et al., 2017; Willems and Busscher, 2019).

2.2.3 Resume

The transition from NPM towards PVM and the related trend towards more area-oriented planning is typical for the challenge in redevelopment of ageing water infrastructure. Most of the objects were built following a line-oriented approach, but redevelopment of those objects requires an area-oriented approach due to changed physical context. The previous sections outlined what impact this has on the functional interrelatedness of the system in which an object is situated. A certain object could have been developed 60 years ago in a rural context, but can now be situated in an urban context. This automatically means that, spatially, the functional relations of that object have changed, and that the redevelopment of that object requires careful consideration of the changed context.

Increased functional interestedness automatically means that more stakeholders are going be involved. Heeres et al., (2016) refers to this as institutional interdependency, in which all stakeholders are brought together by means of governance and policy. The next sections will elaborate on the institutional interdependency between different levels of governance related to the redevelopment challenge.

2.3 Area-oriented planning - Institutional interdependencies

Functional interrelatedness automatically leads to institutional interdependencies. If the scope of the project becomes broader due to area-oriented planning, more stakeholders will have to be involved. Not only because of the benefits of participation, but simply due to the fact that there will be multiple owners of infrastructure aspects and other pieces of land. This section will give a basic overview of the institutional framework relevant to the redevelopment challenge on a European, national, and local and regional scale. The Hoofdvaarweg Lemmer-Delfzijl (HLD – the main waterwayconnection between Lemmer and Delfzijl) is used as an example throughout this institutional framework.

2.3.1 European

The highest governmental level which is relevant for the redevelopment challenge is the European Union. The HLD is part of the North Sea Baltic corridor of the Trans-European Transport Network (TEN-T). This demonstrates the significance of the HLD in the European waterway network (European Commission, n.d.). On a European scale there are two international organizations that work out policy for waterway networks: the European Commission (EC) and the United Nations Economic Commission for Europe (UNECE) (RWS, 2020). According to RWS (2020) there are no significant differences between the two organizations with regard to their policy for the Dutch waterway system.

European directives for waterways do not go into much detail. Both the EC (2018) and the UNECE (2012) determine minimum days of availability of the waterway for economical purposes, and base minimum heights of bridges on the European Conference of Ministers of Transport (ECMT – see ECMT, 1996, and appendix 1). Furthermore minimum draught numbers are given, which only allow deviations under special circumstances. The EC (2018) and UNECE (2012) decided that all newly constructed bridges and locks on TEN-T waterways should adhere to minimum international standards. Room for context-specific development remains vague, as both documents exactly similarly state: "*The value of the recommended height under bridges (5.25, 7.00 or 9.10 m) should be ensured over the highest navigation level, where possible and economically reasonable*" (European Commission, 2018 p.61; UNECE, 2012 p.26). The values 5.25, 7.00, and 9.10 meters are related to respectively 2-, 3,- and 4-layer container vessels.

2.3.2 National

This section will dive into the most recent national policy documents that are relevant for the redevelopment challenge in the Netherlands. finds that from 2012 onwards, a shift in policy making has occurred which put redevelopment as a general concept higher on the agenda, but that area-oriented approaches were uncommon at the time. Redevelopment of ageing water infrastructure was already briefly mentioned in the '*Structuurvisie Infrastructuur en Ruimte'* (Planning Act for Infrastructure and Spatial Planning), a policy document on general spatial development (I&W, 2012). The latest version on general spatial development, the '*Nationale Omgevingvisie'* (National Planning Act), repeats its predecessor in almost the exact same words (BZK, 2020).

Rijkswaterstaat publishes a more sector-specific annual document in which a general strategy for infrastructure development is presented: the *Meerjarenprogramma Infrastructuur, Ruimte en Transport* (MIRT) (Long-term program for infrastructure, spatial planning, and transport). A difference between the MIRT of 2017 and 2021 is that in the national strategy the MIRT 2017 states that the main focus of redevelopment is to sustain the current functionality of the system (I&W, 2017). However, MIRT 2021 does explicitly state that the redevelopment challenge also provides an opportunity to link different societal and spatial challenges together, thus making it more integrative (I&W, 2021).

We can also observe a shift in the reasoning behind the redevelopment of the objects specifically at the HLD. The MIRT 2017, in its problem statement, formulates that the only reason for redevelopment is the lack of accessibility for *Class Va ships* (Figure 6, RWS, 2017). The MIRT 2021 broadens this problem statement by including the notion that many of the bridges and locks located on for example the HLD are due for redevelopment (RWS, 2021).

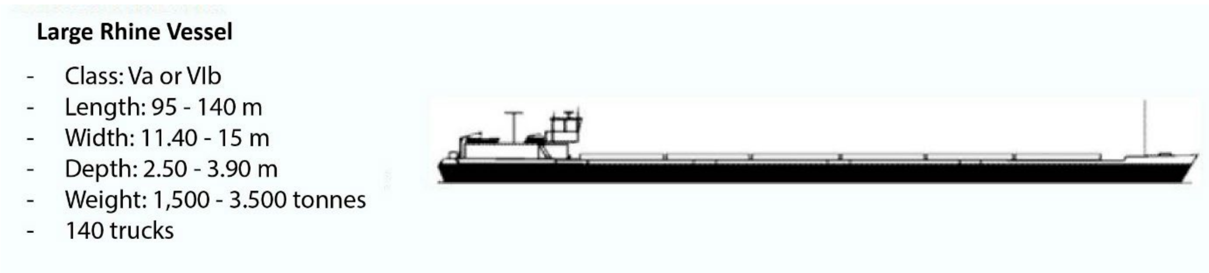

Figure 6: Class Va ship. (ITB, n.d)

Responsibilities with regard to the redevelopment of water infrastructure can shift over time. For example, In the MIRT 2017 responsibility for the planning for redevelopment of water infrastructure in phase two at the HLD was transferred to the provinces of Friesland and Groningen (RWS, 2017). In MIRT 2021 it is stated that the responsibility was transferred back to Rijkswaterstaat again, instead of the provinces (RWS, 2021). Governmental agreements between regional and national governments are often made to assign the leading actor in a collaboration between governments. In the case of the HLD the party who were in the lead shifted multiple times, which in the end turned out to be important for one of the cases, more on this in chapter 4 (results).

Next to general infrastructure (re-)development policy, RWS (2015) published the *Vervangingsopgave Natte Kunstwerken* (VONK) (Redevelopment strategy waterworks), a strategy for systematically tackling the redevelopment challenge. This policy announces the ambition to tackle the redevelopment in an integrative, area-oriented way. Accordingly, it characterizes the redevelopment challenge as a complex problem, something which will be elaborated on later in this theoretical framework.

Next to more strategic planning documents, Rijkswaterstaat also presents a document with the technical guidelines for waterways (RWS, 2020). This guiding document is inspired by European directives, but states that much of the European directives for waterway development do not fit a Western European context anymore. As such, Rijkswaterstaat decided to translate European directives to the Dutch context. A key addition related to the Dutch context, and relevant for this research, is the inclusion of minimum dimensions for moveable bridges as opposed to fixed bridges, something which is missing in European directives (ECMT, 1996). The full table of dimensions for moveable bridges at the Dutch waterway system can be found in appendix 2.

2.3.3 Local

Even though a waterway network such as the HLD is managed by the national government, the direct impacts of the waterway are seen at the regional and local level, as was already shown in figure 7. Dutch land use planning is predominantly managed by local governments (municipalities) (Rijksoverheid n.d.). Planning acts such as the 'mobiliteitvisie' (mobility vision), 'omgevingsvisie' (spatial planning vision), and 'woonvisie' (housing vision) are all part of municipal policy with respect to overall spatial planning. These visions often consist detailed, but long-term plans for how the city should function in the future. They are only able to do so while keeping in mind the functional interrelatedness between all the functions in the city. Sometimes, even more detailed plans are being made on the neighbourhood level.

The spatial planning acts from the municipalities have an impact on the objects that need to be redeveloped. While for example the objects on the HLD are managed by RWS, the space that they are built in/on are often managed by municipalities. That means that there is an interdependency between the infrastructure operator and the local government. This relation becomes even more intense when objects are located in urban areas, as the amount of acts that may have an impact on a certain object increase.

Regardless of all the planning acts and visions that are published at the national level, it is still often the municipality that can decide what happens or not. On the other hand, the redevelopment challenge impacts local governments as well. Meaning that they are dependent on the operators to repair, replace, or redevelop objects in their municipalities. The institutional interdependency between national and local governments at redevelopment projects is clear.

2.3.4 Resume

As with all sub-headings, we finds an increasing degree of complexity throughout this section. The smaller the governance scale gets, the more detailed the plans can become. Details do not mean specific designs for projects, but rather outline specifically the different stakeholders involved. European directives only define minimum heights, that can be deviated from certain (unknown) circumstances. The most recent national policy documents acknowledge the need for area-oriented planning, but do not specify how this can be accomplished. Local policy documents define opportunities for the local context of the object that will be redeveloped.

Especially national and regional policy documents seem to acknowledge the functional interrelatedness in planning for redevelopment, resulting in institutional interdependency. This is an important factor for spatial planning in general, as institutional interdependency legitimizes the functional interrelatedness that is inherently present (Heeres et al., 2016). Through policy, stakeholders find themselves entitled to be able to have their say in spatial development. In practice, well organized institutional interdependency can lead to successful integration between different land-uses (Heeres et al., 2016). Heeres et al. (2016) gives numerous examples on how institutional interdependency can guide functional interrelatedness to comprehensive spatial planning, in which, instead of compromises between land-uses, synergies can be formed and exploited.

However, acknowledgement by government institutes alone is not enough to reach area-oriented planning in practice. Willems et al. (2018) for example found that some regional governments take a wait-and-see position when it comes to infrastructure development. And as stated many times before, Rijkswaterstaat on its part has trouble engaging the public debate, closely related to regional governance. In the end it seems that both regional and national institutions have to increase efforts to come closer into each other's 'bubble', in order to get to more area-oriented planning. Hence the usage of the term institutional interdependency.

Increased functional interrelatedness and institutional interdependency are of lead to complexity, and is representative for the increased complexity of spatial planning in general. The complexity perspective can benefit from a theoretical background which helps to understand how complexity – and complex systems - works and how it conceptually differs from simplicity (simple systems). Section 2.4 will introduce systems theory as a mean to provide a better understanding of what complexity implies for the way spatial planning is organized. Section 2.4.1 will first introduce general systems theory, that will be followed by sections 2.4.2 and 2.4.3 which introduce a spatial planning perspective to the systems theory.

2.4 Systems theory in planning and engineering

2.4.1 Systems theory, different perspectives

Systems theory is a way to explain the functioning of the world (Mele et al., 2010). According to Meadows (2008 p.12) "a system is more than the sum of its parts". In other words, based on Mele et al. (2010), the functioning of the world cannot solely be explained by analyzing the functions of each object. All functions combined do not directly lead to a functioning system. The interaction between the objects are just as, if not more, important for that. Meadows (2008) refers to these interactions as flows. In this case, the interaction between object and context can be regarded as flows.

According to Meadows (2008) systems theory is able to conceptualize the functioning of extremely simple systems as well as complicated systems. Figure 7 shows that even the for the simplest systems to function, flows are needed. Meadows gives the example of a bathtub system. In which the tap, the tub, and the drain are the parts and the water represents the flows. In this system the flows and the results of the flows are predictable. As a person, one is fully in control of the ins and outflow of the water in the bathtub, which can be regarded as a simple system (Meadows, 2008).

The simple system theory is well applicable to the case of the system of an (isolated) infrastructure object – as discussed in section 2.1.1. When the object is being approached with the assumption that it is a simple system, which operates only within its own system, the redevelopment of that object can be regarded a simple task.

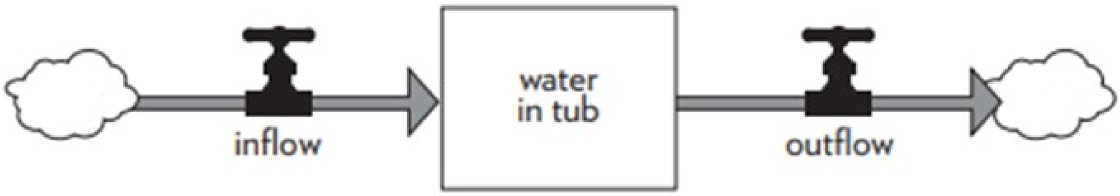

Figure 7: A simple bathtub system (Meadows, 2008)

Another key element in the systems theory is that without flows between system-parts, there can be no evolution of the system (Meadows, 2008). In other words, when the parts are in complete isolation, without any interaction with other parts or even within their own part, no evolution takes place. *Evolution* in this sense means that the system learns from feedback on its development and from its environment and adapts or evolves. Theoretically isolation exists, but in reality one can image that every part of the world is affected by one major 'flow' which is 'time'. Time can be regarded as an automatic mechanism that initiates evolution of the system. This relates quite well to the redevelopment challenge in which, due to time, the bridges and locks are nearing the end of their lifecycle. This then leads to replacement, which can be regarded as a form of evolution. In the redevelopment challenge time can be regarded as a predictable flow. In essence this is true, but the complexity of the system depends on the *scope* of the challenge. Generally speaking, the broader the scope, the more reciprocal flows can be observed, and the more complex the system gets.

The way this study approaches the redevelopment challenge is in need for a more 'complexity perspective' on systems theory. Contrary to the simple system depicted above (figure 7), the complete complex of interactions (read reciprocal flows) between the object and the context, as well as within the context itself (chapter 2.1.1) is not predictable. This is a direct consequence of increasing the scope from the object towards the object *and* its context (also represented in the shift from line-oriented towards area-oriented). A complex system shows adaptive, self-evolutionary behavior (Leenderste, 2015). The complex of interactions in complex systems are non-linear, meaning that any 'flow' can cause multiple reactions that could not have been predicted beforehand (Duit and Galaz, 2008). Figure 8 gives a schematic view of the interactions in a complex system, based on figure 1 and 5.

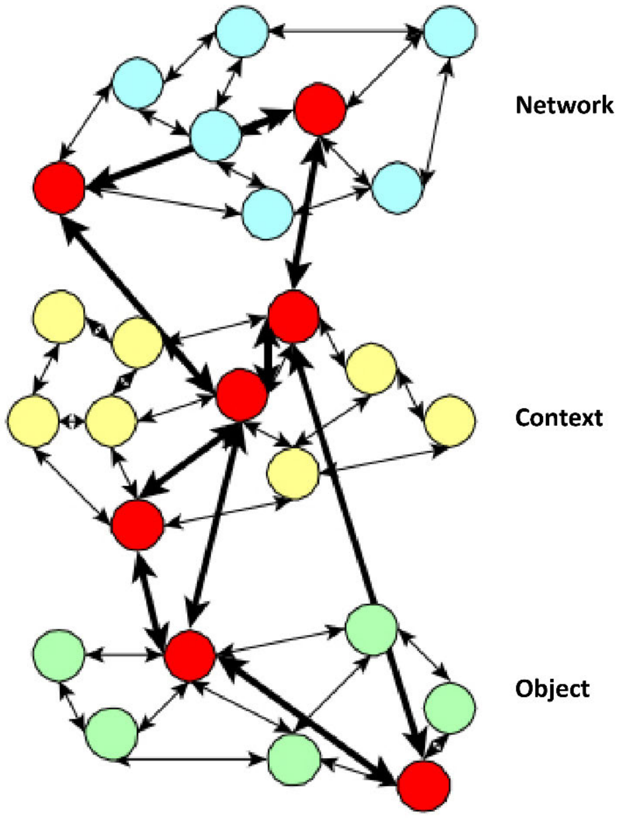

Figure 8: Representation of a complex system. Based on Geldof (2004), adjusted to represent figure 1. Unlike the simple system, the complex system has no clear beginning or end. It is a constantly evolving system which has no 'end goal'.

There are multiple ways of looking at systems. This research will focus on two main strands of philosophies to explain different perspectives on systems theory. Mele et al. (2010) states that systems theory can be used as a holistic way to explain how the worlds works. Meadows (2008) finds that systems theory both holistic as well as reductionistic. According to Meadows (2008) the reductionist philosophy suits simple system theory, while the holistic approach is more in line with complex systems theory.

The *reductionist approach* of systems theory is somewhat in line with classical spatial planning from the 50's and 60's. Traces of reductionism can also be found in NPM and subsequently line-oriented planning. Both of these concepts have hierarchical characteristics, which inclines a top-down (reductionist) strategy in terms of their general proceedings. On the other hand *more holistic approaches* to planning are emerging with the introduction of PVM and area-oriented planning, as both of these concepts acknowledge the significance bottom-up planning practices (Arts et al., 2016; Heeres, 2012; Stoker, 2006). Even though the need for holistic planning approaches is acknowledged, in practice the most dominant planning approach for infrastructure development is still of reductionist nature. The following section will outline the basic principles of SE, and will elaborate on its position in the systems theory and complexity discourse.

2.4.2 Systems Engineering

Systems engineering finds its origins in the US military aviation industry from the second world war (Ferris, 2007). Systems engineering was used to streamline the production process of fighter planes for the US air force in the war. The aviation industry is a typical technocratic kind of industry, in which a reductionist approach is highly effective. Therefor, the reductionist character of SE is exceptionally fit for production of airplanes. In essence the airplane industry is comparable to the simple bathtub system from (Meadows, 2008). In a technical system the flows are predictable, the effect of each component on the air plane is planned by individuals who are fully in control of the process. In other words, the totality of all parts result in a functioning system.

INCOSE is the international council on systems engineering. It is a branch organization for SE in its broadest sense. Next to infrastructure planning organizations such as the Dutch GWW-sector, parties like Petronas or NASA are also affiliated with INCOSE (INCOSE, 2021). Below this paragraph INCOSE's definition of SE can be found. Most interesting in the definition is the statement that SE is capable of coping with complex situations.

"Systems engineers are at the heart of creating successful new systems. They are responsible for the system concept, architecture, and design. They analyze and manage complexity and risk. They decide how to measure whether the deployed system actually works as intended. They are responsible for a myriad of other facets of system creation. Systems engineering is the discipline that makes their success possible – their tools, techniques, methods, knowledge, standards, principles, and concepts. The launch of successful systems can invariably be traced to innovative and effective systems engineering" (INCOSE, n.d.).

The interpretation of the word complex may be of importance here, as INCOSE's definition of 'complexity' might be different from complexity in the social sciences. It can very well be the case that for INCOSE the word 'complex' is the same as 'complicated', but in the social sciences, these words have completely different meanings. From a social sciences perspective INCOSE's definition can be misleading to some extent, but that does not mean that SE cannot be applied in the social sciences. Systems engineering is applicable in many different industries, of which the characteristics are different from each other. This asks for tailormade translations of the general SE approach to a certain sector. It becomes interesting when a certain technical sector that uses SE, increasingly has to cope with the social realm due to area-oriented planning practices. Such transition can be observed in Dutch infrastructure planning.

From approximately 2000 onwards SE has become common practice in Dutch infrastructure planning (LeidraadSE, 2007). Of course, the tools that SE has to provide are adjusted in such a way that SE is better applicable in the infrastructure planning industry. What remains however, is its reductionist system approach. It is debatable whether such a reductionist approach is suitable in an industry in which not everything is predictable and the infrastructure object and its context are closely interrelated. Compared to the aviation industry, in which there are hardly any outside influences to the production process, the planning discipline is increasingly being known for its complexity

System engineering is translated to fit the Dutch infrastructure sector in the *Leidraad voor Systems Engineering binnen de GWW-sector.* The first version was published in 2007, soon after SE was actually introduced into the GWW-sector. This version was used to formalize the process for all parties that are affiliated with the GWW-sector, among which are RWS, ProRail, and the branch organization for contractors. The formalization of SE in Dutch infrastructure planning was the basis for its dominance in the following years. The most recent version of the *Leidraad voor Systems Engineering binnen de GWW-sector* was published in 2013. Compared to the 2007 version, the 2013 version has made progress in terms of integrated working amongst stakeholders and more structured communication between stakeholders.

But even though the GWW-sector increased its integration and communication abilities, the fact still remains that SE is a reductionist approach. Its basic workflow starts with the definition of the system that has to be engineered. Often this only includes the technical object itself. The area around the object is regarded as context, and is not engineered as such. The context of the object determines much of what the object should look like through a series of 'customer-requirements', but is often not included in the scope of the project. When all customer-requirements are collected, the system engineer finds the most optimal solution. Even though the presence of customer-demands seems to enhance the area-orientation of the project, it is still rather object oriented.

This reductionist approach would work fine if infrastructure development would only operate in the technical realm, but based on literature by Heeres et al. (2012), Hijdra et al. (2014) and Willems et al. (2018) we know that infrastructure development has to increasingly deal with functional interrelatedness and institutional interdependency through area-oriented planning. In theory this would mean that infrastructure development needs a holistic approach, something which the current appliance of SE often does not provide.

2.4.3 Complex systems

Complex system (CS) theory may help us understand the actual dynamics of the redevelopment challenge from a complexity perspective. 'Complex systems' is not a practical method, it is merely a way of explaining how a system works. It can help to understand how planners can deal with complexity that comes with increased functional interrelatedness and institutional interdependency. The GWW-sector as a whole has been characterized as a CS before by Leendertse (2015 see also Verhees, 2013). Following that claim, this study assumes that the context of the redevelopment challenge in combination with area-oriented planning can also be characterized as a complex system.

This is further circumstantiated by the increasing need for methods to deal with complexity due to general trends in urban planning. The increased importance of PVM and the increasing interest in area-oriented development both have to cope with increased complexity due to increasing interrelatedness in the system. The introduction of the GWW-sector into the socio-political world is challenging, but on top of that, the GWW-sector also stays in the technical realm at the same time, which makes it an even more challenging subject. Geels (2007) refers to this as socio-technical systems.

A CS contains three main processes that cause a system to behave in a particular manner: variation, selection, and retention (Figure 10, see also Axelrod and Cohen, 2001). Pressure from the environment causes the system to develop variation in order to cope with changing circumstances, system variation causes the system to make a choice of direction, the chosen direction may lead to an adaptation of the system when it is reentered in the in the system or organization. However, the adapted system will trigger more response from the environment, which may lead to the system to react.

This circular concept is called a feedback loop. If there was no feedback loop, the system would be stable, which would mean that there will be no change in the system. Generally speaking, the more feedback loops, the more complex the system becomes. Increasing functional interrelatedness and institutional interdependency in infrastructure planning, and in this particular case the redevelopment challenge, results in increased amount of feedback loops.

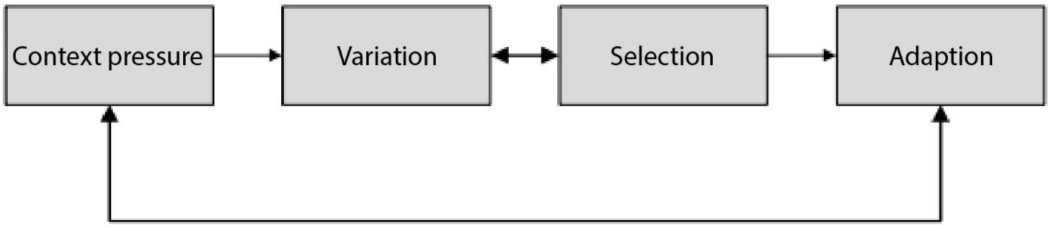

Figure 9: Schematic representation of how a CS functions (Leendertse, 2015)

Figure 10 gives a schematic spatial overview of how feedback loops work in infrastructure development. The figure is derived from a model used by Heeres et al. (2012), but adds the flow from the infrastructure towards its surroundings, which is needed to create a circular dynamic between all the parts of the system. The outcomes of the interactions between the parts are non-predictable (Duit and Galaz, 2008), which results in a theoretical claim that a holistic approach for infrastructure planning is plausible (Leendertse, 2015)

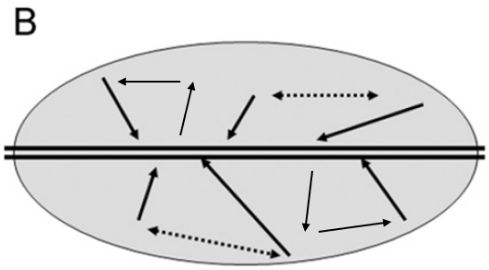

Figure 10: Spatial representation of feedback loops. Inspired by Heeres et al. (2012)

This statement is considered the basis for the discussion on the functioning of SE in the redevelopment challenge. If the components and their relationship of the redevelopment challenge is regarded a CS, then how does SE function in this?

2.4.4 Loosely coupled systems

It is good to realize that holistic and reductionist approaches do not exclude each other. Meadows (2008) states that both approaches can be present in the world at the same time. A potential key approach to deal with reductionism and holism in the redevelopment challenge is the theory of loosely coupled systems. Orton and Weick (1990) find that loosely coupled systems theory views systems as entities in which tight and loose couples are ‘simply there’ between actors in the system. Dubois and Gadde (2002) argue that the GWW-sector can typically be seen as a loosely coupled system, in which tight couplings are found *within* individual projects and loose couplings are found *between* individual projects.

Tight couplings in the GWW-sector are characterized by high degree of standardization, for example in terms of workflow and tendering (Orton and Weick, 1990). According to Dubois and Gadde (2002) tight couplings are often found in within individual projects, in which the objectives are made clear and the context is ought to be relatively stable. This means that in this case, the application of SE in individual projects seems to be appropriate. The question however is whether it is at all possible to set clear objectives and assume that the context is stable.

It is evident to understand that certain relationships simply exist. Assuming that the context of an individual project is stable might be an oversimplification. This is especially true once the projects context is regarded complex. Functional interrelatedness and institutional interdependency *are* the relationships that are simply there, and are typically regarded as complex, non-predictable concepts.

Systems engineering, having a reductionist philosophy, assumes a stable system, in which all elements are predictable. The relations between actors and their demands for a project are being gathered in a top-down manner (Leidraad SE, 2013). In this way, SE tries to make the complexity of the project more comprehensible. The relationships between the object and its surroundings are then seen as loose couplings, as each individual relationship defines how the system as a whole is functioning. From an SE perspective that means that all relationships can be decoupled from each other without major consequences. It is however, questionable if this works for cases in complex contexts.

Tightening up couplings can also be found in national and regional policy documents (I&W, 2021). The term 'meekoppelkansen' (linking opportunities) is often used as a way to make projects more integrated with its surrounding. However, from a loosely coupled systems theory perspective this can be regarded as a rather deterministic approach to linking opportunities. The perceived holistic approach to integration between sectors is lost because policy makers themselves determine which systems can be integrated or not, while essentially some systems are simply coupled to each other whether you like it or not.

Both engineers as well as policy makers tend to tighten couplings in projects in GWW projects (Dubois and Gadde, 2002) (Figure 11). Whether a project is complex or simple, in both cases only the infrastructure object will be the main focus, the system which has to be engineered. The area around it is merely there to give input on how the object should look like and how it should function, it is regarded as context. It is rather questionable whether this approach would work in area-oriented projects. However, this is especially true for the more complex cases. The simple case might very well be still system engineered in an object-oriented approach, as the area around it relatively simple and stable.

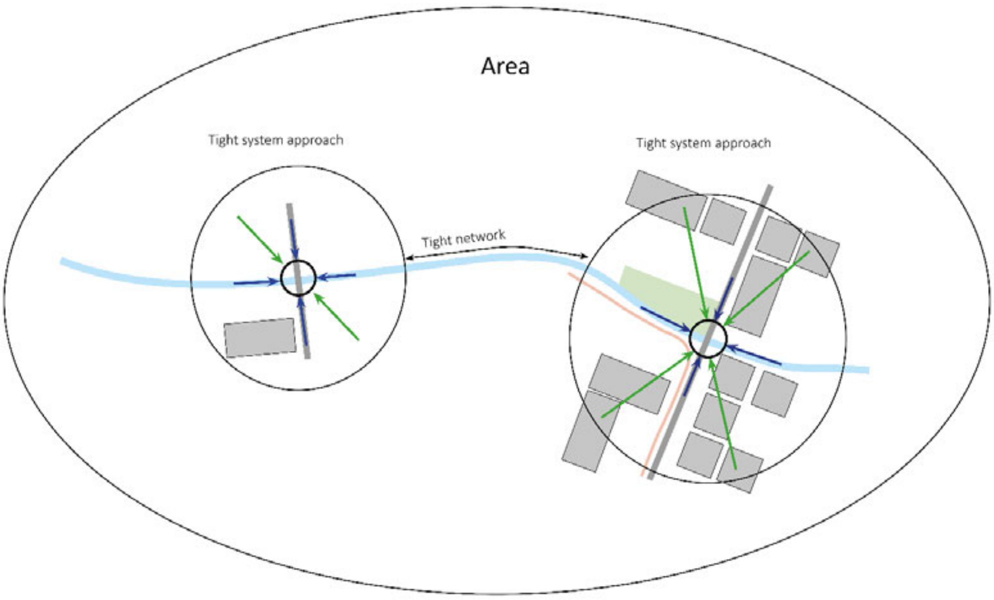

Figure 11: Tight coupling within projects characteristic for current redevelopment practices. Blue arrows represent functional interrelatedness and green arrows represent institutional interdependency

Dubois and Gadde (2002) find that in the GWW-sector couplings between projects are often of loose nature, due to the differentiation among project developers. Dubois and Gadde (2002) also finds that once couplings between projects are tight, opportunities arise with respect to innovation through learning. The fact that the redevelopment challenge is being developed by making use of as 'masterplan' approach means that couplings between individual projects are likely tight. These tight couplings potentially enable project developers to learn from each other with respect to experiences from projects all over the network.

Contrary to figure 11, figure 12 shows that different degrees of complexity in the system may lead to differentiation between tight and loose couplings for each individual project. As mentioned before, lower degrees of complexity may result in the ability to decouple context relations from the object without major consequences (Weick, 1976). This also means that the specification of the system that has to be engineered becomes much easier, as all the relations can be decoupled (left case in figure 12). A linear, top-down SE approach may very well be successful here.

In a complex case, the relationships between the object and context cannot be decoupled as such. The multitude of stakeholders result in reciprocal feedback loops between all stakeholders in the context of that case. Essentially, these tight couplings cannot be decoupled from the object, meaning that a linear SE approach, in which context relations are assumed to be loose, might result in problems here.

Loosely coupled systems theory may however help cope with complexity in another way. According to Dubois and Gadde (2002), in a complex system, once project developers accept loose couplings, the project itself will be able to better cope with that complexity (right case in figure 12). The outward pointing arrows represent a holistic approach to finding synergies between the object and its related functions and institutions. The dashed circle represents the notion that the system of a project does not have to be determined beforehand, and should be able to adapt to changes throughout the project. By not predetermining the scope of the project, additional (loose) couplings can be activated to enhance capabilities to cope with complexity. The acceptance of loose couplings between elements results in multiple benefits for project management in multiple facets: Weick (1976) argues that a loosely coupled systems approach allows for certain elements to be persistent without compromising the functioning of the object in the broader network. Weick (1976) also finds that loose couplings can be activated and deactivated at any point without major consequences. The activation and deactivation of loose couplings may help to break out of a deterministic approach to planning for infrastructure objects.

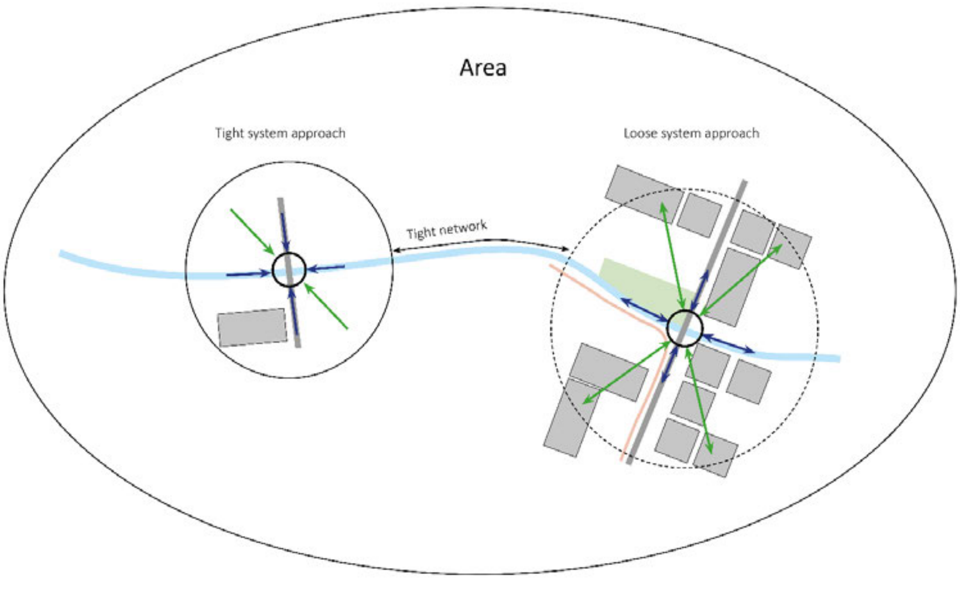

Figure 12: Differentiation in systems approach due to acceptance of difference in complexity for each individual case. Blue arrows represent functional interrelatedness and green arrows represent institutional interdependency.

2.5 Conceptual model and research focus

Figure 13 gives a schematic view as a conclusion of the theoretical framework. Similar to figure 12, the conceptual model shows that different degrees of complexity in projects among the same network might require different project management strategies. This is what this study will be focussing on in the following chapters.

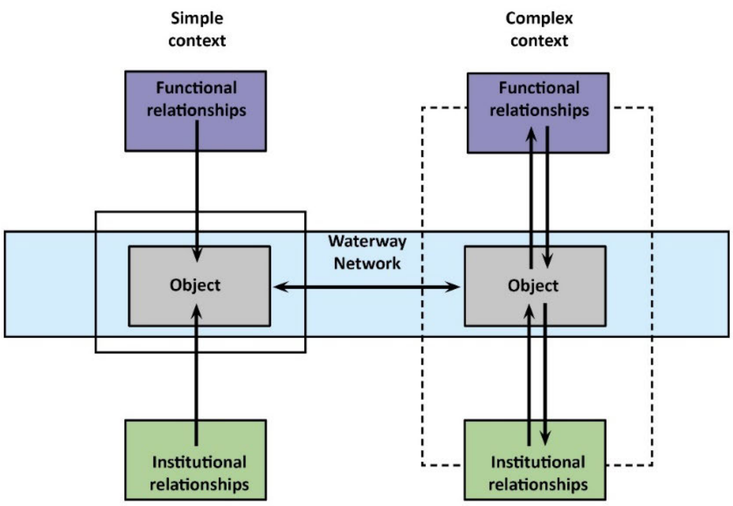

Figure 13: Conceptual model.

Based on the theoretical framework, the model in figure 13, shows a hypothetical situation which presumes that an object located in a simple context can still be developed from a classical SE approach and a conventional governance perspective. The context of the object is determined beforehand, and the functional and institutional relationships are (most of the time) one-dimensional. On the contrary, the model challenges these practices when it comes to objects located in a complex context. The system cannot be determined beforehand, and the relationships between the object, functions and institutions are two-dimensional. In this case a loosely coupled systems approach may help better deal with the complexity of the problem. One example of both will be addressed in the next chapters.

3 Methodology

This study aims to answer secondary research questions three to five by making use of empirical data. This chapter aims to provide a basis for how the empirical data is collected. The following sections will elaborate on what data is collected, why it is collected and how it was collected.

3.1 Research design

The aim of the research is explore how to apply SE in *redevelopment* projects rather than new infrastructure development *and,* how SE can be applied in *area-oriented* planning activities. The theoretical framework identified functional interrelatedness and institutional interdependency as indicators for complexity in projects. In order to explore these interrelations and interdependencies detailed, case specific is needed.

Baxter and Jack (2008) find that the *multiple qualitative case study* methodology is exceptionally effective in gaining detailed information on various cases, from various sources. This is not something which can be gathered via quantitative data collection methods. On top of that Yin (2003) finds that case studies are helpful for answering 'how' and 'why' questions, which fits perfectly with secondary research questions three to five. Yin (2003) also states that case studies are desirable in studies at which there is no clear boundary between the phenomena and its context, something which is especially relevant in this research. This is will be further elaborated on in chapter 5: Discussion.

Based on this it makes sense to proceed this research by following a qualitative double case study method. It is the aim of this research which pushes this research in this direction. The plurality of the research aim requires multiple cases, and the nature of the research aim requires us to dive in to the fine-grained details of the cases.

3.2 Literature research

The main source to find scientific literature has been search engine Scopus as well as PhD-theses linked to the University of Groningen. These PhD-theses mostly concerned studies on topics such as public private partnerships, area-oriented planning and waterway renewal. The scientific literature used in the PhD studies have been used to create the basis of the theoretical framework. On top of that, many of the authors of such PhD-theses published peer reviewed articles in journals such as the *'Transportation Research Procedia', 'Environment and Planning C: politics and space', 'Transport Policy', and 'Planning Theory & Practice'.*

Knowledge gaps are predominantly found with respect to SE in planning and systems theory. The absence of literature on SE in combination with planning confirms yet again the relevance of this study. The knowledge gap on SE is mostly filled through official documents that outline the application of SE in Dutch infrastructure planning. The systems theory literature is mostly found through scientific search engine Scopus by making use of terms such as *'systems theory AND planning', systems theory AND area-oriented planning', and 'systems theory AND project management'.*

Approximately 40 peer reviewed scientific articles have been used for this research. Articles on *area-oriented planning* and *redevelopment* mostly date from 2010 onwards, as these themes recently gained attention. On the other hand the systems theory literature which is used ranges from 2010 back to studies from the 1973's. This can be justified through the notion that systems theory is more than just an idea, it is an ontology, a way to explain how the world works. And the fact that even the most recent peer reviewed literature still cites literature from the 70's and 80's tells us that these sources are still relevant enough to use on this study.

3.3 Case selection

The goal is to explore the applicability of SE at redevelopment projects as opposed to new infrastructure development, but also to explore the applicability of SE in complex area-oriented planning practices. The differentiation between redevelopment and development requires this research to select a minimum of two cases: a redevelopment case and a development case. The exploration of the applicability of SE in complex area-oriented planning practices also indirectly requires a minimum of two cases: the effect of complexity can only be explored if a 'simple case' is researched as a reference.

In order to make a meaningful comparison between the cases, two extremes have been chosen: (1) a development case situated in a relatively simple context and, (2) a redevelopment case situated in a complex context. It is evident that in both cases SE should have been or should be applied. By selecting cases through these requirements this study will be able to examine both the difference of SE at development and redevelopment as well as the difference of SE for simple and complex cases (Table 1). To create coherence between the cases additional requirements for each case are determined:

- 1. the object has to be a bridge of some sort. Generally speaking bridges have more spatial impact than other objects such as locks and weirs, making them in essence more complex.
- 2. Both cases should be situated on the HLD
- 3. Both cases are (re)developed by the same operator

During the preparation of the data collection these additional requirements turned out to be unfeasible. While the complex redevelopment case did suffice the additional requirements, a 'simple' development case could not be found. For timing purposes the a exception had to be made for the selection of the 'simple' case.

	Case 1: Gerrit Krolbrug	**Case 2: Pieter Smitbrug**
Structure	Bridge	Bridge
Location	Groningen (HLD)	Winschoten (Winschoterdiep)
Type	Development	Redevelopment
Initiator(s)	RWS/Gemeente Groningen	Provincie Groningen
Context	Simple	Complex

Table 1: Case selection

3.4 Data collection

In order to collect the data semi-structured interviews are held with professionals from either the cases themselves as well as professionals specifically specialized in SE in general. The case interviews are used to examine the functional interdependencies and the institutional interrelatedness in each of the cases, as well as the application of SE. The output of these interviews provide answers to the research questions but also form a basis for data collection solely focussed on SE itself. Interviews focussed on specifically SE are planned after the case data collection. This way initial results from the case data can be presented to 'third party' professionals. Their neutral view on the cases are a valuable addition to the dataset as a whole. All data collection has been carried out in the Dutch language to ensure the quality of the interviews.

3.4.1 Document analysis

While the peer reviewed literature and the PhD-theses mostly concern general topics and problems, a case study as such requires written data that specifically concern the cases themselves. Policy documents from governments, project documents, and official letters from and to stakeholders are used to get a first, objective insight into the cases (Yanow, 2006). Based on the information in these documents more specific questions can be asked during the data collection, as much of the general structure of the project should be clear already.

From the a governance point of view the documents that regard transport and mobility seem to be most relevant for this topic. But since this study also concerns area-oriented planning more general policy plans on for example neighbourhood development and housing may also be of interest for the cases, especially for the complex redevelopment case. These documents are found by searching on google and exploring provincial and municipal websites. Project documents such as variant studies and '*Milieu Effect Reportages*' (Environmental Impact Assessments) could also be found by making use of google.

3.4.2 Semi-structured interviews

The semi-structured interview provides freedom which the structured interview does not give (Longhurst, 2016). This is helpful in case studies as it complements Yin's (2003) reasoning of the usefulness of case studies: If the boundary between the phenomena and the context are not clear. As the boundaries still have to be explored, the semi-structured interview seems to be the most suitable method to collect data.

Pieter Smitbrug (PSB)	**Gerrit-Krolbrug (GKB)**	**SE general**
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	
	[redacted]	
	[redacted]	
	[redacted]	

*Table 2: List of interviewees (*Arranging an interview with a System Engineer from RWS did not succeed)*

Table 2 presents the interviewees in three categories. The Pieter Smitbrug required less interviews to reach a certain level of detail as opposed to Gerrit Krolbrug. Ideally case 1 would have included one private party representative but this was abandoned because of timing purposes. From this point onwards the interviewees will be referred to by their respective numbers (#).

Interviews guides were tailormade for each role (Appendix 3). The basis of the interviews with respect to exploring interrelatedness and interdependency remained largely the same, but the questions with respect to SE changed for each role. An environmental manager would receive different questions on SE with respect to technical managers or system engineers.

3.4.3 Focus group

Similarly to semi-structured interviews, Gill et al. (2008) finds that focus groups can be a valuable data collection method for qualitative research. The focus group counted a total of six professionals from both academic as well as private (engineering) backgrounds. This mix was specifically chosen to give extra depth to the discussion, and to highlight the difference between theory and practice. Attendees from the private side were present via open invitation and the academic representative was chosen on the basis of expertise in this specific field (infrastructure development). Attendees were given notice of the time scheme as well as the research aim of this study, but were not given the specific focus group questions beforehand.

The focus group session was organized by a collaboration between the researcher and the corporate supervisor. Organization of the focus group was more challenging than individual interviews due to full schedules, and planned vacations off all potential attendees. It was also inconvenient that only shorty before the focus group for this study, an inhouse meeting at Witteveen+Bos was organized regarding more or less the same topic.

The statements used in the focus group are based on the preliminary findings from the documents analysis of the cases and SE in general, and 10 interviews (Appendix 4). The statements were formulated in such a way that they could complement each other during the discussion. During the focus group session it was convenient to move from one statement to another.

3.4.4 Additional data collection

As a researcher I experienced informal data collection during this study. This information cannot be quoted or used directly as a source for the results of a research but will inevitably influence the direction of the research. For example, This research was partly being executed for Witteveen+Bos, which means that a lot of knowledge was gained through informal conversations with colleagues. As a student from university there still proves to be a lot to learn about how practice works.

A second source of informal data collection was the visiting of citizen events organized by RWS with regard to the GKB. By visiting these events in the very beginning of the research I was able to identify what made the GKB a suitable source for data. By speaking with citizens, professionals and government officials in the same setting one can briefly touch upon the potential interrelatedness and interdependencies before going in depth. On top of that, my own experience with regard to the GKB does give me knowledge with regard to the previous and current situation of the bridge. Thirdly, press releases were also used to collect additional information on public opinions, facts and figures about the cases.

3.5 Data analysis

All interviews have been recorded, the most important findings from the focus group were noted on paper. Interviews were not explicitly transcribed, but analysed with a focus on the most important content of the conversations (at which the interview guide was leading). Each interview lasted ca. 1 hour and resulted in a transcript of approximately 6 pages of text. The transcripts do not provide exact quotes from the interviewees but already represent an interpretation from the researcher.

As part of the analysis, comments were made in MSWord during transcribing in order to make connections between the interview and the literature as well as between the different interviews. The interviews have not been coded, as the goal of the interviews was to get a better general understanding of the complexity of the cases through identification of functional interrelatedness and institutional interdependency, and how SE was applied at both cases. These three concepts are easily identified without making use of a coding system. Notable and typical quotes from interviewees have been written down and are translated to English in order to be used in chapter 4 about the Results.

3.6 Ethical considerations

While quantitative research tries to generalize on the basis of high amounts of data, the qualitative method finds itself in a spot in which individual people give personal views and beliefs as data (MacCallum et al., 2019). In order to create a safe environment for the interviewee a form of consent is used (Appendix 5), in which for example consent is asked for recording of the interview. The recordings and their respective transcripts are stored in a secured online environment.

Secondly, the published version of this thesis anonymises the empirical data-collection. This is yet another ethical consideration that is especially relevant for infrastructure projects. Especially with increasing institutional interdependency the relations between stakeholders become more and more important. Yet, some infrastructure projects are to such an extend controversial that not everyone feels comfortable being completely open in interviews once their name is being published. For this reason this study beforehand decided to anonymize the research to such an extent that the cases and names are not traceable.

The third ethical consideration is that this research is not only being carried out for the University of Groningen but also for engineering firm Witteveen+Bos. Their commercial interest is to be kept in mind, but did not influence the outcome of this study. Full freedom of research design and case selection was allowed.

4 Results

This chapter describes the collected data. First we will address both cases individually, outlining the functional interrelatedness, the institutional interdependencies, and the way systems engineering was applied. After this an updated version of the loose system description as shown in figure 15 will be given in order to move forward to chapter 5: Discussion. Firstly, in section 4.1 we will address the general trends that were found in both cases.

4.1 The application of SE in Dutch infrastructure planning

4.1.1 Use of SE by private and public parties

Rijkswaterstaat has its own 'process description' of how to apply SE in their projects (RWS 2015). Appendix 6 shows the 'general workflow' for SE in RWS projects. Often, private engineering firms that collaborate with RWS are asked to follow this workflow (#9). This is not always the case, there can be slight differences between how engineering firms apply SE and how RWS applies SE. For example, at the GKB the engineering firms originally did not work with baselines as how they are described in RWS's 'process description' (#9). However, in the basis engineering and consultancy firms are asked to follow RWS's process description (#9, #10)

"Rijkswaterstaat pointed towards their preference to work with baselines, we initially didn't work with these in this project. Now, we have to 'reverse engineer' and label the preferred design option for the bridge as being a baseline. It is still up for debate whether this is worth the effort." (#9)

On the other hand, interviewee #10 clearly pointed out that the process description of RWS is not the only definition of SE, but just a translation of the SE methodology for the Dutch infrastructure planning. SE can be applied in many more ways than only what is written in this document.

It is also important to understand that the specification of the system is almost exquisitely done by the client, in most major redevelopment cases by RWS (#10). This means that for engineering and construction firms there is only so much they can do with respect to the system specification they receive. That does not mean that engineering firms cannot give their input with respect to a system specification that they receive from their client. If for example they argue that the proposed system specification of the client will not suffice, they will put that to discussion as part of their consultancy practices (#10).

4.1.2 Use of jargon

A second finding is that the use of jargon remains an obstacle in the (re)development of infrastructure, which was already briefly touched upon in the theoretical framework. The usage of jargon in SE is something which has to be avoided when possible (#7) and if it is being used it meaning should be clearly explained beforehand (#10). An example of potential problematic jargon in SE is the word 'customer-requirement', the term that is used to acquire input for a project from stakeholders.

"Customer and requirement is just wrong twice" (#7)

The quote above is typical for how jargon is considered to be problematic in infrastructure planning. For example, for a private company that wants to sell their products it makes perfect sense to use SE terminology such as customer-requirements. The core interest is singular: sell as much as possible (#8). But in infrastructure development the 'client' or 'customer' are the general public and its representative institutions. Calling them customers might not make sense, because as opposed to a product from a private company, the customers in infrastructure development cannot choose between different suppliers (#7).

The second word 'requirement' might also cause confusion when used in the wrong context. The word requirement may result in false ideas of certainty for stakeholders (#7). On top of that, once something is formulated as a requirement it narrows the design and solution freedom (#7). An alternative would be the use of the word 'concern'. The word concern has much more qualitative content about what the problem really is for a certain stakeholder, it gives much more space for finding solutions (#7). The general social responsibility of RWS makes it that the word 'customer-requirement' may create tension between RWS and, for example citizens that are participating in a project. Citizens might feel entitled to more rights than they actually have when using the word 'customer-requirement'.

4.1.3 Number of customer-requirements

This brings us to the next finding with regard to SE in general: the number of customer-requirements, and the moment that they should be collected. Interviewee #1 pointed out that it might not always makes sense to collect customer-requirements when the only thing you have is a location for the object, without any reference material of how an object can potentially look like and influences its wider context. Generally speaking, people find it difficult to imagine how an object is going to look like without any reference (#2). It relates to the notion that the phase of the project should determine what kind of customer-requirements can be collected (#10).

"It is a strange thing to acquire customer-requirements when there is not even a reference design or anything of a kind. Stakeholders are not able to react to anything yet." (#1)

In the beginning phases of projects, it can occur that customer-requirements are collected which do not necessarily relate to the system that has been designated to be engineered or are too detailed for the phase the of project (#10, #3, #1). As a result, the database of customer-requirements (often Relatics or GRIP, more on this later) can become corrupted with requirements that are outside the project's scope or are too detailed for the phase of the project. This, in the end negatively effects the process of the project (#10, #7, #3)

A high number of customer-requirements may result in a cluttered Relatics database (#7, #9, #10). Some interviewees point out that the context of certain customer-requirements can get lost when there are too many (#7, #9, #10). Interviewee #10, for example, being a system engineer in a private company, added to this that in some cases databases from clients are received that already consist of over a 1000 customer-requirements. Getting to know let alone work with such a database is a challenge on its own (#9)

"You receive a list of over 1000 requirements, and that's where you start. You haven't even had one conversation at that point. It might very well be the case that this database already contains mistakes. The info could be gathered at the wrong stakeholder, context of the requirement might miss, or the formulation of the requirement is unclear" (#10)

The quote above summarizes the cause of the issue quite well. One solution might be to cap the number of customer-requirements at a maximum (#7). On the other hand, in major projects, having many stakeholders, one cannot get away from high numbers customer-requirements. According to interviewee 10, it is not necessarily to lower the number of customer-requirements, but to increase the quality (#10). A key element here is that customer-requirement conversations need to be scoped well (#7, #8, #10). Scoping the conversation simply means that it is made clear beforehand what the topic of the conversation will be, and that no other topics are discussed.

It still happens that these conversations are held with too much 'freedom' for the stakeholder (#10). This again results in customer-requirements which you rather not want to have in your database (yet).

Proper scoping of these conversations will result in requirements which are more focussed on what the issue is, and are more compatible with actual possibilities of a project (#7).

"It is better to collect concerns instead of requirements, and also to temper the expectations. In the end it is the expert who is developing the bridge, they know the possibilities. You cannot build a bridge based on customer-requirements." (#7)

4.1.4 Resume and analysis

The application of SE in Dutch infrastructure planning seems to be well thought through in terms of what has been written in the process description by RWS (2015). However, in practice this does not mean that everything will be perfectly executed in that way. While the word 'customer-requirement itself is presumed to be problematic in some cases, the underlying discussion about when and how to collect them in order to increase the quality of customer-requirements seems to be even more evident.

It is a balancing act between tempering expectations by scoping customer-requirement conversations, and finding out concerns from stakeholders. Interviewees pointed out that proper scoping of customer-requirement conversations is a key factor in keeping the project on the right track. This practically means that for example in exploration phases of projects there will be no discussions about details, or that previous design decisions are not to be discussed anymore in these conversations. These measures will likely result in less customer-requirements but also requirements that are better focussed on the phase the project is in.

But in essence, when conversations are only scoped to what the project team finds relevant, one may be less open to listen to what concerns there really are. The question then becomes who will determine the scope of these conversations, and how to they ensure that important concerns will not be missed? It is rather questionable if such an approach to planning is sufficient for area-oriented planning for (re)development of infrastructure. Chapter 5 (discussion) will elaborate on this.

4.2 Pieter Smitbrug: simple context and new development

Case 1, the 'simple' and new development project is situated in the province of Groningen (figure 17 and appendix 7). With its 800 meters the Pieter Smitbrug (PSB) is the longest cycling/pedestrian bridge in Europe. The bridge was developed by the Province of Groningen, the municipality of Oldambt, and 'project bureau' Blauwestad, and was finished in February 2021. The main purpose of the bridge is to create a better connection between the new real estate developments North of the A7 highway to the centre of the town Winschoten, South of highway A7 (Provincie Groningen, 2021). The bridge is built using sustainable hardwood and should last around 80 years (#1, Blauwestad n.d.)

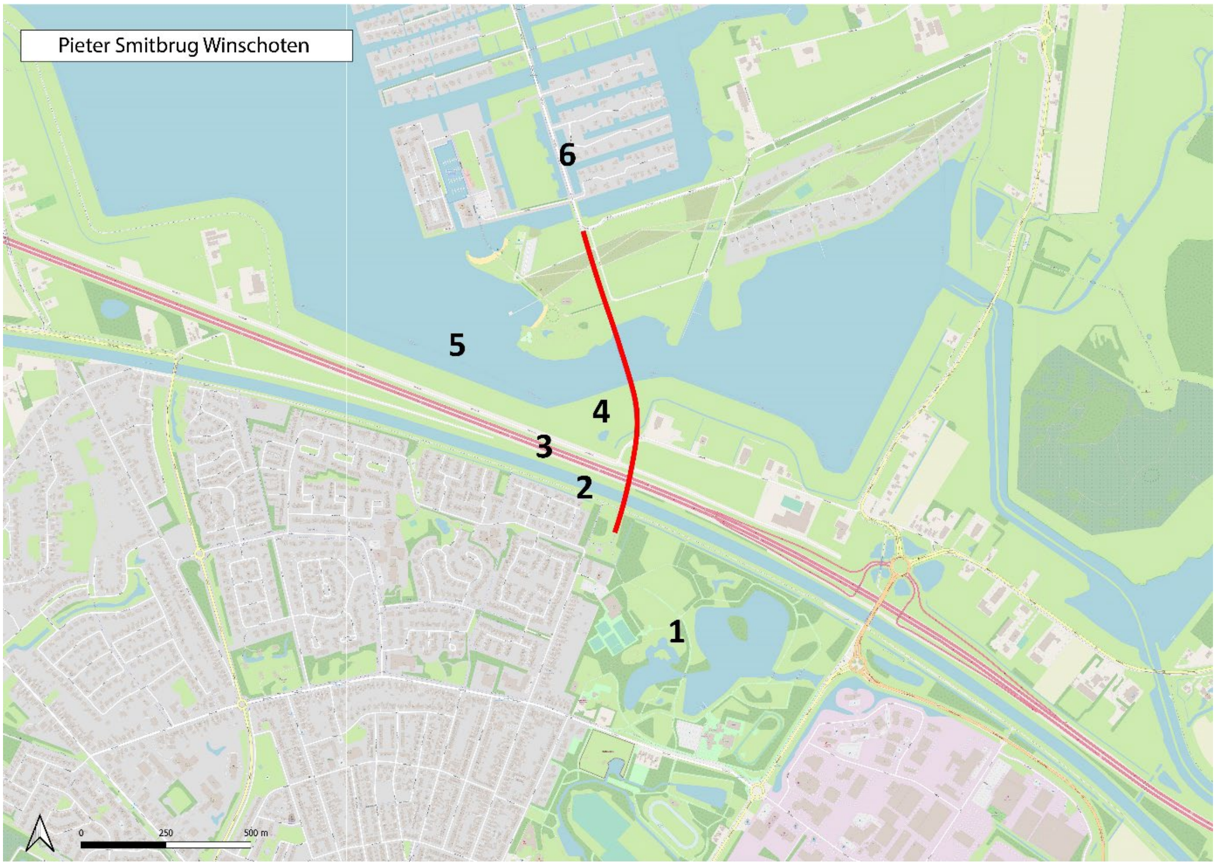

Figure 14: Case 1: Pieter Smitbrug

4.2.1 Functional interrelatedness

Based on the interviews, documents analysed, and the map in figure 17 we have been able to identify some notable functional interrelations between the PSB and its surroundings, such as nature and infrastructure. The introduction of 4.2 already mentioned the connection of the bridge to the neighbourhood North of the highway and the town South of the highway. The functional relation here can be found in the presence of inhabitants on the North side and the presence of facilities on the South side of the project area (Provincie Groningen, 2021, Blauwestad, n.d.). The bridge connects the functionalities 'living' and 'facilities'.

The numbers in figure 14 represent the most mentioned functionalities around the PSB in the interviews and in the exploration phase (Grontmij, 2014). 1) Stadspark Winschoten, 2) Winschoterdiep, 3) National highway A7, 4) Natuurnetwerk Nederland (nature network Netherlands), 5) Oldambtmeer, 6) Housing (on either end of the bridge).

As the bridge is over 800 meters long it crosses a high variety of other functionalities, that do not directly impact the local community. This section will address them from South to North. Firstly, the map shows us that the bridge crosses the 'Winschoterdiep' (point 2 in Figure 18), a minor canal in the North of the Netherlands, managed by the province of Groningen. The Winschoterdiep is used is for both professional and recreational shipping (Hunze en Aa's, 2020, Schuttevaer, n.d.). The Winschoterdiep is a canal which hosts vessels with fixed standing masts, which means that the bridge requires a moving element over the canal in order to be able to pass (Provincie Groningen, n.d., Grontmij, 2014) (Figure 18).

Dykes can be found on either side of the canal. For maintenance purposes of the dykes the bridge has to be of a certain height. Tractors with mowing machines should be able to cross underneath the bridge, this was one of the customer-requirements of the Waterboard 'Hunze en Aa's' (#1, #2). However, this is one of the three customer-requirements that the project team was not able to fit into the design of the bridge (#2). The solution for this was to construct a ramp on either side of the bridge which the tractor is able to cross (#1).

"It was about a tractor being able to mow the dyke and needed to cross underneath the bridge. This required a significantly higher bridge. We probably wouldn't even have the bridge if we had to agree to this requirement" (#2)

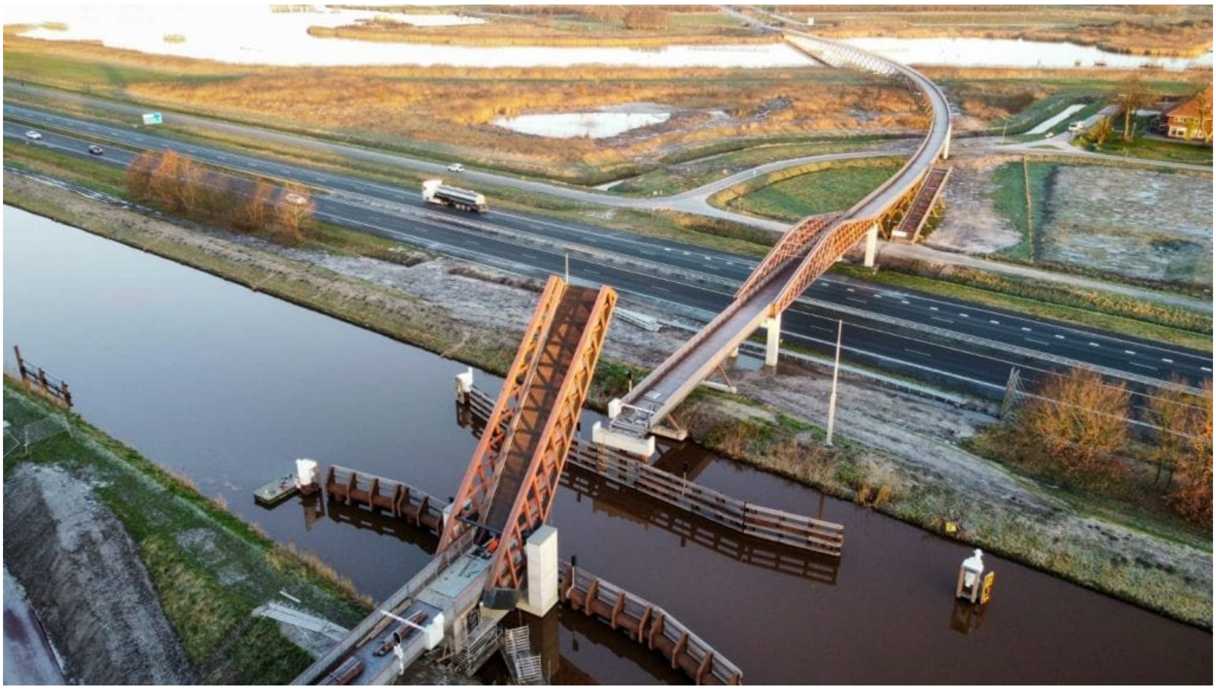

Figure 15: Pieter Smitbrug over the Winschoterdiep (Machinefabriek Rusthoven, n.d.)

Moving further North, adjacent to the Winschoterdiep the national highway A7 is located (point 3 in (figure 18). The highway connects the North of the Netherlands to Germany, and is the fastest connection from Winschoten to the nearest big city, Groningen. RWS manages the national highways and required the bridge to not have a column between the two sets of lanes in each direction (#1). The minimum height of the bridges is determined by the 'Richtlijn Ontwerp Kunstwerken' of RWS (ROK) (translated: Guidelines Design for Works) (RWS, 2011, Grontmij, 2014).

The open area North of the highway is designated as 'nature', even though the lake is artificially developed as part of a real estate developments (points 4, 5 in Figure 18) (Oldambtmeer.nl, n.d.). The area being designated as nature made that the fitting of the bridge into the landscape was a priority (#1, #2, #3, Grontmij, 2014). Developers had to respect the animals that live in the area. Specifically bats have special attention in this case as the bridge crosses a major bat flying route (Blauwestad, n.d.). Interviewee #3 also pointed out that a nature conservation organisation wanted the bridge to be of such a height that wild animals that lived in the area (4) would not experience nuisance from cyclists, even though up until this day there is no cattle to be found in the area (#3). This customer-requirement is based on the fact that area 4 in figure 17 is part of the Nature Network Netherlands (NNN), a spatial planning act that ensures good connectivity between nature areas in the Netherlands for safe passage of fauna (Grontmij, 2014).

4.2.2 Institutional interdependency

As mentioned before, functional interrelatedness leads to institutional interdependency. This means that the aforementioned stakeholders such as the municipality, the province, the waterboard, RWS, and nature organizations should be considered to be within the institutional system of the PSB. The goal of this study is to find whether this functional interrelatedness is in fact reciprocal in this case or if we find primarily one-dimensional relationships, meaning that discussions with regard to the bridge remained relatively predictable.

The relationship with RWS in this case is rather one dimensional. As mentioned before, it was interviewee #1 who stated that the only concern for RWS was not having a column between the two set of lanes and a minimum heights based on the ROK. There was no mention or further discussion on this topic by either of the three interviewees, this requirement was accepted without discussion, meaning a rather one dimensional and predictable relationship.

But this doesn't mean that when 'professional' stakeholders come with standardized guidelines, these are always automatically agreed on. In the example of the ability to mow the dykes with tractors, deviation from the standards was made. Using SE as a design tool led to the conclusion that the customer-requirement by the waterboard was not feasible in any way (#2). The waterboard expected that this customer-*requirement* would be accepted, which resulted in difficult discussions between them and the province (#1, #2). It was pointed out that the waterboard is not used to working with SE (#2). Still, even though this requirement was not accepted, the solution proposed by the project team, a ramp on either side of the bridge, was accepted by the waterboard, which solved the point of discussion.

Reciprocal Interdependency can clearly be found between the municipality and the province. The province is the main developer of the project. Together with several engineering and construction firms they form an alliance to design the bridge (#1, #2). The province also provided 90% of the budgets for the project (#2). The other 10% was provided by the municipality of Oldambt. On top of that, the bridge is built on land owned by the municipality.

The reciprocal interdependency became clear when the PSB is used as part of negotiations between the province and the municipality about real estate development in Blauwestad (the neighbourhood on the North side of the bridge). Around 2016 a discussion between the province and municipality emerged regarding the development of affordable housing in Blauwestad (RTV Noord, 2016a). The province aims to have more affordable housing in Blauwestad and the municipality of Oldambt, as well as other municipalities in the area, disagreed on the matter. According to them, these houses will compete with existing real estate in their municipalities (RTV Noord, 2016b).

In the end, the province and the municipality compromised to cap the amount of affordable housing. Here the PSB is presented in the negotiations as a compensation measure for the municipality of Oldambt (RTV Noord, 2017). This example shows that due to political reciprocal interdependence a project can be included in discussions that are in a different field of interest.

Finally, the bridge has a prominent relation with the inhabitants of the neighbourhood on the North-side of the highway, Blauwestad (4). The bridge was initially built to increase connectivity between Blauwestad and the centre of Winschoten (Provincie Groningen, 2021). However, This relationship did not lead to problems with respect to project-management, due to the fact that everyone wanted this bridge (#1, #2, #3). On top of that, active participation was possible at certain parts of the projects, such as the design of the landings of the bridge at the Blauwestad side (#2). Citizens were also given 'sneak peaks' of new developments during the project (#2).

4.2.3 System Engineering

The application of SE is relatively new for the province of Groningen (#2, #3). Consequently, at the start of the project customer-requirements were collected by the stakeholder manager using an excel-sheet (#2). In order to better structure the customer-requirement process it was recommended to the project manager to use a Relatics database (#1). However in order to successfully apply the Relatics database outside consultancy was needed (#1,#2). It was pointed out that 'the official' way of verifying and validating customer requirements following SE methodology was not used exactly like for example the process description from RWS describes (#2). In practice this meant that not all stakeholders would receive 'official' verification and validation notices.

According to the project team, the main advantage of SE is the ability to track down decision-making (#2, #3). It also helps to recognize when the project team is working on the edge of what is possible (#2). If this happens, Relatics will recognize where in the project problems might surface once a certain path is chosen, shown in the example of the waterboards and their tractors. It was also pointed out that SE is useful for keeping the project on track:

"This person (Outside SE consultant) would sometimes frustratingly remind us that our choices might have an effect on customer-requirements. Sometimes you're floating off, and someone is able to bring you back on track" (#2)

4.2.4 Resume and analysis

All of the functional relations above had an impact on how the object was designed, but did, derived from the number of neglected customer-requirements, hardly led to any major discussions. Customer requirements from parties such as RWS and the waterboard were relatively easy to implement, and if not, a solution was easily found. As a result of this the Relatics database remained relatively stable, meaning that it was relatively simple follow a linear SE process to get to an object design for the project.

The low amount of reciprocal interdependencies between stakeholders resulted in a predictable and stable project-environment. This could also explain why for example the 'verification and validation' process was not followed as strictly as a SE process would normally prescribe. Another key factor for the relative predictability of the project seems to be the fact that (almost) everyone wanted the bridge to be developed. Generally speaking, this makes project development much easier, as it may be more convenient to find compromises among stakeholders.

4.3 Gerrit Krolbrug: complex context and redevelopment

Case two is the Gerrit Krolbrug (GKB) in the city of Groningen. The bridge was originally built in 1936, simultaneously with the construction of the canal. At that time the neighbourhoods on the North side of the canal were not developed and/or planned yet. When the neighbourhoods on the North side were being developed two pedestrian/cycling bridged were added in 1993 on either side of the main bridge in order to give slow traffic a crossing when the bridge is open.

A quick search on local news website RTV Noord ("Gerrit Krolbrug") results in 142 items of which many are about either technical difficulties or social and political disagreement with regard to the new bridge. The bridge is in need for redevelopment because it is at the end of its lifecycle (#4, #5, #6, #7, #8, #9). A notable event is that the bridge was destroyed by a ship collision on the 15th of May 2021 (RTV Noord, 2021). Although this would have been expected to create more urgency for the redevelopment of the bridge, it did not change the project planning (#4, #5, #6). It did cause extra attention for the project from both the media and politics (#4).

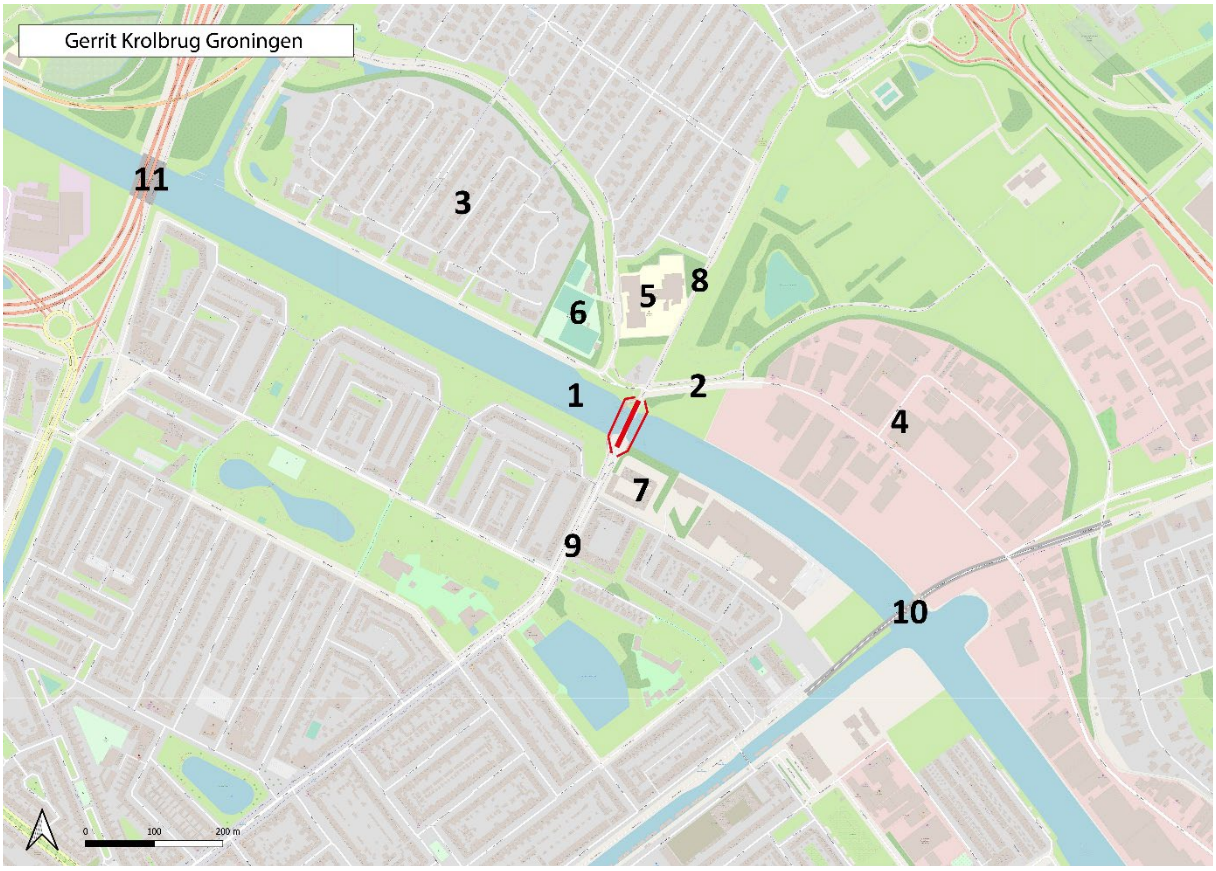

Figure 16: Case 2: Gerrit Krolbrug

4.3.1 Functional interrelatedness

The GKB is located in a complex context. This is reflected by the number of functional interrelations between the bridge and its context. As can be seen in figure 19, there are many functions that depend on the GKB: 1) The van Starkenborgh canal, 2) The Ulgersmaweg, 3) housing, 4) minor industrial companies, 5) high school, 6) tennis club, 7) social housing high rise development, 8) cycling path, 9) Korreweg, 10) Bus lane bridge, and 11) Ringroad. This is merely a selection of the functionalities that have a relationship to the GKB, but shows that there are many to take into account. Selected based on the interviews and press releases, this section will address the functionalities that were mentioned the most (1, 2, 9, and 10).

The GKB is a bridge that crosses the van Starkenborgh canal. This canal is part of the so-called 'hoofdvaarweg Lemmer-Delfzijl' (HLD) which is an essential waterway connection between the port of Amsterdam and the German hinterland (NOS, 2021). In 1997 it was dicided to upgrade the entire HLD to be able to host 'class Va' ships (figure 9). The upgrade was supposed to be finished in 2015 (RWS, 1996). The decision to upgrade the waterway has an impact on all the bridges of the HLD, including the GKB. For fixed bridges the height is set at 9.1 meters and for moving bridges the minimum height according to the guidelines of RWS is 7.4 meters (RWS, 2011). According to interviewee #8, these guidelines are of importance because the uniformity of the waterway will result in more nautical safety. The branch organization for shipping, Schuttevaer opted that the bridge should have an absolute minimum height of 4.5 meters, which is similar to some of the other *redeveloped* bridged on the canal (Schuttevaer, 2020).

"*You can actually view the waterway the same way as a highway. It should look the exact same in the entire Netherlands*" (#8)

Number 2 of Figure…. represents the connection between the GKB and the Ulgersmaweg. This relationship is determined by two factors: the industry at the North side of the canal (4) and the connection to the cycling path (8). The industry is dependent on the bridge because of accessibility for customers. In 2012 the branch organization for entrepreneurs in the area claimed that the closing of the bridge due to technical difficulties resulted in loss of revenues for the different companies in the area (RTV Noord, 2012). The industry here mostly concerns some garage's, pumping stations, thrift shops, and other minor production and distribution sites. The industrial area is still well accessible via the ring road on the North.

The second factor relates to the presence of a busy cycling path. One of the opportunities that is being explored during the planning-phase of this project is to make a safer crossing between the cycling path and the Ulgersmaweg (#4, #5, #6). In the situation before the bridge got hit, when one crosses the bridge from South to North, the car traffic that comes from the right has to give way to the cyclists that come from the left, which often creates unsafe situations such as almost-accidents between cars and cyclist who both expect priority (#8, own experience) (Figure 20). The re-arrangement of this crossing allows for chances with regard to this open space in general. In this specific example the restauration of an old creek is being discussed (#6, #7, #8).

Figure 17: View when just having crossed the bridge. The cars come from the right but still have to give way to the cyclists. (Street view, 2021)

Finally, The Korreweg is one of the busiest cycling routes in Groningen, it hosts close to 15.000 cyclists every day (Gemeente Groningen, 2015). In 2015 the municipality of Groningen published a document called the 'Fietsstrategie Groningen' (Cycling strategy Groningen) which allocated the Korreweg as one of the main opportunities for the development of a cycling street (Gemeente Groningen, 2015). In this strategy, the Korreweg will lose its function as a 'gebiedsontsluitingsweg' (distribution road) and will continue to be serving only slow and local traffic. This was formalized in 2021 in the 'mobiliteitsvisie' (mobility vision), either the bus lane bridge (number 10 in figure 19), or a new bridge will take over the distribution function from the Korreweg and will serve more regional traffic (Gemeente Groningen, 2021).

"*The Korreweg is one of our busiest cycling routes. At rush hour the cycling paths are completely full, while car traffic is low. That is why we want to redevelop the Korreweg to a cycling-street. This plan needs to be executed in good collaboration with the plans for the Oosterhamriktracé and the redevelopment of the Gerrit Krolbrug.*" (Gemeente Groningen, 2015)

During the interviews the re-arrangement of the Korreweg towards a cycling-street was not mentioned such, but during the participation evening for the GKB the plans for the cycling streets were presented. On top of that, documents presented by the gemeente Groningen (2015, 2021) show that the conversion of the Korreweg to a cycling-street is continuously on the agenda. In 2018 the 'project team for the replacement of the Gerrit-Krolbrug' advised the municipal council to agree on the downgrading of the GKB to fit the future context of the bridge (Gemeente Groningen, 2018).

Consequently, the new design of the bridge incorporates the plans for the cycling street which also results in a bridge that fits within the future plans. Questions were asked by citizens about the function of the GKB with respect to heavy vehicles, that may or may not be allowed to cross the bridge, as well as the Korreweg, with exception of emergency services. This discussion is still ongoing (#5, #6, RWS, 2019).

4.3.2 Institutional interdependency

The functional interrelatedness between the GKB and the Korreweg is typical for the institutional reciprocal interdependency between the municipality of Groningen and RWS. The GKB is being redeveloped in cooperation between RWS, the municipality of Groningen and engineering firm Royal Haskoning DHV (RHDHV), of which each party has its own project manager (#4, #5, #6). RHDHV has an advisory role in the planning phase of the project, and is therefor not necessarily regarded as an example of institutional interdependency (#5, #9, Gemeente Groningen, 2019).

Contrary to the PSB where there is only one governmental agency active in the project development, the GKB has to deal with two. Both RWS and municipality agree on the fact that the development of the project is a common effort (#4, #6). This means that each decision is being made in good consultation between these two parties. Interviewee #4 highlights that it is extremely important that the municipality and RWS present themselves as one development team. Interviewee #6 states that over time, the coherence between RWS and the municipality increased.

"*Once you have to go to the municipal council you don't want to be standing there as 'us – them, but as one team.*" (#4)

Before we continue with the interdependency between the municipality and RWS it is good know that RWS has not always been in the project team for the redevelopment of the GKB. In 2014 the management of the canal was transferred from the province to RWS. From 2014 onwards the province started working on plans for redevelopment of the GKB (#1, #7, #8). The province would execute the planning phase of the project. They got as far as a 'variantenstudie' (variant study), which was made in collaboration with Witteveen+Bos (Witteveen+Bos, 2015).

Based this study, a final option was chosen and agreed upon by the municipal council (#1). According to RWS the legal procedure to get to full realisation of a new bridge was not executed in the right way, which could potentially be catastrophic for the future of the project (#7). The province of Groningen wanted to proceed with the project regardless of the fact that the proposed width of the bridge was ought to be too narrow, and would result in an unsafe traffic situation with respect to cyclists and car-drivers sharing the same road. Note that at this stage (2015) the Korreweg was still meant to be a distribution road for regional traffic. This was one of the reasons that RWS decided to take control over the redevelopment of the GKB. In practice this meant that the entire 'variant study' had to be done all over again (#7, #8). This includes the entire participation process that had been carried out by the province.

"*It is important to follow the right procedures. If you don't, you open the door to objections against your project. You will just don't make it. Especially in a complex administrative context, in which people are not afraid to stand up for what they want*" (#7)

The new study that was carried out by RWS looking at two different options for the GKB: 4.5 meter in height and 5.7 meter in height. According to interviewee #8 it seemed that due to the inclusion of the 5.7-meter option, the discussion about the height of the bridge became more intense. This is also reflected when examining the publishments in the press with respect to the GKB. The first article on RTV Noord which discussed the height of the bridge dates from January 2020, shortly after RWS took over the project (RTV Noord, 2020).

This discussion was initiated by citizens that live near the GKB and reached its peak when it was discussed in the Dutch parliament. The minister of I&W accepted a motion that stated that RWS and the project team must consider an option to make the bridge 3.0 meters high (#4, #5, #6, #7, #8). Both the municipality and RWS agreed that carrying out the study for a 3.0 meter option was needed. The municipality supported the motion that was presented in the Dutch parliament because according to them the study was needed to objectively reject the 3.0-meter option (#6). RWS representatives agreed on this by stating that *if* the 3.0 was chosen it creates precedence for other places, careful rejection of the option was needed to prevent this (#8). A 3.0-meter option does not meet any of the ROK guidelines nor has it ever been carried out on a waterway which has to host 'class Va' ships. As a result of the accepted motion RHDHV had to carry out additional studies to examine the 3.0-meter option (#4, #8). Based on these studies the 3.0-meter option was regarded not sufficient (#4, #6, #7, #8).

"*Because of political and administrative pressure the 3.0 meter variant was taken into account to be able to make a well-considered reasoning to reject the option*. (#6)

4.3.3 System Engineering

The application of SE at GKB is not applied from the beginning of the project. Even though RWS took over the project from the province, they still used some of the work the province has carried out (#1, #7, #8). This regards phase one of a traditional MIRT* infrastructure project: 'verkenning' (exploration). As a result of this SE was introduced in the project during the second phase, the planning phase (#8).

RWS projects work with a database which is similar to Relatics: GRIP. As a system engineer in this project interviewee #9 often receives reports from customer-requirement conversations and is then asked to filter out the actual customer-requirement. Accordingly to the SE methodology in LeidraadSE (2013) these 'translations' are verified and validated by their respective stakeholder. It is hard to say whether this process is different for redevelopment projects with respect to new developments (#9). The major difference is that with redevelopment projects most people already have a reference on which they can base their 'customer-requirements'.

Interviewee #9 experienced what was already mentioned in section 4.1.3, the amount of stakeholder requirements and the timing of when you receive them can be challenging. In this case, interviewee #9 received a dataset of over 900 customer-requirements from RWS *after* the final variant was chosen. This means that while keeping in mind all the customer-requirements that have been accepted based on the chosen variant, the new 900 options have to be put into the new database, preferably without causing any contradiction with the existing requirements.

4.3.4 Resume and analysis

The case of the GKB confirms the notion that increased functional interrelatedness leads to increasing institutional interdependency. The GKB is part of the local and regional traffic system of Groningen. In

2015 the province of Groningen presented the first plans to develop the Korreweg as a cycling street, but these were non-binding. This may have resulted in the fact that in the initial plans for redevelopment, the province of Groningen had to presume that the bridge would keep its distribution functionality. Which resulted in plans that were either unsafe, or too expensive (Gemeente Groningen, 2018).

When the plans for the cycling street became more embedded in municipal policy, and an alternative for the distribution road was found (the bus lane bridge), RWS, together with the municipality was able to develop a bridge that is safe for cyclists and pedestrians, as they *were* able to take the cycling street into account.

Important to note here is that the variant study by Witteveen + Bos (2015) did include the cycling street, but clearly stated that the feasibility of this option was dependent on the long term plans of the municipality. In the end, proper redevelopment of the GKB was only possible when the plans for the cycling street, and the broader traffic system of Groningen were in an advanced enough stage.

This clearly had an effect on how the bridge is going to look like, the system that will be engineered. Now that the bridge only has to serve slow and local traffic, the bridge can be much narrower as opposed to the plans that were developed by the province. It seems that if the plans of the province were executed, the bridge would not have fit its future context as well as it will do with the current designs.

A key factor here is that for SE to be successfully applied, a project team should only move forward to a next phase (baseline) when all parties involved are on the same page. The amount of uncertainty that the province had to deal with in their initial plans, not knowing what function the Korreweg would have in the future, made it that it was extremely difficult (and risky) to move towards the next phase, which would have been execution.

What does remain is the discussion about the height of the bridge. It was stated that uniformity of the waterway is of major importance for the nautical safety of the canal (#8). On the other hand Schuttevaer (2020) stated that the minimum height of the new GKB should be at least 4.5 meter in order to create uniformity between other redeveloped bridges in the province of Groningen west of the GKB, as these are also 4.5 meter. One could make the argument that a 4.5 meter GKB would *increase* the uniformity of the canal.

4.4 Analysis of the application of SE: development vs redevelopment and simple vs complex

4.4.1 Development vs redevelopment

Looking at the two cases shows that the application of SE is not necessarily different between redevelopment and new development. It is the content of steps that change. It means that for example, the process description of RWS can be applied regardless of whether a project is new development or redevelopment.

> "*The process is basically the same. You just have a different project*" (#7)

According to the focus group redevelopment projects are prone to more uncertainty than new developments. In a redevelopment project the state of both the object itself, as well as its context is often not clear. For example, in the case of quay redevelopment of the HLD the project team does not possess all the necessary data in order to create a predictable system (focus group). The solution for this was to embrace the uncertainty in the first phases of the project to gather data and try to make predictions for the upcoming phases (focus group). This automatically means that the scope of the project cannot be determined beforehand essentially forcing the project team to leave room for adaptability in the planning process. Interviewee #10 also pointed out that this also counts for single object that are in need for redevelopment.

"*Same as with renovating your house. When you rip out the floor, there is a chance that you find out that the beams are rotten. So, you're exploring the scope*" (#10)

The functional interrelatedness between a redevelopment project and its context is often relatively tight due to the fact that all functionalities in proximity to that object depend on the function that the current object has. The vested interests of the stakeholders at redevelopment projects play an important role here. This can clearly be seen at the GKB when looking at the views of the citizens that live around the GKB as well as the interests of the entrepreneurs on the North side of the bridge.

A clear example of how this functional interrelatedness influences the institutional interdependency is shown through the current (vested interest) *and future* function the GKB has in the traffic system of the city of Groningen. The newly developed 'mobility vision' for Groningen will influence the potential functionality of the GKB. The project team of the GKB is therefor dependent on broader policy with respect to the traffic system of the entire city of Groningen. Which in the end has an effect on the system (the bridge) that is going to be redeveloped.

With respect to SE, the tight couplings between object and context are for example reflected by the degree of ability to engage with customer-requirements. For a redevelopment project it can be challenging to collect and deal with customer-requirements because based on the context the object is situated in, a lot of the design choices are already implicitly made (#10, focus group).

For the PSB, the functional and institutional setting is much clearer. As the object still has to be developed, there are hardly any vested interests with respect to that object. This may have been one cause that almost all stakeholders were in favour of the development of this bridge.

4.4.2 Simple vs complex

The second reason to believe that there is a difference in application of SE between the two cases is the fact the PSB and its context are relatively predictable (simple case) and the GKB and its context are relatively unpredictable (complex case). According to the focus group the complexity of the case has the most influence on the application of SE. This is most likely due to the fact that regardless of development or redevelopment, the functional interrelatedness and institutional interdependency is always higher in complex cases when compared to simple cases.

One thing that is not different between the simple and the complex case is the system definition step in the SE approach. In both cases, the system that has been identified to (re)develop is the object itself. After all, the actual system that has to be engineered is only the bridge itself, everything else is context (#1, #4, #10, focus group). It may be questionable if such an approach justifiable in a complex case.

As we have seen in the case of the GKB there are many functional interrelations, and thus institutional interdependencies between the specified system and its context (tight couplings). We have also examined that the process of this project is not going without any flaws. As was stated in the focus group, the 'system GKB' seems to be difficult to separate from its context. Both regarding the waterway network (neighbouring bridges such as the bus lane bridge), the other infrastructure networks (local traffic system) as well as (accessibility for) spatial functionalities such as housing, businesses, and facilities (shopping, education, and healthcare). In other words, the actual existing system of the GKB might to have been considered broader than what was specified by the project team, especially during the phase that the province was initiator of the project.

"*If you're only insulating the walls in your house you don't have anything to do with the neighbours. If I decide to install a heat-pump with a noisy ventilation system in your garden you will create interference with your neighbours*" (#10)

The way the context is being approached *is* different for both cases. This can for example be seen if we compare the customer-requirement processes of both cases. It was pointed out that at the PSB (simple case) the 'official' verification and validation steps were not necessarily taken at all times (#1). On the other hand, at the GKB (complex case) the SE process is very much done according to the rules of the book (#9). At the PSB an official verification may not have been needed because of the relatively simple institutional context of the project. However, the absence of verification and validation may also be dependent on the actual project team.

The results have shown that at the PSB there were relatively few functional (reciprocal) interrelationships and institutional interdependencies. From a systems theory perspective this means that the (tight and loose) couplings between the object and its context are easily identified and predictable. As a result of this, the system could easily be reduced and defined as the object and was relatively simple to (linearly) 'engineer'.

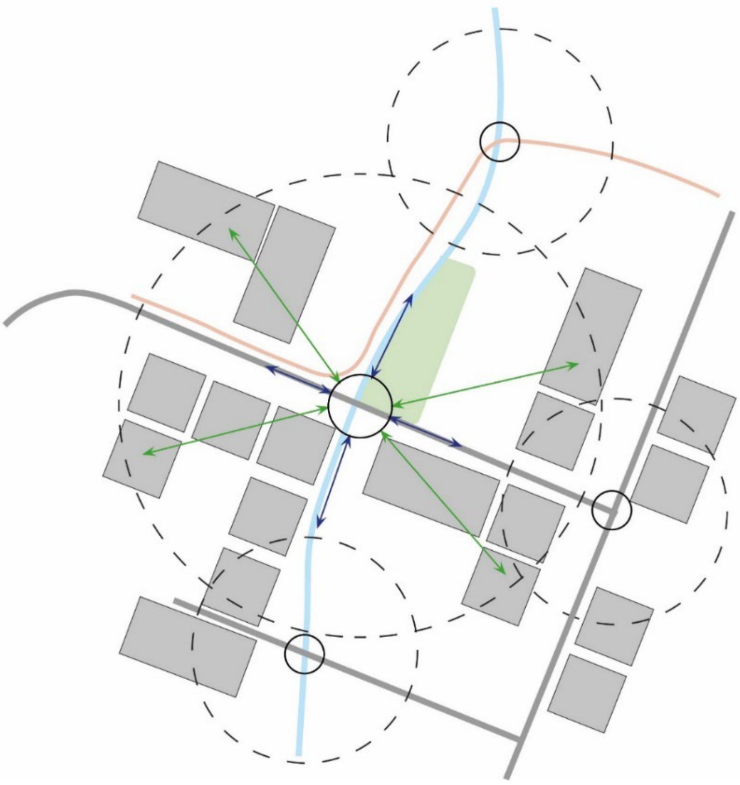

Figure 18: Loosely coupled systems approach in practice

The question is how to apply system engineering in complex cases. This is where the loosely coupled systems approach, visualized in figure 21, may help. By increasing the context of the project, loose couplings can be made with other projects/plans/stakeholders which broadens the solutions space for the focal project. A good example is the inclusion of the 'mobility vision' of Groningen in the development of the GKB, resulting in the ability to make a smaller bridge. As these couplings are loose, these projects can then be decoupled from the focal project without major consequences. This way, the tight couplings between the object and its context in the focal project are easier to deal with, as the solution space in general becomes bigger. A major prerequisite for this from a SE perspective is that a project should not move forward until all subsystems are able to make a step (focus group). This is reflected at the GKB at which the decision for a bridge that fits the cycling street could only be made when the plans for the cycling street were concrete enough.

4.4.3 Resume and analysis

The complexity of cases has more influence on the actual application of SE than the differentiation between development and redevelopment. Redevelopment projects show more uncertainty with respect to the technical state of the actual object, but the complexity debate adds a discussion regarding the actual functioning of the object in its wider context.

The PSB is a clear example in which the relations between object and context are predominantly loose, and a tight project organisation based on the SE approach was very successful. On the other hand, the GKB is a clear example of how in complex cases, the relations between object and context are tight. Tight relations between object and context result in high numbers of reciprocal feedback loops, which *is* what makes the case complex. A linear SE approach does not seem to make sense here. However, the problems at the GKB cannot solely be prescribed to the fact that classic SE was applied, because of the amount of institutional disruptions at the project, such as shifts between operators and project developers, also played a role in this.

The loosely coupled systems theory that was described in the theoretical framework seemed to be (intentionally or not) applied at the GKB (Dubois and Gadde, 2002; Weick, 1976). The inclusion of the mobility vision does not seem to be directly necessary for the development of the object itself, but this loose coupling did help the project overcome one of its major debates: safety for cyclists. The key here seems to not predetermine (and fix) the scope of the project, but to actively search for additional projects and stakeholders that may help widen the possibilities for the focal project.

5 Discussion

One of the initial reasons to conduct this study was the notion that planners should seize the opportunity of the development challenge to create sustainable and future proof infrastructure (Willems et al., 2016). One of the reasons to conduct this research is that SE is a dominant approach in infrastructure planning. The questions is how to do this, what are the main barriers and success factors, and conditions for successful redevelopment while making use of the SE approach (sub-question 5)? This chapter will answer this question by addressing the main themes from the theoretical framework (functional interrelatedness, institutional interdependency, and loosely coupled systems), while linking them to the two cases.

5.1 Functional interrelatedness

One of the approaches to seize the opportunity that Willems et al. (2016) proposes is area-oriented planning (Heeres et al., 2018). In area-oriented planning approaches objects are not developed as if they are situated in a fixed context separated from their environment, but the ever changing context of an object is being accepted and incorporated in the planning process. One of the main prerequisites to successfully do this is to find and determine the nature (tight or loose) of the functional interrelations between the object and its context (Heeres et al., 2017).

From a SE perspective, both cases show that the object is defined as the system, and everything outside the object itself is defined context. The results show that both cases have functional reciprocal interrelatedness with respect to their context, but the main difference is the degree of relatedness or the tightness of the relationships of the object with its environment. The PSB had a relatively stable and predictable context, which is essentially comparable to the 'simple bathtub system' as described by Meadows (2008) (Figure 10).

The location within a city, as well as the number of vested interests usually in redevelopment challenges, makes the context of the GKB much more complex. Here we see that the entire local traffic network of the city of Groningen is part of the functional context of the GKB. This is reflected by for example the representation of a complex system by Geldof (2014) (Figure 11). The increased functional interrelatedness of the GKB compared to the PSB makes it more difficult to design an object that perfectly suits all functionalities. The interrelationships strongly influence the design and the design itself has influence on the relationships (reciprocity).

The identification of the degree of complexity of these functional interrelations may help system engineers better understand how to approach these context functions in the planning and design process. In complex contexts it becomes much more important to realize that the system that is being engineered is part of a larger system. In practice this means that the context of an object is much more than for example only the direct users, or all citizens that live within a 1 km radius of the project.

On top of that, the redevelopment of the GKB highlights an additional complexity that was not identified in the theoretical framework as such: the presence of vested interests. Vested interests will likely exists in at new development, but seemed to be more prominent in redevelopment projects. Direct users and stakeholders at an infrastructure redevelopment project have most likely been used to a certain functionality and design of an object for a long period of time. These vested interests might be problematic for the application of SE as they most likely represent customer-requirements that want to keep the current functionalities of an object. This potentially results in a high degree of predetermination of how the object should be designed, or may result in discussion about any proposed changes with respect to the functionality.

Vested interests at redevelopment projects therefor also may limit the possibility of area-oriented infrastructure planning, in combination with seizing the opportunities of infrastructure redevelopment. While area-oriented planning practices require active engagement with the context of an object (Arts et al., 2016), it is exactly the context of that object that limits opportunities that are proposed by Willems et al. (2018) (See also Willems (2018) and Willems et al. (2016)). The question for area-oriented planning then becomes how to choose between the vested interests of the context versus the perceived opportunities to change the functionality of the object.

5.2 Institutional interdependency

Functional interrelations automatically lead to increased institutional interdependency (Heeres et al., 2016 and 2017). The results show that there are hardly any institutional interdependencies at the PSB. The main reason for this is that there are only little functional interrelations between object and context, and if they were there, they were easily solved by minor design changes.

The GKB shows that the complexity of the context leads to actual institutional interdependency between, first the province of Groningen and later RWS, and the municipality of Groningen. The future functionality of the new GKB is highly dependent on the broader plans for the city of Groningen. The literature points towards institutional fragmentation as one of the reasons why project management in these cases might not go smoothly (Arts et al., 2016; Busscher and Willems, 2019; Heeres et al., 2017). The more complex the project is, the more stakeholders are going to be involved, especially when engaging in area/oriented planning practices. All of these stakeholders have different interests, views, approaches etc., but have to work together in order to successfully apply area/oriented approaches, often resulting in long lasting discussions.

In the case of the GKB, the two ´major´ stakeholders formed a collaborative project team. The municipality of Groningen to represent and facilitate the interests from the local stakeholders and RWS to represent and facilitate national interests. Such a collaborative agreement might have helped resolving part of the institutional fragmentation as in this setting the two ´major´ institutions have to come to an agreement and show unity in workflow and views to the broader public, even though they represent different views.

The institutional interdependency (coupled with functional interrelatedness) is an import factor when collecting customer-requirements (SE). As mentioned in the section above, the functionalities of the context already determine much of the design choices for a project. This is true for any project situated in a complex context, but seems to be especially true for a redevelopment project in a complex context due to the vested interests.

From an SE perspective it is therefor important to realize that this has an effect on the amount of input from stakeholders that can be incorporated in the project. As was already pointed out in the results, professionals find it of great importance that customer-requirement conversations are scoped well in order to prevent discussion about topics that cannot be discussed due to the limited opportunities of a redevelopment project in a complex environment. The problem here is that the scoping of the project is often being done from the perspective of the object: *what functionalities are important to incorporate for the design of this bridge?*

This is a rather deterministic way of exploring how to apply area-oriented planning approaches in infrastructure planning, as the project team determines which functionalities are included, and which are not. This way, planners (but also managers) can decide not to incorporate certain stakeholders for various reasons. However, the fact may still remain that this stakeholder is tightly coupled to the project, almost inevitably resulting in problems later on in the project.

A predetermined project scope in combination with scoped customer-requirement conversations will highly limit both area-oriented planning (Arts et al., 2016), as well as the ability to seize the opportunity of the redevelopment challenge (Willems 2018, Willems et al, 2018 and Willems et al., 2016). It was already pointed out in the results that for some redevelopment projects, the scope cannot always be predetermined beforehand either because the technical state of the existing object is not clear, and because it is hardly possible to determine the entire functional system around an existing system. While at first glance this seems to be a problem for overall project management, it actually can be an opportunity to for area-oriented planning practices, as the project team is not even able to predetermine a fixed scope.

Some professionals also indicated that collecting *concerns* is a better alternative rather than requirements due to the fact that with concerns one can identify the reason behind a requirement. However, to find concerns the conversations with stakeholders will likely need opportunities to speak outside the 'scope' of the conversation, meaning that only changing the word *requirement* to *concern* will most likely not be sufficient to solve all problems. Finding the right balance between scoping and opening customer-requirement conversations is a difficult, but key condition for successful application of SE in redevelopment projects.

5.3 Loosely coupled systems

The loosely coupled systems approach may help system engineers to better understand the context of a complex case. Dubois and Gadde (2002) stated that in complex systems the finding and engaging of loose couplings between the project and its context may help to cope with the complexity of the project. The analysis, combined with the theory from Weick (1976) show that this can only be possible once the scope of a project is not predetermined. However, most (technical) interviewees focus on the fact that for example, customer-requirement conversations should be 'scoped' well enough, or that customers get too much 'freedom'. While this seems to help better structure the project, what it actually does is predetermining the scope of the entire project, resulting in lower amounts of possibilities to engage with loose couplings.

Such a technical view on infrastructure planning can be successful in cases that are less complex. The project team at the PSB was able to successfully decouple the relations (loose couplings) between the object and its context in a predetermined scope without causing disruption to the system as a whole. It confirms the theory that the linear application of SE is very well possible at relatively simple cases (Dubois and Gadde, 2002, Weick, 1976, Meadows, 2008).

Engaging a loose coupling in a complex case is reflected by the GKB and the inclusion of the 'mobility vision' in the context of the bridge. As mentioned before, the inclusion of the mobility vision as part of the context of the bridge made sure that the GKB is redeveloped accordingly to the future plans of the municipality of Groningen, and can thus be used for a more sustainable way of travelling by means of the cycling street that the bridge will serve in the future.

Important to note here is that once the projects 'GKB' and 'mobility vision' are aligned with each other, they can be decoupled from each other and developed separately again. This is also the essence of how Weick (1976) presumes loosely coupled systems work in practice. Loose systems can be coupled and decoupled without major negative consequences for either system.

From a SE perspective it is evident that the project can only move forward when all involved stakeholders are on the same page. For a relatively simple case this is easier to organize than for the complex case, simply because there are less stakeholders. However, important to notice here is that the importance of coordinating moving to a next phase counts for both tight couplings as well as loose couplings. While for tight couplings this seems to be self-evident, the coordination of moving towards the next project phase is just as important for loose couplings.

From a systems theory perspective this seems to be what went wrong when the province tried to realize a new GKB without waiting for the mobility vision to be ready for the next step: confirming that the Korreweg becomes a cycling street. One could therefor even argue that the mobility vision of the city of Groningen should be regarded as a tight coupling, due to its direct influence on the development of the GKB. If the mobility vision is in fact a loose coupling, decoupling should not affect the functioning of the object in the greater system (Weick, 1976). It seems however, that decoupling could have an effect on the functioning of the GKB in the broader system, meaning that it was in fact a tight coupling.

On the other hand one can also argue that when the mobility vision was not included, the GKB would still be a functioning bridge in the broader system, only the design would most likely have been different. From this perspective the mobility vision was a loose coupling that helped broaden the possibilities for the GKB.

However this seems to be a matter of how the project team defines the couplings, but as far as this study goes, this is still up for discussion. Regardless of that the defining of tight and loose couplings in projects might still be a valuable tool for project developers. Accepting the tight couplings may help planners and developers better understand the complexity of the project. Identifying loose couplings can be helpful to increase the possibilities for a project but also requires greater coordination effort between a wider range of stakeholders.

6 Conclusion

That final recommendation brings us to the conclusion of this research in which the answers to the research questions will be presented. It will sum up the most interesting findings and recommendations, but will also point the reader towards follow-up research as well as the limitations of this specific research. A conclusion would not be complete without clear recommendations for the actual practice of SE, but also for the broader planning discipline.

6.1 sub-research questions

1. *In what way can area-oriented planning lead to more integrated planning for redevelopment of ageing water infrastructure?*

This first sub-questions is based on the notion that redevelopment of ageing (water) infrastructure presents the opportunity to rethink the infrastructure's functionality in the broader system and to increase its value for society. It is evident to understand that one on one redevelopment of this infrastructure will not succeed in this, so new ways have to be found to do this. A promising approach to planning is area-oriented planning. The area-oriented planning approach highlights two main factors that need to be taken in to account when trying to actively apply it: Functional Interrelatedness and Institutional Interdependency. Identifying functional interrelatedness is used to find all the functions that directly or indirectly relate to the main project. The identification of these functions is key to successfully identify the institutional interdependencies between a project and the interrelated functionalities. These functionalities are being represented by governments, stakeholders, or other groups which depend on what choices are made for a project. But this is the same the other way around, a project team is dependent on the choices that are being made outside their own project. Again, the GKB and its related mobility vision proves to be a good example.

The area-oriented planning approach is predominantly applied at the development of new infrastructure, but there seem to be additional challenges. The results shows that the functional interrelatedness and institutional interdependencies at redevelopment projects might be more difficult to define as the 'to be redeveloped' object is already part of a vast network of usage, habits, and vested interests. The fact that the object is situated in an existing system might suggest that the interrelations and interdependencies are easily found, but that does not necessarily have to be the case, especially in the more complex cases. It was pointed out in the results that at redevelopment projects, often the scope of the system is being explored throughout the project. This may be regarded as an additional challenge for area-oriented planning at redevelopment projects

2. *What is the role of 'systems theory' in planning for redevelopment of ageing water infrastructure?*

The role of systems theory in the planning of redevelopment projects does not seem be necessarily different from new projects. However, it does help planners to better understand how to define the functional interrelatedness and the institutional interdependencies in projects (which is especially relevant for complex redevelopment projects). The theory shows a differentiation between simple and complex systems. This is elaborated in the theory for example by the differentiation s between tight and loose couplings within a system …or system with its context. Tight couplings are characterized by reciprocal relations between the object and its context, in infrastructure projects tight couplings are often represented by nearby functionalities and their representatives. Loose couplings are characterized by their ability to be added and/or decoupled from the context of your scope without having major negative impacts. In fact, theory has shown that the adaption of the loosely coupled systems theory may help find better solutions for complex projects. The identification of whether certain interrelations or interdependencies are tight or loose can help planner better understand systems.

Simple systems are relatively stable and easy to predict, meaning that the functional interrelations and institutional interdependencies between object and context are easy to define, and hardly show any unexpected and uncertain behavior. The case of the PSB is a clear example of such a system in infrastructure planning. The loose couplings between the stakeholders and project hardly showed unexpected behavior or any uncertainties, making this project relatively easy to develop.

On the other hand, complex systems have uncertainties and show unexpected behavior. The number of tight functional interrelations and institutional interdependencies between a project and its context result in feedback loops between involved stakeholders, resulting in an unpredictable, constantly changing context that influences the system as a whole. As these are tight couplings, they cannot be decoupled from each other in order to structure the system.

The triggering of loose couplings between the projects' system and other systems may help better understand the functioning of the projects' complex system in an even wider context. Which is what we have seen in the case of the GKB and the respective mobility vision. By not predetermining the scope of a project, more options are kept open to activate loose couplings which can result in more area-oriented solutions and designs for projects.

The theories of SE and 'systems theory' in planning seem to not have much in common. While 'systems theory' concerns the functioning of an object in its bigger system, the essence of SE is to engineer the actual object. SE does acknowledge that every object has a context, and that is where these two theories overlap. A good understanding of the context through 'systems theory' can help to engineer an object related to its environment.

3. *How is systems engineering currently being applied in the redevelopment of ageing water infrastructure?*

Based on the interviews and the focus group we can conclude that the actual process of SE at redevelopment does not differ from development of new infrastructure. All of the steps in the SE approach are applicable at redevelopment practices. It was however, pointed out that the content of the steps is different. As said before, due to uncertainty in redevelopment projects, the scope of the project is still to be explored during the process. The same counts for the actual system that has to be engineered. Often, the technical state of an object is unclear, which adds another layer of uncertainty to the redevelopment project.

On top of that, it was often pointed out that from a systems perspective infrastructure projects are to a great extend bound to what is already there. The functionalities around the system that is being (re)developed already limit the possibilities of a certain project. This is especially true for redevelopment projects, as pointed out before, the vested interests and existing functionalities around the object are often very dominant. This has an effect on the customer-requirement phase within the SE approach.

The collection and processing of customer-requirements is one of the key steps in the SE approach. In this step all stakeholders are approached to give their input for the project. These 'customer-requirement' conversations are of official nature, meaning that they (should) have actual influence on the outcome of the project. The redevelopment project however is in an awkward situation when it comes to customer-requirements. Because to what extend can customer-requirements still be collected when the system around the object already pre-determines '90%' of the design choices?

One of the solutions for this is to deliberately not predetermine the scope of the project. This results in possibilities with respect to engaging loose couplings, which may result in more room for discussion on what the object should look like or how it should function.

4. *How can increasing functional interrelatedness and institutional interdependency be included in systems engineering practices?*

So, how can we actually integrate the ideas of area-oriented planning and 'systems theory' in the SE approach? The first step to do this would be to include the identification of the functional interrelations in the SE approach as an actual step to be taken, the second step is to include how to deal with institutional interdependencies. To some extend this is already being done, via steps such as 'beheren scope en projectplan' (managing scope and project plan) and 'analyseren stakeholders' (analyzing stakeholders) (Appendix 6). However, an additional step would be to determine the nature of the interrelation or interdependency: should it be regarded as a tight coupling, a loose coupling, or somewhere in between?

Based on the theory as well as the results from the cases one can argue that at a relatively simple case it is likely that all of the functional interrelations in the context are loosely coupled to the object. Based on the systems theory, the relations between the object and its context should then be relatively easy manageable. From a SE perspective this would mean that for example it is easier to keep track of customer-requirements as they are less likely to change, and if they change, the impact on the other stakeholders is still manageable.

This is different for a complex case. As mentioned before, here the functional interrelations between the object and its context are so extensive that the interaction between them is not manageable. This is due to the amount of feedback loops, the uncertainty, and the unpredictability a complex system typically has. What might be key here is to identify which of the functional interrelations (and thus institutional interdependencies) are of tight nature and of loose nature. This can help better structure the complexity of the project whereas the loose couplings *can* be decoupled from the main project at certain times, which might make the project more comprehensible.

On the other hand, a project team might actively search for loose couplings that can be engaged during a project. As was argued as part of the answer on sub-research question 2, the addition of extra loose couplings can result in more design options which may help deal with the complexity of the project. Another result of this may that the perceived limited possibilities at redevelopment projects can be overcome.

5. *What are barriers, success factors, and conditions for the application of system engineering at infrastructure redevelopment projects?*

Of course, there are barriers, success factors, and conditions for the application of SE in infrastructure redevelopment projects, especially when this is combined with area-oriented projects in complex contexts. One major success factor here is to *know* the context of a project. This seems rather straight forward, and is being done through steps such as a stakeholder analysis. However, the identification of tight and loose couplings can create an even better understanding of the position of a certain stakeholder in a project. The identification of tight couplings can help understand the complexity of the case, and can help better understand the relation *between* the stakeholders, while the identification of loose couplings can help simplify the case through decoupling or create more opportunities for the case by engaging new couplings.

The opposite of this, underestimating the complexity of a project by assuming that one can manage a vast range of stakeholders that are tightly coupled to you project is the main barrier for successful application of SE. The fact that the system that is being engineered only regards the object itself does not mean that SE cannot suffer from such an underestimation, because everything that happens in the contexts determines what the system is going to look like, and the other way around. If the context is unclear or the complexity is underestimated, one could end up with an object which is sub-optimal for all stakeholders.

As mentioned before, not predetermining the scope and actively engaging loose couplings at projects may be beneficial for complex projects, However, this does come with the condition that parties involved in these loose couplings should be committed to each other. From an SE perspective it was pointed out that for a successful SE process, every involved stakeholder should be able to move towards the next step at the same time. This seems logical for the tight couplings, but is just as much true for the loose couplings. The challenge here is that loose couplings may result in less commitment and coordination because in the end, the development of the two systems will be separated again. It adds another layer of complexity to the collaboration between already fragmented institutions, but may also result in more opportunities for institutions to work together and align their approaches and goals.

6.2 Main research question

> *How can systems engineering support area-oriented planning for the redevelopment of ageing water infrastructure in the Netherlands?*

The aim of this research was to explore how SE can be applied at *redevelopment* projects rather than new infrastructure development as well as exploring how SE can be applied in *area-oriented* planning practices. Systems engineering in will not allow, nor does is disallow, area-oriented development for infrastructure redevelopment. It is merely a design tool, developed to structure complicated projects and to make them comprehensible. Once the 'main project choices' (for example functionality in the broader system and main dimensions) are made, SE will very effectively come to an optimal technical design.

It is however the process to come to these 'main project choices' which is of major importance, especially for complex redevelopment projects. The first steps in SE are predominantly focused on the definition of the system and the identification of the stakeholders. This is where proper application of SE can make a difference for redevelopment projects. A project team should not only identify the stakeholders, but should also identify whether they are tightly or loosely coupled to the project and the broader system of stakeholders and their mutual relationships. On top of that, project teams may want to actively search for loose couplings that may help to develop their project while being more aware of the broader system, resulting in more area-oriented development. This can especially be helpful in redevelopment projects due to the perceived limitations at such projects.

This research only considered two cases: simple/new development and complex/redevelopment. For a more complete view a simple/redevelopment case and a complex/new development case should also be explored. On top of that it is good to realize that due to a difference between operators at the cases, differences between approaches are inevitably there. This should be kept in mind when analyzing the differences between the cases.

If we put this into the broader planning perspective such an approach can also be very suitable for any new developments. It also supports the sustainability ambitions that many governments and organizations have. Because area-oriented planning results in plans that are future proof, the risk that these projects become obsolete within a short period of time is much lower. This study also showed that systems theory cannot only help build systems such as bridges or tunnels, but can also help planner better understand the context they are daily working in.

6.3 Recommendations for future research

Next to the recommendation that a case study regarding a new development in a complex context would complement this research, there are other topics that deserve additional attention. To extend knowledge on how to actively apply 'system thinking' in the planning discipline it would be valuable to do research on how and when to define whether couplings are tight or loose. In essence the couplings *are* of a certain nature, but it is still up to the policy makers and project team to find out what they are. A case study on this would most certainly help to better understand how this works in the planning discipline.

On top of that a follow up research may focus on when and how to actively engage loose couplings. Where in the project timeline should planners look for loose couplings that may help solve complex projects? And is this still possible when the project is in a relatively far stage? Once these loose couplings are made or have been identified it can be beneficial to research how to increase commitment between the two projects, as from the theory we know that creating ownership for projects can be quite problematic in a loosely coupled systems approach. The lack of ownership may be related to institutional fragmentation, which is a topic that will become more important once loose couplings between additional projects, and thus stakeholders, are made.

6.4 Recommendations for practice

Systems engineering is a great tool for efficiently building systems such as bridges or tunnels, but is cannot be regarded as a panacea. The effectiveness of the tool is at times dependent on how it is applied in certain situations. If we look at how SE can be applied at for the redevelopment of ageing infrastructure this thesis recommends that in order to create more possibilities rather than one on one replacement project teams should look beyond the direct context of a project.

It would be beneficial for systems engineers not only to understand the specific system that they are designing, but also to understand how the context functions as a 'system', by defining the functional interrelations and institutional interdependencies as well as the nature of their connection towards to main project: tight or loose (or somewhere in between)? Adding such a step to the system engineering approach shows potential, as the systems engineers are already familiar with thinking in systems. Knowing the context of a project is key to engineer a successful system. This is especially true for redevelopment projects because of the vested interests and the perceived limitations of redevelopment. A systems theory view on the context rather than only the object may help overcome these problems.

Actively searching for loose couplings is the next step. On the one hand its logical that at first, the inclusion of additional projects and stakeholder makes projects unnecessarily more complex than they might already be. However, based on this research this can be regarded a misconception. The inclusion of new stakeholders may increase the amount of work in stakeholder management practices, but will create more opportunities in the long run. This way, the system engineer does not only react to a changing context, but he will be able to actively navigate through a changing context. Planners, developers and systems engineers might start thinking about how to create sufficient commitment between the projects, but this is also something which can benefit from more in depth research.

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8 Appendix

Appendix 1: Classification of European inland waterways of international importance

-33-

CLASSIFICATION OF EUROPEAN INLAND WATERWAYS OF INTERNATIONAL IMPORTANCE */

Type of inland waterways	Classes of navigable waterways	Motor vessels and barges — Type of vessel: General characteristics: Designation	Maximum length	Maximum beam	Draught 6/	Tonnage	Pushed convoys — Type of convoy: General characteristics	Length	Beam	Draught 6/	Tonnage	Minimum height under bridges 2/	Graphical symbols on maps
			L(m)	B(m)	d(m)	T(t)		L(m)	B(m)	d(m)	T(t)	H(m)	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
OF INTERNATIONAL IMPORTANCE	IV	Johann Welker	80-85	9.5	2.50	1,000-1,500		85	9.5 5/	2.50-2.80	1,250-1,450	5.25 or 7.00 4/	
	Va	Large Rhine vessels	95-110	11.4	2.50-2.80	1,500-3,000		95-110 1/	11.4	2.50-4.50	1,600-3,000	5.25 or 7.00 or 9.10 4/	
	Vb							172-185 1/	11.4	2.50-4.50	3,200-6,000		
	VIa							95-110 1/	22.8	2.50-4.50	3,200-6,000	7.00 or 9.10 4/	
	VIb	3/	140	15.0	3.90			185-195 1/	22.8	2.50-4.50	6,400-12,000	7.00 or 9.10 4/	
	VIc							270-280 1/ 195-200 1/	22.8 33.0-34.2 1/	2.50-4.50 2.50-4.50	9,600-18,000 9,600-18,000	9.10 4/	
	VII						7/	275-285	33.0-34.2 1/	2.50-4.50	14,500-27,000	9.10 4/	

*/ Classes I - III are not mentioned in this table, being of regional importance.

UNECE (1996

Appendix 2: Minimum heights for bridges based on vessel-classification

<table>
<tr><th>klasse</th><th>hoge variant</th><th>containervaart</th><th>midden variant</th><th>lage variant</th></tr>
<tr><td>I</td><td>5,25</td><td>5,25</td><td>4,75</td><td rowspan="4">0,5 à 1,0 of hoogte van recreatievaart</td></tr>
<tr><td>II</td><td>6,1</td><td>5,6</td><td>5,6</td></tr>
<tr><td>III</td><td>6,6</td><td>6,2</td><td>6,2</td></tr>
<tr><td>IV</td><td>7,0</td><td>7,0</td><td>6,4</td></tr>
<tr><td>V</td><td>9,1</td><td>9,1</td><td>7,4</td><td rowspan="2">niet doen</td></tr>
<tr><td>VI</td><td>9,1</td><td>9,1</td><td>niet doen</td></tr>
</table>

RWS (2020)

Appendix 3: Interview guide

In depth interview Environmental manager

Self-note: Start by introducing myself, the study, and the three themes: functional relations, institutional relations, and systems engineering.

Introduction

1. What is this project about?

2. Why is the redevelopment of "*to be selected object*" necessary?

3. What is your role in the project?

Functional interrelatedness

4. In addition to the waterway and the road, what other functionalities are/were within the project scope?

5. Why were these other functionalities identified?
   a. How were these translated to customer demands?
   b. Were there any functionalities of which its role was unclear?

6. Could you think of functionalities outside the project scope which might be/have been relevant?
   a. If yes, how did you deal with them?
   b. If no, why do you think there weren't any?

7. Next to the redevelopment of the object itself, were there any other projects considered?
   a. If yes, what were they and why were they selected?
   b. If no, why do you think there weren't any?

Institutional interdependency

8. Who were the main stakeholders, and why were they involved?

9. Outside these main stakeholders, were there any minor stakeholders involved?
   a. If yes, who were they and why were they involved?
   b. If no, why do you think there weren't any or why weren't they involved?

10. How were customer requirements acquired, and why did you do it like that?

11. Were there any customer requirements which seemed to be problematic?
    a. If yes, how did you deal with them, and why did you do it in that way?
    b. If no, why do you think there weren't any?

12. Were there any customer requirements that changed during the project process?
    a. If yes, from which stakeholder(s), and what did you do with them?
    b. How did project management respond to it?
    b. If no, why weren't there any?

Systems engineering

13. Are you familiar with systems engineering?
    a. If yes, what was your experience with it?
    b. If no, how did you experience collaboration with technical managers?

Outro

14. Could you point me towards any other important externals, internals, documents, or other relevant persons?

In depth interview project manager

Mezelf introduceren. Functionele relaties, institutionele relaties en systems engineering.

Introduction

10. Waar gaat dit project over?

11. Waarom is de vervanging van de Gerrit Krolbrug nodig?

12. Wat is jouw rol bij dit project??

Functional interrelatedness

13. Naast de vaarweg en weg, zijn er nog andere functionaliteiten die worden meegenomen bij het project?

14. Waarom zijn deze meegenomen?
    c. Hoe is dit vertaald in de klanteneisen?
    d. Waren er functionaliteiten waarvan het onduidelijk/betwijfelend was of je ze mee zou nemen?

15. Zijn er nog functionaliteiten die je achteraf mee had willen nemen?
    a. Zo ja, heb je daar nog wat mee gedaan?
    b. Zo niet, waarom waren die er niet?

16. Naast de vervanging van de Gerrit Krolbrug, zijn er nog andere projecten meegenomen in de projectontwikkeling?
    c. Zo ja, waarom is dit meegenomen?
    d. Zo niet, waarom waren die er niet?

Institutional interdependency

17. Wie waren de belangrijkste stakeholders, en waarom zijn dat de belangrijkste?

18. Naast de belangrijkste stakeholders, zijn er nog stakeholders die minder op het voorgrond aanwezig zijn?
    c. Zo ja, wie zijn dat en waarom zijn de betrokken?
    d. Zo niet, waarom waren ze er niet, of waarom zijn ze niet betrokken?

10. Zijn er klanteneisen die niet te honoreren zijn?
    a. Zo ja, hoe zijn jullie daar mee om gegaan, en waarom hebben jullie dat zo gedaan?
    b. Zo niet, waarom denk je dat ze er niet waren?

11. Zijn er klanteneisen die tijdens het proces zijn veranderd?
    a. Zo ja, vanuit welke stakeholder, en hoe zijn jullie daar mee om gegaan?
    b. Zo niet, waarom denk je dat ze er niet waren?

Systems engineering

12. Ben je bekent met systems engineering?
    a. Wie was de leider wat betreft SE bij de Gerrit Krolbrug
    b. Wat is je ervaring met systems engineering?
    c. Hoe ervaar je de samenwerking met RWS als partner?
    d. What did it add to the project?
    e. Did you experience any shortcomings with regard to SE?

Outro

13. Could you point me towards any other important externals, internals, documents, or other relevant persons?

In depth interview System engineer

Self-note: Start by introducing myself, the study, and the three themes: functional relations, institutional relations, and systems engineering.

Introduction

19. What is this project about?

20. Why is the redevelopment of "*to be selected object*" necessary?

21. What is your role in the project?

Functional interrelatedness

22. In addition to the waterway and the road, what other functionalities are/were within the project scope?

23. Did you have a role in the identification of related functionalities?
    e. If yes, what was your role and why did you do it like that?
    f. Were there any functionalities of which its role was unclear?
    g. If no, why weren't you involved in this?

24. Next to the redevelopment of the object itself, were there any other projects considered?
    e. If yes, what were they and why were they selected?
    f. If no, why do you think there weren't any?

Institutional interdependency

7. What was your role with respect to customer requirements?
    a. Why was that your role?

8. Were there any customer requirements which seemed to be problematic?
    a. If yes, how did you deal with them, and why did you do it in that way?
    b. If no, why do you think there weren't any?

9. Were there any customer requirements that changed during the project process?
    a. If yes, from which stakeholder(s), and what did you do with them?
    b. If no, why weren't there any?

Systems engineering

10. How was systems engineering deployed in this project?
    a. Which SE tools were used in the project?
    b. When in the process were these tools used?
    c. Why were specifically these tools used?
    d. What did SE add to the project process?
    e. Has SE been used to cope with problematic and/or changing customer requirements?
        1. If yes, which tools were used, why were they used and how did this go?
        2. If no, why wasn't SE used for this?

Outro

11. Could you point me towards any other important externals, internals, documents, or other relevant persons?

In depth interview technical manager

Self-note: Start by introducing myself, the study, and the three themes: functional relations, institutional relations, and systems engineering.

Introduction

25. What is this project about?

26. Why is the redevelopment of "*to be selected object"* necessary?

27. What is your role in the project?

Functional interrelatedness

28. In addition to the waterway and the road, what other functionalities are/were within the project scope?

29. Did you have a role in identification of related functionalities?
    a. If yes, what was your role and why did you do it like that?
    b. Were there any functionalities of which its role was unclear
    b. If no, why weren't you involved in this?

30. Next to the redevelopment of the object itself, were there any other projects considered?
    g. If yes, what were they and why were they selected?
    h. If no, why do you think there weren't any?

Institutional interdependency

7. What was your role with respect to customer requirements?
    a. Why was that your role?

8. Were there any customer requirements which seemed to be problematic?
    a. If yes, how did you deal with them, and why did you do it in that way?
    b. If no, why do you think there weren't any?

9. Were there any customer requirements that changed during the project process?
    a. If yes, from which stakeholder(s), and what did you do with them?
    b. If no, why weren't there any?

Systems engineering

10. How was systems engineering deployed in this project?
    a. Why was systems engineering used?
    b. Who was responsible?
    c. At which point in the project has it been used?
    d. What did it add to the project?
    e. Did you experience any shortcomings with regard to SE?

Outro

11. Could you point me towards any other important externals, internals, documents, or other relevant persons?

Appendix 4: Questions focus group

1. De systeem definitie voor VenR opgaven is wezenlijk anders dan bij nieuwe infrastructuur.
2. Ik ben als opdrachtnemer volledig afhankelijk van de systeem definitie van de opdrachtgever.
3. Het is makkelijker om een bestaand systeem te optimaliseren, dan een geheel nieuw systeem te ontwikkelen.
4. Een uitgebreid KES proces gaat ten koste van creativiteit en ‘out of the box’ zoeken naar oplossingen.
5. Een grote hoeveelheid klanteneisen en het kwantificeren hiervan leidt tot een over-simplificatie van je systeem. Bijvoorbeeld het missen van de ‘waarom vraag’ bij een klanteneis.

Appendix 5: Interview agreement form

university of groningen

faculty of spatial sciences

research ethics committe

Agreement to participate - Research Ethics Committee (REC)
in (doctoral) research project:
Title:
Subtitle:

The purpose of the research is (explain in maximum 1 – 2 sentences your research project in lay terms intelligible to a wider audience)

- I have read and I understand the information sheet of this present research project.
- I have had the opportunity to discuss this study. I am satisfied with the answers I have been given.
- I understand that taking part in this study is voluntary and that I have the right to withdraw from the study until the moment that the study has been published, and to decline to answer any individual questions in the study.
- I understand that my participation in this study is confidential. Without my prior consent, no material, which could identify me will be used in any reports generated from this study.
- I understand that this data may also be used in articles, book chapters, published and unpublished work and presentations.
- I understand that all information I provide will be kept confidentially either in a locked facility or as a password protected encrypted file on a password protected computer.

Please circle YES or NO to each of the following:

I consent to my interview being audio-recorded YES / NO

I wish to remain anonymous for this research YES / NO

If YES
My first name can be used for this research YES / NO

OR
A pseudonym of my own choosing can be used in this research YES / NO

"I agree to participate in this individual interview and acknowledge receipt of a copy of this consent form and the research project information sheet."

Signature of participant:_________________________________Date: ______________

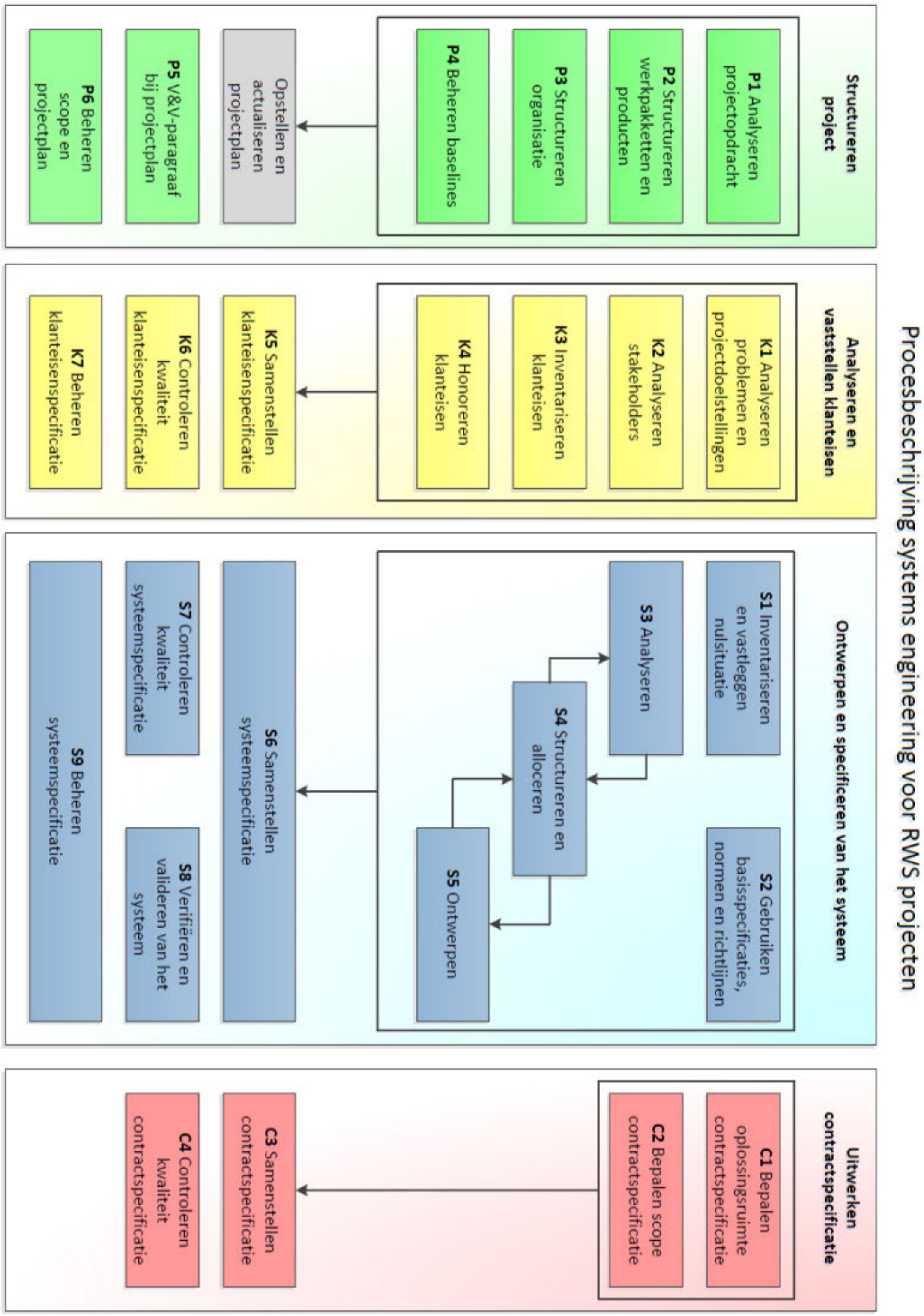
"I agree to abide by the conditions set out in the information sheet and I ensure no harm will be done to any participant during this research."

Signature of researcher:_________________________________Date: ______________

Please fill in the following information. It will only be used in case you want to be sent a copy of interview notes so that you have the opportunity to make corrections.

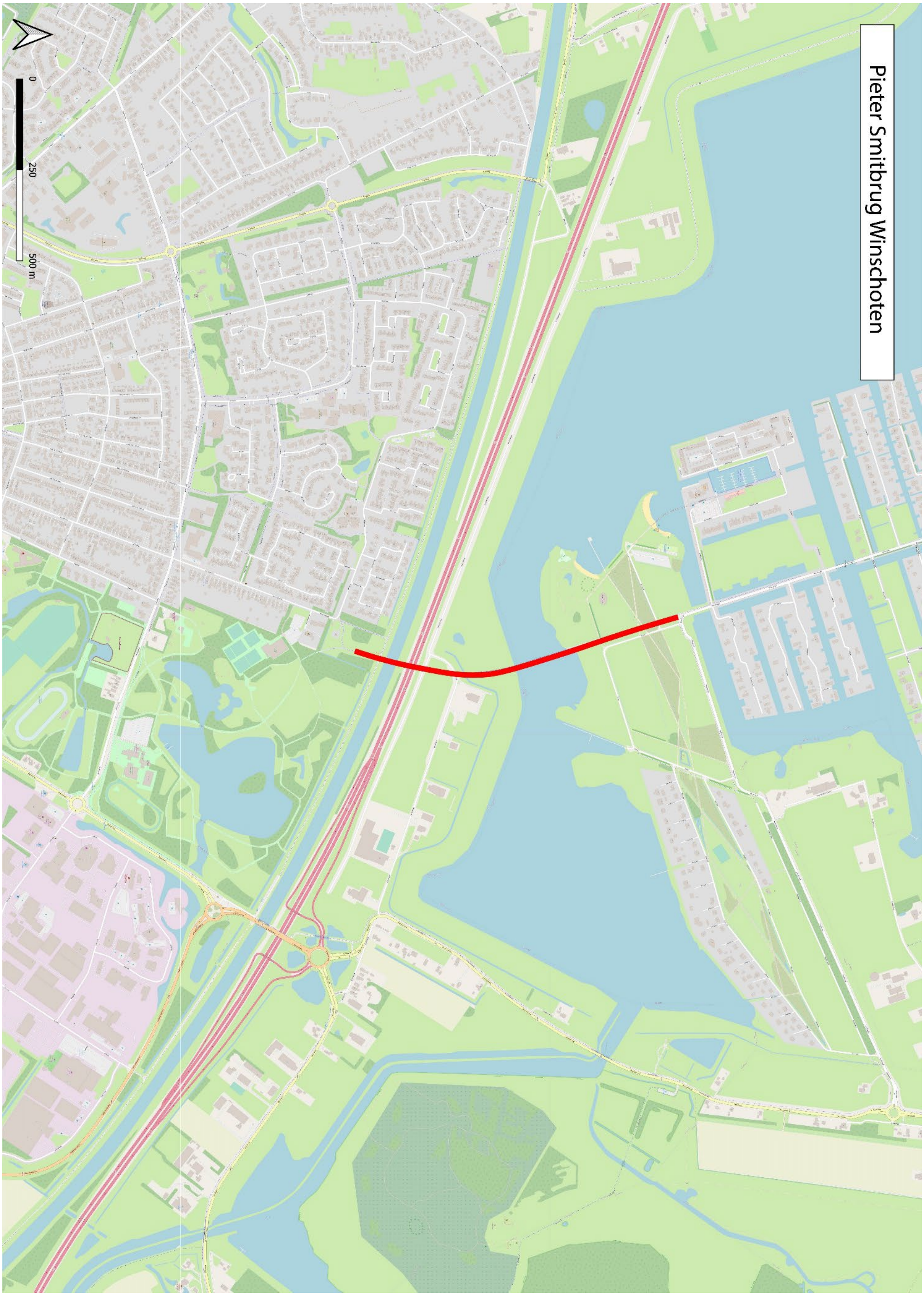
Address:
Email:

Appendix 6: Process description SE by RWS



RWS (2015)

Appendix 7: Map Pieter Smitbrug



Appendix 8: Map Gerrit Krolbrug