Towards design productivity improvement

An explorative research into the enhancement of design processes' productivity

Delft University of Technology
Witteveen+Bos

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PREFACE

This research is my final work as a student of Delft University of Technology and with this thesis I conclude my wonderful 6.5 years in Delft. The graduation journey began approximately eight months ago, when I went to a company day in Eindhoven without any expectations. It seemed to me that after three years of studying a so-called 3TU master, it might be the perfect opportunity to actually visit one of the other universities. During the day, I came to talk to a representative of Witteveen+Bos to whom I told that I wanted to do 'something with process management and/or systems engineering'. Who would have thought that a description this vague would eventually lead to this thesis?

The process of this graduation research has given me so much more than the knowledge that I have obtained while figuring out the most suitable design method that may contribute to enhancement of the design productivity of infrastructure projects. It has also given me the opportunity to get a glimpse of the working life that is ahead of me and this would not be possible without a graduation internship. Therefore, I would firstly like to thank Witteveen+Bos for granting me the opportunity of conducting this research and providing me with all the tools I needed.

Secondly, I would like to thank my entire graduation committee, Hans Bakker, Ruud Binnenkamp Sander van Nederveen, Ernst Molier and Maarten-Kees van Breukelen, for their support and guidance throughout this process and especially for challenging me to narrow down my scope over and over again. Without them this thesis would be nothing more than 'something with process management and/or systems engineering'.

Last, but most certainly not least, I owe much gratitude to all my parents, mom, Rafaël, dad, and Barbara, for being curious and supporting me through this process, my sister Cheyenne for the mental support and helping me choose the right words, and of course my boyfriend Nick for his patience and for supporting me in every way he possibly could.

Sheneequa van Lieshout, March 2018

SUMMARY

The Dutch construction industry is rising again. The economical crisis has had a major impact on the infrastructure sector, as the sector has experienced many cutbacks. Even though the economy is recovering, the consequences of these cutbacks are still present. According to the Economisch Instituut voor de Bouw (2016), the Dutch infrastructure task for the period of 2015-2030 amounts to almost €245 billion.

In response to the major infrastructure task, the Ministers of Economic Affairs, Housing & Public Services, and Infrastructure & Mobility initiated 'De Bouwagenda' late 2016. The aim of De Bouwagenda is to strengthen the construction sector and to offer solutions to the encountered challenges, as it is not feasible to realise the urgent task within the current system. One of the three concrete objectives that result from the initiative is a productivity increase of at least 10% in the construction industry by 2025.

This exploratory research project focuses on improving the design productivity, which can be defined as "the efficiency of the production of a design solution, that is effective to the overall requirements and customer needs". The aim of this research is to discover which (combination of) design method(s) contributes to the enhancement of the design productivity of Dutch infrastructure projects, in order to contribute to the productivity objective of De Bouwagenda at a meta-level. In order to do so, this research identifies the factors that affect the current design process of infrastructure projects, also referred to as *waste*, and explores design methods that address these wastes.

The waste identification consists of several forms of input, being the output derived from literature, earlier conducted research, interviews, and questionnaires. The outcomes of all these different forms of input have resulted in a ranking of top types of waste. After that, several design methods have been explored through a literature study in order to gain insight into possible methods that address these identified top types of waste. Then, the outcomes of both the waste identification and possible design method exploration were merged in a matrix in order to identify and analyse the interfaces between the two. The aim of the matrix is to determine the most suitable design method that addresses the identified top types of waste in the current design process. From this matrix, Systems Engineering (SE) was found to be the theoretically most suitable design method.

In order to analyse the implementation of SE in practice, case studies have been carried out from which it can be concluded that the implementation of SE in practice is not as satisfying as described in theory. This conclusion is drawn based on the fact that several types of waste still occurred even though SE was implemented. This may be due to the fact that SE is not implemented correctly and the implementation should be improved or it may be due to the fact that SE is not as efficient as theory argues and should thus be complemented by (an)other method(s).

Another conclusion that can be drawn from the case studies is that there currently is no uniform way of coping with best practices and lessons learned from previous projects. Therefore, it is recommended that a database containing best practices and lessons learned with regard to the design process is set up. On the one hand, the set-up of the database responds to preventing, mitigating and/or eliminating the insufficient use of existing knowledge, more specifically process-based knowledge. On the other hand, the set-up of the database may also contribute to preventing, mitigating and/or eliminating other types of waste as it provides best practices and lessons learned regarding previous projects, which may include the similar types of waste.

Furthermore, the issues that arise and the wastes that occur in the current design processes of infrastructure projects are not related to technical complexity, which is the main focus of all engineering firms. The complexity within the design process of the infrastructure project is rather related to organisational complexity and environmental complexity. As every engineering company operates in the so-called client-designer-user triangle, they should not solely focus on the technical complexity of a project. In order to enhance the design process and subsequently the design productivity, they should also look into on the organisational and environmental complexity. However, further research needs to be conducted into these complexities and possible methods and/or strategies to deal with the complexities.

So, based on all findings throughout this research, it can be concluded that Systems Engineering is a suitable method to contribute to the enhancement of the design process. However, it should be either complemented with other methods or more aligned with theory in order to be more effective and thus enhance the design productivity, as waste still occurs in projects even though SE is implemented. A valuable and highly recommended addition to SE is the set-up of a process-based database containing best practices and lessons learned from previous projects. The database addresses one of the most important identified types of waste, being insufficient use of existing knowledge. Besides, it also contributes to mitigating other important types of wastes as the database provides for insight into efficient ways, methods, strategies and tools to deal with types of waste, based on learning experiences from previously completed projects.

Although it cannot be quantitatively concluded that SE contributes to the enhancement of the design productivity in practice and to what extent, valuable recommendations have been provided in order to take the first step into enhancing the design productivity. Moreover, valuable lessons have been obtained from this research that result in recommendations for further research. Besides, through this research a list has been established of the identified types of waste, which can be seen as a contribution to bridging the knowledge gap with regard to improving the design productivity.

SAMENVATTING

De Nederlandse bouwsector trekt weer aan! De economische crisis heeft voor veel bezuinigingen in de infrastructuursector gezorgd, met grote gevolgen van dien. Hoewel de economie herstellende is, zijn de gevolgen van deze bezuinigingen nog steeds duidelijk voelbaar. Volgens het Economisch Instituut voor de Bouw (2016) heeft de Nederlandse infrastructuuropgave voor de periode 2015-2030 een omvang van bijna €245 miljard.

Als respons op de enorme infrastructuuropgave hebben de ministers van Economische Zaken, Volkshuisvesting en Openbare Diensten en Infrastructuur & Mobiliteit eind 2016 'De Bouwagenda' geïnitieerd. Het doel van De Bouwagenda is het versterken van de bouwsector en het bieden van oplossingen voor de actuele uitdagingen, omdat het niet haalbaar is om de urgente opgave binnen het huidige systeem te realiseren. Eén van de drie concrete doelstellingen van dit initiatief is een productiviteitsstijging van minstens 10% in de bouwsector in 2025.

Dit exploratieve onderzoek is gericht op het verbeteren van de ontwerpproductiviteit, die gedefinieerd kan worden als "de efficiëntie van de productie van ontwerpoplossingen, die effectief is voor alle eisen en behoeften van de klant". Het doel van dit onderzoek is om te achterhalen welke (combinatie van) ontwerpmethode(n) een bijdrage kan leveren aan de verbetering van de ontwerpproductiviteit van Nederlandse infrastructuurprojecten, om zo bij te dragen aan de productiviteitsdoelstelling van De Bouwagenda op een meta-niveau. Om dit doel te bereiken worden factoren die van negatieve invloed zijn op het huidige ontwerpproces van infrastructuurprojecten, ook wel *verspillingen* genoemd, geïdentificeerd en worden verschillende ontwerpmethoden onderzocht die gericht zijn op het aanpakken van deze verspillingen.

De identificatie van de verspillingen heeft verschillende vormen van input, namelijk resultaten van literatuuronderzoek, eerder uitgevoerd onderzoek, interviews en questionnaires. De bevindingen van al deze verschillende vormen van input hebben gezamenlijk geresulteerd in een ranking van de belangrijkste soort verspillingen. Na de identificatie van de verspillingen zijn de verschillende ontwerpmethoden onderzocht door middel van een literatuuronderzoek, om zo inzicht te krijgen in de mogelijke methoden om de geïdentificeerde top verspillingen aan te pakken. Vervolgens zijn de resultaten van zowel de verspilling identificatie als het onderzoek naar mogelijke ontwerpmethoden samengevoegd in een matrix. Met behulp van deze matrix zijn de raakvlakken tussen beiden geïdentificeerd en geanalyseerd. Het doel van de matrix is om op basis van de raakvlakken de meest geschikte ontwerpmethode te bepalen. Uit de matrix is uiteindelijk gebleken dat Systems Engineering (SE) de theoretisch meest geschikte ontwerpmethode is.

Om de implementatie van SE in de praktijk te kunnen analyseren zijn er verschillende *case-studies* uitgevoerd, waaruit geconcludeerd kan worden dat de implementatie van SE in de praktijk niet zo bevredigend is als staat beschreven in de theorie. Deze conclusie is gebaseerd op het feit dat er nog steeds verschillende soorten verspillingen aanwezig zijn in het ontwerpproces, ondanks het feit dat SE werd geïmplementeerd. Dit kan te wijten zijn aan het feit dat SE niet correct geïmplementeerd is en dus verbeterd moet worden of het kan te wijten zijn aan het feit dat SE niet zo efficiënt is als de theorie suggereert. In geval van het laatste zal de SE methode in de praktijk aangevuld moeten worden met (een) andere methode(n).

Daarnaast kan uit de *case-studies* de conclusie getrokken worden dat er momenteel geen uniforme manier is om de *best practices* en *lessons learned* van eerder voltooide projecten te verwerken. Daarom beveelt dit onderzoek aan om een database op te zetten waarin *best practices* en *lessons learned* met betrekking op het ontwerpproces te achterhalen zijn. Enerzijds speelt het opzetten van een database in op het voorkomen, verminderen en/of elimineren van het

onvoldoende gebruik van bestaande kennis, waarbij specifiek procesmatige kennis wordt bedoeld. Anderzijds kan het opzetten van een database ook bijdragen aan het voorkomen, verminderen en/of elimineren van andere soorten verspillingen, aangezien de database *best practices* en *lessons learned* met betrekking tot eerder voltooide projecten bevat, waaronder mogelijk vergelijkbare soorten verspillingen.

Bovendien hebben de problemen die zich voordoen en verspillingen die optreden in het huidige ontwerpproces van infrastructuurprojecten weinig tot geen relatie met technische complexiteit, wat juist het belangrijkste aspect is waar ingenieursbureaus zich op focussen. De complexiteit binnen het ontwerpproces van infrastructuurprojecten hangt eerder samen met de organisatorische complexiteit en de omgevingscomplexiteit. Gezien het feit dat elk ingenieursbureau zich in de zogenaamde klant-ontwerper-gebruiker driehoek beweegt, is het van belang dat de ingenieursbureaus zich niet alleen op de technische complexiteit richten. Om het ontwerpproces en daarmee de ontwerpproductiviteit te verbeteren, is het van belang dat er ook er ook gekeken wordt naar de complexiteit van de organisatie en de omgeving. Daarom moet er nader onderzoek worden verricht naar deze vormen van complexiteit en de mogelijke methoden en/of strategieën om met deze vormen van complexiteit om te gaan.

Op basis van alle bevindingen in dit onderzoek kan worden geconcludeerd dat SE een geschikte methode is om een bijdrage te leveren aan de verbetering van het ontwerpproces. Echter, deze methode moet worden aangevuld met andere methoden of beter worden afgestemd met de theorie om effectiever te kunnen worden geïmplementeerd in de praktijk en dus daadwerkelijk de ontwerpproductiviteit te verbeteren. Dit is gebaseerd op het feit dat er nog steeds verspillingen te ontdekken zijn in projecten waar SE reeds is geïmplementeerd. Een waardevolle en sterk aanbevolen toevoeging aan de SE methode is de opzet van een op het proces gefocuste database die *best practices* en *lessons learned* uit eerder voltooide projecten bevat. Deze database wordt continu bijgewerkt, omdat alle maatregelen gemonitord, geëvalueerd en gedocumenteerd moeten worden, zodat de meest effectieve maatregelen in de database worden opgenomen. De database richt zich enerzijds op één van de belangrijkste geïdentificeerde soort verspilling, omdat er momenteel onvoldoende gebruikt wordt gemaakt van bestaande kennis met betrekking tot het proces. Daarnaast draagt de database ook bij aan het verminderen van andere belangrijke verspillingen, aangezien de database inzicht verschaft in methoden, strategieën en hulpmiddelen die op basis van ervaring uit eerder voltooide projecten effectief zijn gebleken.

Er zijn twee specifieke aanbevelingen gedaan over hoe SE kan worden aangevuld met andere methoden. De aanname management methode van Turbit (2005) wordt als waardevol ervaren met betrekking tot het werken met de verkeerde aannames en de Last Planner Methode, die deel uitmaakt van de Lean filosofie, wordt als waardevol ervaren met betrekking tot het gebrek aan afstemming tussen disciplines. De effectiviteit van deze methoden is echter nog niet bewezen. Daarom moet, indien toegepast, de effectiviteit worden gemonitord, geëvalueerd en gedocumenteerd worden om zo te kunnen bepalen of de geïmplementeerde methoden de meest effectieve methoden zijn met betrekking tot de bijbehorende type verspillingen.

Hoewel dit onderzoek niet kwantitatief kan concluderen dat SE bijdraagt aan de verbetering van de ontwerpproductiviteit in de praktijk en in welke mate, bevat dit onderzoek wel waardevolle aanbevelingen die de eerste stap zetten in het verbeteren van de ontwerpproductiviteit. Bovendien zijn er waardevolle lessen verkregen uit dit onderzoek die resulteren in aanbevelingen voor nader onderzoek. Daarnaast is door middel van dit onderzoek een lijst opgesteld van geïdentificeerde soorten verspillingen, wat gezien kan worden als een bijdrage in het overbruggen van de huidige kenniskloof met betrekking tot het verbeteren van de ontwerpproductiviteit.

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LIST OF ABBREVIATIONS

APN	Assumption Priority Number
BAM	Beheersmaatschappij Antwerpen Mobiel
BVP	Best Value Procurement
CAD	Computer Aided Design
CE	Concurrent Engineering
CFT	Cross Functional Team
cIPO	concept Integraal Plan Ontwerp
CQT	Central Quality Team
CRS	Customer Requirements Specification
DO	Definitief Ontwerp
DSM	Daily Standup Meeting
IDA	Institute of Defence Analysis
IM	Infrastructure and Mobility
INCOSE	International Council on Systems Engineering
IPO	Integraal Plan Ontwerp
LPM	Last Planner Method
LP	Lean Planning
NCOSE	National Council on Systems Engineering
OD	Open Design
PD	Parametric Design
PPC	Percent Plan Complete
PVA	Plan Van Aanpak
QCM	Quality-oriented Construction Management
RGO	Risico Gestuurd Ontwerp
RIP	Rijksinpassingsplan
RPN	Risk Priority Number
RWS	Rijkswaterstaat
SAA	Schiphol-Amsterdam-Almere
SE	Systems Engineering
SO	Schets Ontwerp
TB	Tracé Besluit
TFV	Transformation Flow and Value
TMO	Temporary Multi-Organisation
TPS	Toyota Production System
UAV-GC	Uniforme Administratieve Voorwaarden - Geïntegreerde Contractvormen
UO	Uitvoerings Ontwerp
VO	Voorlopig Ontwerp
VPI	Verifiable Performance Indicator
VTW	Verzoek Tot Wijziging
V&V	Verification & Validation
WSM	Weekly Standup Meeting

PART I. INTRODUCTION

1 INTRODUCTION

This chapter gives an introduction into the conducted research. First, an introduction regarding the subject is provided. Then, the problem will be analysed, which results in a problem definition at meta-level. After that, the scope demarcation will be discussed, which is followed by the research objective. Lastly, the structure of the report will be explained.

1.1 Introduction to the subject

According to research from the Economisch Instituut voor de Bouw (2016), the Dutch infrastructure task for the period of 2015-2030 amounts to almost €245 billion. This is amongst others caused by the economic recovery, which increases the pressure on the infrastructure. In addition, economic recovery also leads to higher social and individual requirements in the field of infrastructure. Next to the economic recovery, The Netherlands has to deal with urbanisation. Urbanisation is a highly comprehensive and complex challenge, which ensures an increase in pressure on the available space and existing infrastructure works in the cities at a high pace. The combination of urbanisation and economic growth leads to an increasing demand for mobility and, consequently, a growing need for good infrastructure. Moreover, it must be taken into account that the infrastructural tasks are more and more combined with other tasks in order to achieve sustainability, circularity, and security goals. These challenges lead to an even more complex infrastructure task (Economisch Instituut voor de Bouw, 2016; Taskforce Bouwagenda, 2017).

In response to the above, the Ministers of Economic Affairs, Housing & Public Services and Infrastructure & Environment took the initiative for 'De Bouwagenda' late 2016. De Bouwagenda aims to strengthen the construction sector and to offer solutions to the encountered challenges, as it is not feasible to realise the urgent task within the current system. The initiative has resulted in the following three concrete objectives:

- to come to an energy-neutral built environment in 2050; and 100% energy neutral new housing and utility buildings from 2020;
- 50% less use of primary raw materials in construction in 2030; by 2050 the sector must be completely circular;
- at least 10% increase in productivity in the construction industry by 2025.

1.2 Problem definition

In view of the urgency of the challenges and the concrete objective of at least 10% increase in productivity in the construction industry it is really important that the process of making the construction industry future-proof starts immediately. Especially when it is taken into account that the construction industry has an investment cycle of decades. Generally speaking, the construction industry is characterised by fragmentation and inefficiency, which in itself is not contributing to a more productive industry. Therefore, in order to achieve more productivity within the construction industry, a different way of thinking is required (Taskforce Bouwagenda, 2017).

Furthermore, the civil engineering sector in the Netherlands previously was a regionally oriented market. However, over the last few decades a lot of developments have been taking place, which led to the shift from a regionally oriented market into a dynamic and global oriented market. This shift amongst others occurred due to the withdrawing of the Dutch government and the development of legislation on transparency. Nowadays, the Dutch government is allocating more and more to the market and instead of actively participating in the project their role has shifted to a more process-oriented nature. This shift consequently entails that other shifts are also urged to take place. For example, the roles of the involved parties need to change as well as the relationship between the client and the contractor. Nevertheless, these urged shifts also create opportunities for the involved parties to provide their own input, which can in their turn increase both the efficiency and effectiveness of the project (ONRI, 2005).

Even though De Bouwagenda clearly states that the productivity of the civil engineering sector has to increase, no specific measures are prescribed to achieve the productivity objective while also bearing the corresponding shifts in mind. At a meta-level, the following problem statement is assumed:

'In order to comply with the productivity objective of De Bouwagenda, a (combination of) suitable method(s) has to be implemented that addresses the developments within the construction industry.'

1.3 Scope definition

The scope of this research is demarcated by three main aspects, being the type of company, the type of project and the project phase (see Figure 1.1). The following subsections will elaborate on the three aspects that define this research's scope.

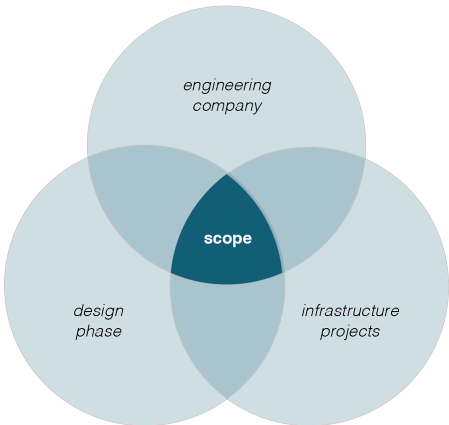

Figure 1.1 I Scope definition (own illustration)

Type of company

This graduation research is aimed at providing an advice for Dutch engineering firms. Therefore, the research is carried out at a Dutch engineering firm, being Witteveen+Bos. An increase in productivity for an engineering firm will lead to the possibility of executing more projects in the same amount of time and consequently improving the status of the firm and earning revenues sooner.

Witteveen+Bos was founded in 1946 by the engineers W.G. Witteveen and G.S. Bos. Currently, Witteveen+Bos is one of the larger and leading engineering companies in The Netherlands, with over 1000 employees and offices in 11 countries throughout the world. Witteveen+Bos delivers consulting and engineering services for the design of water, infrastructure, environment, and construction projects. The employees are clustered in 26 Product Market Combinations (PMCs), each focusing on a specific market segment. All 26 PMCs belong to one of the four sectors, also referred to as business lines, being Built Environment, Deltas, Coasts and Rivers, Energy, Water and Environment, and Infrastructure and Mobility (IM) (Witteveen+Bos, 2016a, 2016c, 2017d). An organisational chart of Witteveen+Bos can be found in Appendix A.1.

The major advantage of carrying out the graduation research within a company is the opportunity of gaining knowledge from practice. Simultaneously, a consequence may be that the conclusions and recommendations are focussed on the company specific even though this research aims to provide recommendations that can be applied in any engineering company within the Netherlands. However, Witteveen+Bos is assumed to be a representative company for every other engineering company in the branch. This assumption is based on the designer-client-user triangle in which the engineering company takes part when carrying out projects (see Chapter 3 for further elaboration on the triangle). As other engineering companies have the same clients and users and thus take part in the same triangle, they also have to deal with the same context and the same kind of projects as Witteveen+Bos. Therefore, the outcomes of this research are assumed to be applicable to any engineering company in The Netherlands.

Type of project

Based on the urgency stated in De Bouwagenda, which has been published early 2017, the type of project to focus on during this research is chosen. As stated, an enormous infrastructure task is to be fulfilled in the next 15 years and the perception of the government is that this will not be feasible with the current methods and systems within the construction industry. Therefore, a solution has to be found in order to comply with the infrastructure task of the coming years. As the research is carried out within the company of Witteveen+Bos, the research topic regarding the infrastructure task belongs to the Infrastructure and Mobility sector within Witteveen+Bos.

Project phase

The productivity of infrastructure projects can be increased throughout the whole lifecycle of the project. However, this research will focus on the design phase of infrastructure projects only (see Figure 1.2). Not many studies regarding design productivity were found. So, by carrying out this explorative research, a first step into closing this knowledge gap is taken which will hopefully lead to more in depth research in the nearby future. Moreover, the choice for the design process also arises from my interest in design and the knowledge that I have gained during my studies, namely the Bachelor of Architecture.

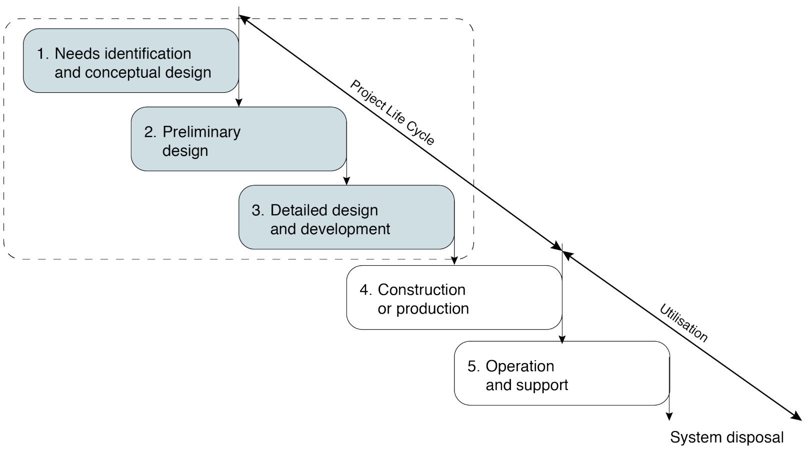

Figure 1.2 | Scope demarcation in the Project Life Cycle of a construction project (Nicholas & Steyn, 2012)

1.4 Research objective

At a meta-level, the research objective is to advice on how to enhance the productivity of the Dutch construction industry in order to comply with the productivity objective of De Bouwagenda. By taking the scope demarcation of this research is into account, the research objective of this research is to provide an advice to Dutch engineering companies on how to enhance the design productivity of infrastructure projects. This research will be of exploratory nature, as there is little information available regarding productivity of the design process; this research will therefore also be a first step into closing the existing knowledge gap. The purpose of this research is to identify the factors that lead to a lack of productivity in the design phase of infrastructure projects, determine which of these factors are the most influential and which (combination of) method(s) addresses these factors and thus provides possibilities for improving the design productivity of infrastructure projects.

This graduation research is aimed at:

'Identifying the factors that affect the design productivity of Dutch infrastructure projects and exploring the (combination of) possible method(s) that address these factors, so that the conclusions will provide an advice on how the implementation of the found (combination of) method(s) might contribute to enhancing the design productivity of Dutch infrastructure projects.'

1.5 Structure of the report

This graduation report is subdivided into six parts and consists of 14 chapters in total. Figure 1.3 illustrates the structure of the report and shows which chapters can be found in each part.

PART I. INTRODUCTION	1 Introduction 2 Research methodology
PART II. BASELINE	3 Design process 4 Design productivity 5 Lean principles
PART III. RESEARCH	6 Waste identification 7 Design method exploration 8 Most suitable design method
PART IV. CASE STUDIES	9 Case study sessions
PART V. ADVICE	10 Proposed recommendations 11 Validation 12 Final recommendations
PART VI. CONCLUSIONS & DISCUSSION	13 Conclusions 14 Discussion
BIBLIOGRAPHY	

Figure 1.3 I Report structure (own illustration)

2 RESEARCH METHODOLOGY

The aim of this chapter is to provide insight in the methodology of the conducted research. The first section, section 2.1, describes the general research set-up. Then, the corresponding research questions will be presented in section 2.2, followed by the detailed research design in section 2.3. Lastly, section 2.4 will elaborate on the research methods that are used.

2.1 General research set-up

The objective of this exploratory research is to advise on possible enhancement of the design productivity of Dutch infrastructure projects, by identifying factors affecting the current design process, exploring possible methods that address these factors and advising on the implementation of a (combination of) design method(s). In order to be able to provide such an advice, a few steps have to be taken and this is illustrated by the general research set up in Figure 2.1.

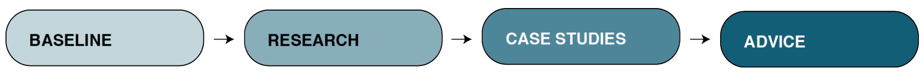

Figure 2.1 I General research set-up (own illustration)

First of all, a **baseline** has been provided in order to provide insight into the main topics of this research. After the baseline has been established, the research can begin. The **research** part aims to find the theoretically most suitable design method for the top types of waste that occur in the current design process. The design method that turns out to be the most suitable design method will then be analysed in practice through **case studies**. Based on the outcomes of the case studies, an **advice** will be formulated with regard to implementation of the proposed design method in order to enhance the design productivity.

2.2 Research questions

In order to be able to provide the abovementioned advice, the following main research question is established:

"Which (combination of) design method(s) contributes to the enhancement of the design productivity of Dutch infrastructure projects?"

In order to structure the research and to give a well-grounded answer to the main research question, the following sub-questions are formulated:

1. What is design productivity?
2. What is the current design process of infrastructure projects?
3. Which factors affect the design productivity of the current design process?
4. Which design methods address the main factors that contribute to the lack of design productivity in infrastructure projects?

2.3 Research design

This research entails an exploratory, empirical research, which leads to qualitative results. The main advantage of an exploratory research is its flexibility and adaptability to change, but this also brings along the risk of losing focus on the actual research subject and objective (Saunders, Lewis, & Thornhill, 2009). By setting a clear goal and adjusting the research methodology and the research design throughout the research accordingly, the risk of losing focus is attempted to be reduced. As already stated and illustrated in section 2.1, the goal of this research is to provide an advice with regard to the possible enhancement of the design productivity of infrastructure projects. In order to achieve this goal, the research design that is illustrated in Figure 2.2 will be followed.

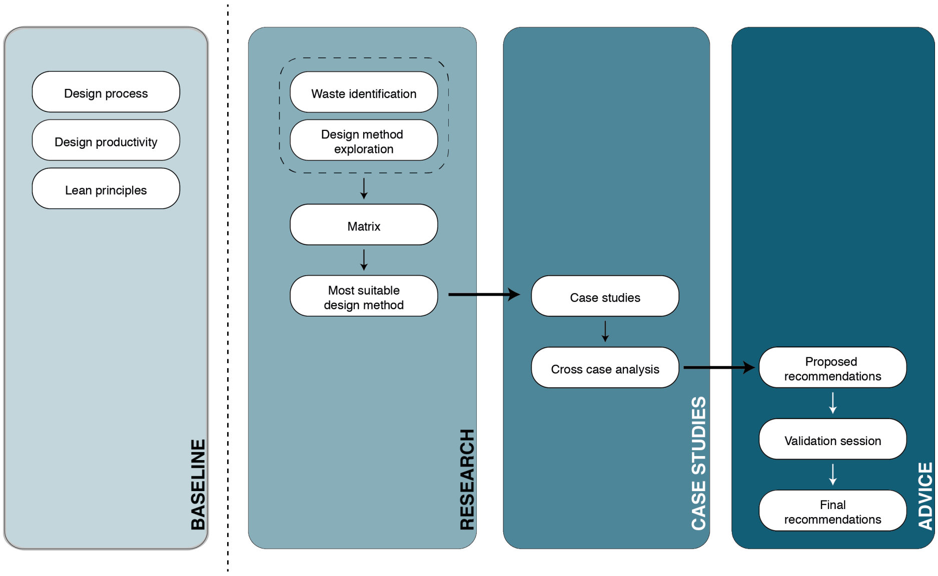

Figure 2.2 I Research design (own illustration)

As depicted in Figure 2.2, the research starts with providing a baseline of which the objective is to provide insight into the main topics of this research. In order to do so, the **design process** (chapter 3) will be discussed first, followed by the **design productivity** (chapter 4). After that, the **Lean principles** (chapter 5) will be introduced.

Now that the baseline has been established, the research part can be carried out. The objective of the research part is determining the theoretically most suitable design method. Therefore, the **top types of waste** (chapter 6) in the current design process need to be identified. After the waste identification, the **possible design methods** (chapter 7) can be explored. The findings of both the waste identification and the design method exploration will serve as input for the **matrix** (chapter 8), so that the interfaces can be analysed. The analysis of the interfaces will result in a prevailing design method, which is then determined as the **most suitable design method** (chapter 8) with regard to addressing the identified waste.

As the determination of the most suitable design method is based on theory, **case studies** (chapter 9) will be carried out to analyse the implementation of the design method in practice. The outcomes of the case studies will serve as input for the final advice.

In order to provide a feasible advice, **recommendations** will be proposed (chapter 10) which will then be validated (chapter 11). After validating the proposed recommendations, the results from the **validation** (chapter 12) will be processed and taken into account while providing the **final recommendations** (chapter 13).

2.4 Research methods

In this section, the various research methods that have been applied during the research will be discussed briefly.

Literature study

The main purpose of the literature study is to gain insight into a specific topic. During this research, literature studies are carried out multiple times to gain knowledge on the design process (chapter 3), the design productivity (chapter 4), Lean principles (chapter 5), waste in the design process (chapter 6), and the exploration of possible design methods (chapter 7).

Semi-structured interviews

According to Saunders et al. (2009), semi-structured interviews are often referred to as 'qualitative research interviews'. In these interviews, the researched will have a list of themes and questions to be covered, although these may vary from interview to interview. This means that you may omit some questions in particular interviews and the order of questions may also be varied. This method thus ensures flexibility of the conversation during the interview and allows for the interviewee to freely decide on which information is provided. In this research, the semi-structured interviews were gather professionals' perspectives on the current design process (chapter 3), the definition of design productivity (chapter 4), and the types of waste that occur in the current design process (chapter 6).

Questionnaire

According to de Vaus (2002), a questionnaire is a technique of data collection in which each person is asked to respond the same set of questions in a predetermined order. The questionnaire is one of the most widely used data collection techniques within the survey strategy. Because each person (respondent) is asked to respond to the same set of questions, it provides an efficient way of collecting responses from a large sample prior to quantitative analysis (Saunders et al., 2009). In this research, the questionnaire was used to determine the top types of waste in the current design process (chapter 6).

Focus group

A focus group is used to refer to those group interviews where the topic is defined clearly and there is a focus on enabling an interactive discussion between participants (Carson, Gilmore, Perry, & Grønhaug, 2001). The participants of the focus group are selected based on common characteristics that relate to the topic being discussed and they are encouraged to discuss and share their point of view without any pressure to reach consensus (Krueger & Casey, 2000). The discussions are conducted several times, with similar participants, in order to identify similarities and patterns when the data collected are analysed (Saunders et al., 2009). In this research, focus groups were used for the case study analyses (chapter 9) in order to gain insight to the implementation of the most suitable method in practice.

Validation panel

In this research, the validation panel was used in order to validate the proposed recommendations (chapter 11) with regard to the feasibility of the proposed recommendations and the willingness of the employees to implement the proposed recommendations. The use of the validation panel is similar to the use of the focus group.

PART III. BASELINE

3 THE DESIGN PROCESS

People have been designing things for as long as we can remember or archaeologically uncover. Given the long history of people designing artefacts, it is useful to establish what the engineering design process looks like. This chapter will present the outcomes of a literature study on engineering design, which consists of two sections. The aim of the literature study is to gain an understanding of one of the main topics of the research. First section 3.1 will provide a definition and common elements of engineering design. After engineering design is defined, section 3.2 will explore design as an activity. Then, the results of the analysis of the design process in practice will be presented in order to gain insight into how the design process is carried out in practice.

3.1 Defining engineering design

In order to explore the engineering design process, it is important to have a clear understanding of engineering design. According to Dym and Little (2004), engineering design can be defined as follows:

> *"The organised, thoughtful development and testing of characteristics of new objects that have a particular configuration or perform some desired function(s) that achieve the stated objectives and satisfy the specified constraints"*

It also has to be noted that engineering problems are rather hard, as their solutions cannot normally be found by applying mathematical formulas or algorithms in a routine or structured way. Moreover, engineering design problems are open-ended because they usually have several acceptable solutions. Designers often reduce the number of possible design solutions beforehand, as they are overwhelmed by the possibilities otherwise.

Due to the complexity of engineering design problems as well as the fact that engineering can be found in a broad field, it is worth looking into any common elements in the engineers' situations or in the ways that they approach their tasks. The existence of such commonalities makes it possible to describe the design process and the context in which it occurs (Dym & Little, 2004).

Firstly, every engineering design project contains the designer-client-user triangle. In this triangle, the designer needs to understand what the client wants, but the client also has to understand what the users need and communicate that to the designer. These three different roles within engineering design can be identified as follows:

1. the **designer** - the person must develop specifications such that something can be built to satisfy parties involved to a certain extent
2. the **client** - the person or group or company that want a design conceived
3. the **user** - the person who will actually use the artefact being designed

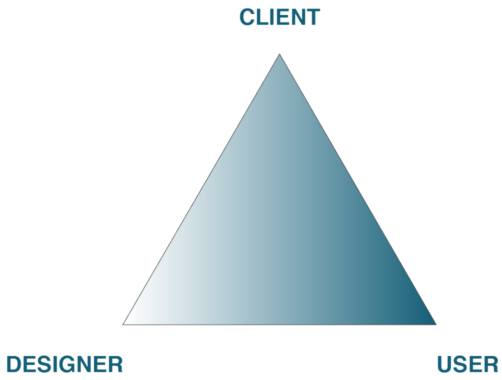

Figure 3.1 I Designer-client-user triangle (Dym & Little, 2004)

Another aspect of the engineering design process is the use of teams in order to be able to carry out the design. This is more and more common in projects and firms of all sizes and mainly due to the multidisciplinary nature of many engineering problems nowadays. Because of this multidisciplinary nature, there is a need to understand the requirements of clients, users, and technologies in very different environments. This, in turn, requires the assembling of teams that can address such different sets of environmental needs.

3.2 Design as an activity

The progress of a project from the initial idea to an engineering artefact may be depicted by a process such as shown in Figure 3.2. This is a five-stage prescriptive model of the design process that defines what is done in each stage by incorporating ten design tasks. Each phase requires an input, has design tasks that must be performed, and produces an output or product. Note that the output of each stage serves as the input to the following stage.

An engineering design project typically starts with a verbal statement and ends when the final design is documented for the client. The verbal statement states the desired features of function, form, intent or legal requirement, which is also known as the client statement. This often short, verbal statement suggests that the designer's first task is to clarify what the client really wants and translate it into a form that is useful for the engineering designer. Furthermore, large and complex projects often lead to very different interpretations of client statements and user needs. Designers thus have much to do when clarifying what a client wants and translating those wants into an engineered artefact. The five steps between the client statement and the final design are as follows:

1. During the **problem definition** the client's objectives are clarified and the information that is needed to develop an engineering statement of the client's wants is gathered
2. In the **conceptual design** phase, concepts or schemes of candidate designs are generated
3. In the **preliminary design** phase, the principal attributes of the design concepts or schemes are identified
4. During the **detailed design** phase, the final design is refined and elaborated in more detail
5. In the **design communication** phase, the specifications and the corresponding justification are documented

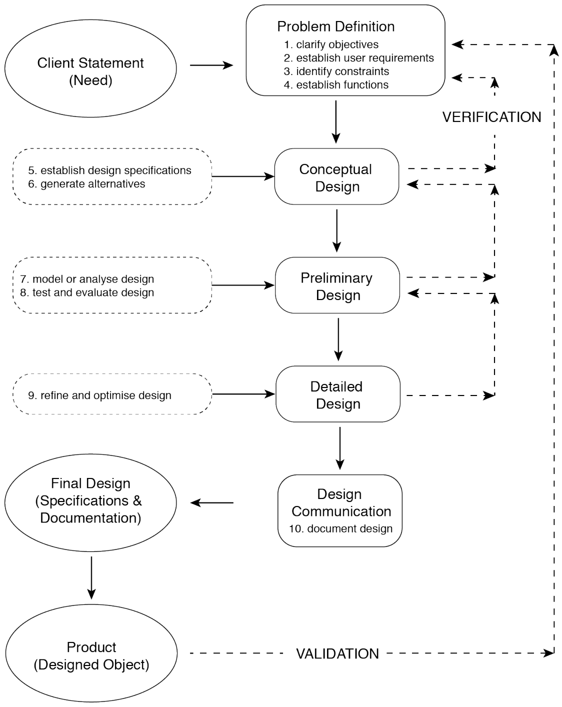

Figure 3.2 I A five-stage prescriptive model of the design process (Dym & Little, 2004)

As can be seen from Figure 3.2, the design process is presented as a linear process. However, designing is an iterative process in which each iteration is aimed at increasing the level of information in order to improve the decision-making. Iterations occur when a common method or technique is applied repeatedly at different points in a design process, although the repeated applications occur at a different level of abstraction or on a different scale. In the five-stage model, the iterations occur in the conceptual, preliminary, and detailed design. The iteration involves repeating the first four tasks in some form.

Besides, Figure 3.2 also entails verification and validation arrows. These arrows represent two types of feedback, which entails feeding information back into the process regarding the output of the process with the aim of obtaining better results. The first type of feedback is an internal loop, in which the results of performing the test and evaluation tasks are fed back into the previous design phase(s) in order to verify that the design performs as intended. The second type of feedback is an external loop, which occurs after the final product resulting from a design has been used in the market for which it was intended. User feedback then provides validation for the design.

3.3 The design process in practice

Within Witteveen+Bos, the Integral Design Approach has been established and implemented. Appendix X elaborates further on this approach. In order to gain insight in the implementation of this design approach, several semi-structured interviews have been conducted in which the interviewees were asked about the different steps of the design process (see Appendix B.1 for a complete overview). The output of the interviews is compared to one another to find recurring steps and to finally be able to map the general design process that is used within Witteveen+Bos.

Reference projects

A total of four reference projects are taken into account during the interviews, which are all large infrastructure projects in which Witteveen+Bos was involved in the plan study phase of the design phase. A concise introduction to each project will be provided first, in order to make the outcomes of the interviews more understandable.

Afsluitdijk - The 80-year-old Afsluitdijk, which is a 32-kilometer long flood defence, turned out to be performing insufficiently and thus needed measures to secure the hinterland in the long term (Witteveen+Bos, 2017e). The aim of this project is twofold, namely improving the water safety as well as improving the water drainage. In order to comply with these two aims, the dyke is strengthened to be resistant to overflow over the entire length and the locks and sluice gates are reinforced, respectively pumps are incorporated into the existing discharge complexes (EH, personal communication, September 29, 2017 & PM, personal communication, October 11, 2017). Incorporating the pumps will considerably increase the discharge capacity. In May 2015, a milestone was reached by signing the Rijksinpassingsplan (Dutch: RIP) (Witteveen+Bos, 2016d).

Figure 3.3 | Afsluitdijk (Witteveen+Bos, 2014)

Beatrixsluis - The Princess Beatrixsluis is the largest monumental inland lock in the Netherlands, which is located in the Lekkanaal near Nieuwegein. Annually, about 50,000 ships pass this lock. However, due to the increase in traffic and the increase in scale of inland navigation, the lock with two channels is threatened to become a bottleneck in the Amsterdam-Rotterdam-Antwerp waterway. The Beatrixsluis was one of the first major plan studies that was put in the market as a best value procurement (BVP) project (RH, personal communication, October 3, 2017). BVP is a procurement method in which tenders are assessed based on their value rather than on the lowest price, meaning that the tender that provides the most value to the client is awarded with the assignment (Kusters, 2016).The aim of the Beatrixsluis project is to achieve a better flow of shipping. In order to reach this, the canal is widened and a third lock chamber is built (Witteveen+Bos, 2012, 2016d). By constructing the third lock chamber, vessels can pass the Beatrixsluis considerably faster, as the expected passing time in 2030 is reduced from 1,5 hours to 30 minutes (Rijkswaterstaat, 2013).

Figure 3.4 | Beatrixsluis (Witteveen+Bos, 2015)

Blankenburgverbinding - The A20 Westland/Haaglanden and the A15 Maasvlakte/Mainport Rotterdam are connected by the Blankenburgverbinding on the west side of Rotterdam. Good accessibility of the Rotterdam region is of great economic importance. However, due to congested roads the accessibility is coming under pressure. The aim of this project is to be able to guarantee accessibility and economic activities in the future. In order to provide this access, two large junctions, a land tunnel and a sink tunnel will be constructed (JV, personal communication, October 5, 2017). At Vlaardingen the A20 is widened, the new connection consists of 2x3 lanes and connects to the A15 again at Rozenburg (Witteveen+Bos, 2017b). By constructing the Blankenburgverbinding, the accessibility of the Rotterdam region is increased, the road users get an extra alternative to pass through the Nieuwe Waterweg, the traffic flow is improved, a reliable network is created, and the Benelux tunnel is unloaded. Additionally, the Blankenburgverbinding contributes to the growth of the Port of Rotterdam and Greenport Westland (Rijkswaterstaat, 2017).


Figure 3.5 I Blankenburgverbinding (AT Osborne, 2017 & Rijkswaterstaat, 2017)

Zuidasdok - The Zuidasdok is a big project in a complex location, situated on the south side of the Amsterdam ring road, being the A10 South. The aim of this project is to tackle several problems: from the traffic jams on the A10 to the queues for escalators at the station. In terms of scope, the existing highway is expanded from 2x4 lanes to 2x6 lanes and the highway is tunnelled over a length of 1 kilometre. In addition, the project also includes the modification of the train station Amsterdam South, which is expanded and modernised. Lastly, the whole surrounding environment is redesigned (SD, personal communication, October 18, 2017). By investing in the development of the area and connecting different functionalities, the Zuidas will remain an easily accessible financial centre, with opportunities for further development and where it is pleasant to stay (Witteveen+Bos, 2017f).


Figure 3.6 I Zuidasdok (Witteveen+Bos, 2015)

Interview results

Based on the answers obtained during the interviews, visualisations of each design process were made. After all interviews were conducted, each design process was further analysed and rephrased in order to be able to make a comparison. Thereafter, each design process was listed below one another and then restructured in order to derive recurring steps (see Table 3.1). From the blank cells in the table it is evident that not all design processes are equal and that not every project goes through all the design steps. Moreover, every project has a different starting point and final product. However, by structuring the steps at an abstract level, seven general steps are derived:

1. **Starting point**: Assumptions, conditions & client requirements or reference design
2. **Design loop I**: Determine possible solutions
3. **Converge alternatives**: Promising alternatives
4. **Design loop II**: Elaborate promising alternatives
5. **Converge alternatives**: Preferred alternative
6. **Design loop III**: Elaborate preferred alternative in detail
7. **Final product**: Documentation

Table 3.1 I Overview of interview results

	starting point	design loop I	converging	design loop II	converging	design loop III	final product
Afsluitdijk	Assumptions, conditions, client requirements	Generate alternatives	Promising alternatives	Elaborate remaining alternatives	Preferred alternative Assessment of support	Design & optimise Environmental impact studies	Procedural documentation in RIP
Beatrixsluis	Reference design	Generatie alternatives			Preferred alternative	Elaborate preferred alternative	Documentation of aspects in VSE
Blankenburg	Project awarded based on BVP	Rough design based on expert judgement	First EIA Obtaining and clarifying client requirements	Elaborate on rough design	Extensive EIA	Design in detail	Documentation in contract
Zuidasdok	Base design of RHDHV Analysis of the current situation Obtaining client requirements	Generate alternatives			Preferred alternative	Elaborate preferred alternative	Documentation of new design

Design method as implemented by Witteveen+Bos

From the interviews two main things can be found. The first finding is regarding the iterative nature and the division of the design process into three design loops, in which the loops are characterised by their level of detail. The level of detail of the final design depends on the client's request. The second finding is regarding the undefined design levels. Nowadays, no clear definitions of the different design levels exist anymore. This is due to the fact that the design level is determined on a risk-base and can even differ per product in the same project.

Design loops - The design process can be characterised by three design loops. This corresponds with the integral design approach, which is developed by Witteveen+Bos (see Appendix A.2). Based on the integral design approach, the current design process as described in Table 3.1 can be translated into an iterative, cyclic design process. Figure 3.7 visualises the iterative design process as derived from the interviews, in which:

1. The first design loop concerns the establishment of **functions**. By generating functions, an understanding of the scope and the client's needs can be obtained.
2. The second design loop concerns the **alternatives**. By converging from functions to alternatives, an understanding of the solution space is obtained.
3. The third and final design loop concerns the design decision or elaboration of the **preferred alternative** at the desired detail level. By elaborating the preferred alternative, an understanding of the solution and its corresponding risks is obtained.

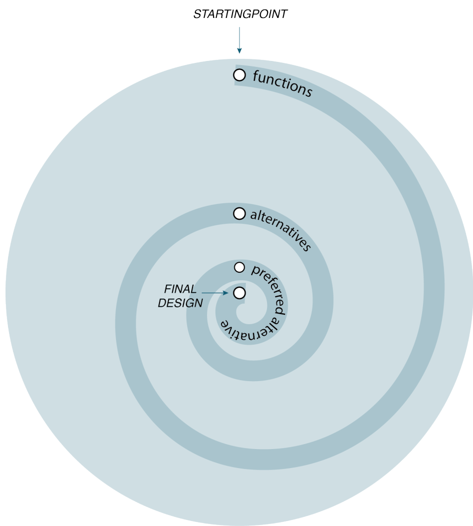

Figure 3.7 | Iterative design process (own illustration)

At the end of every design loop, it is important that the design is verified and validated. Verification in order to check whether the design complies with the requirements and validation in order to check whether the design fulfils the client's needs. Moreover, it is important to check whether the level of detail is suitable for the decision to be made in the concerning loop.

The differences between the three design loops are the level of detail of the design and the corresponding drawings with their different levels of scale. Moreover, every designer implements the approach in a different way, which also results in different levels of detail per design loop. In each design loop, the design will be further demarcated as requirements are becoming clearer and more requirements are taken into account. The former is due to the fact that enhanced insights (Dutch: voortschrijdend inzicht) are embedded in designing. For example, laymen do not have the capabilities of identifying conflicts in design drawings, let alone in (their own) client requirements. Generally, these conflicts will become evident to laymen once drawings are made and presented to them. Resulting in adjusting or adding requirements during the design process. The latter is due to the fact that designing is risk-driven and based on the decision to be made. During the design process, more detailed decisions are to be made once the design evolves. Meaning more detailed requirements are to be taken into account in each design loop, but also more requirements in general.

Undefined design levels - Traditionally, design levels could be clearly defined in terms of sketch design (Dutch: SO), preliminary design (Dutch: VO), final design (Dutch: DO) and execution design (Dutch: UO). However, nowadays it is hard to determine the demarcation line between these levels as not every aspect of the design is elaborated at the same level. This can be traced back to the arrival of the UAV-GC contracts in which the contractor is responsible for the design. Because of this, the definitions of the design levels and the demarcation line between these levels are fading. Also, every designer

Moreover, the starting point of each project may be different as well as the final products that are requested per project. This mainly depends on the prior and intended decision-making. For example, in a certain project the client may have already drawn up a preliminary design, which the engineering company then has to evolve into a final design. Whereas in another project, the client may only provide the engineering company with assumptions, conditions and requirements and requests a design at preliminary level. Therefore, it is important that the starting point and final product(s) are clearly defined beforehand.

While taking the above findings into account, the general design process within Witteveen+Bos can be mapped, which is visualised in Figure 3.8. As aforementioned, it is important that the starting point and final product(s) are clearly defined in every stage. Nevertheless, no matter what the starting point and final product(s) per stage are, the design process within each stage is essentially characterised by the three design loops.

A comparison of the established design process and the design process found from literature shows that both design processes highly correspond to one another:

- starting point - The mapped design process generally starts with client requirements, in case no prior design has been made, which corresponds to the engineering design process.
- iterative process - Both design processes have an iterative nature, in which the design evolves to design at a detail level that is specified beforehand. Even though the names of the design loops within the iterative process differ from one another, the essence of the design loops of both design processes correspond to one another. Starting with concepts that are first converged to alternatives that correspond to the solution space and then to a refined and preferred alternative.
- final product(s) - The mapped design process generally ends with the documentation of the requested design (see Table 3.1). This corresponds with the design communication phase of the engineering design process.
- verification & validation - Even though the point in time differs, both processes include verification and validation of the design.

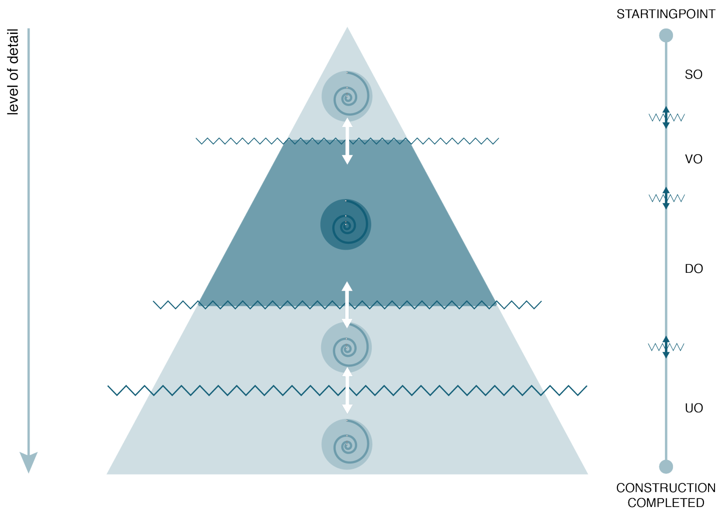

Figure 3.8 I Undefined design levels (own illustration)

4 PRODUCTIVITY IN THE DESIGN PROCESS

Now that the design process is explained, the productivity within the design process can be discussed. In order to be able to define design productivity, this chapter will start by discussing and defining the productivity in general in section 4.1. Thereafter, the productivity with regard to the design process will be defined and discussed in section 4.2, based on literature findings and perceptions on the term that were found from practice. In addition, section 4.3 provides a first insight into the improvement possibilities.

4.1 Defining productivity

The Oxford dictionary productivity in general can be defined as follows:

> *"The effectiveness of productive effort, especially in industry, as measured in terms of the rate of output per unit of input"*

The rate of output per unit of input can also be explained as the ratio between benefits and costs. The latter corresponds to the perspective of in 't Veld (2002), who argues that productivity generally consists of two components, being efficiency and effectiveness. In which efficiency entails the ratio between the benefits and costs:

$$Efficiency = Benefits/Costs$$

where

$$Benefits = Value\ of\ design \begin{array}{l} \nearrow \quad technical\ (product) \\ \searrow \quad lead-time\ (process) \end{array}$$

and

$$Costs = Value\ of\ capital, labour\ and\ overheads$$

Effectiveness, although it cannot be expressed in a simple formula, entails the measure of the achievement of the desired effect or outcome (Duffy, 1998).

4.2 Defining design productivity

Design productivity, however, differs from the productivity in for example the construction site during execution. This is mainly because producing engineering designs embraces a large number of complex, interdependent tasks, which are not as easily measured and flowcharted as construction work units (McGeorge, 1988). Also, design processes of infrastructural projects are characterised as non-linear processes that are highly dynamic and include a lot of uncertainties (see Figure 4.1). Moreover, the objectives of the projects differ per client and per project and therefore the processes are characterised as a continuous succession of problem-solving cycles. This asks for a process with sufficient flexibility in order to comply with the specific client needs and the unpredictability of the process itself (Amelsvoort & Metsemakers, 2003).

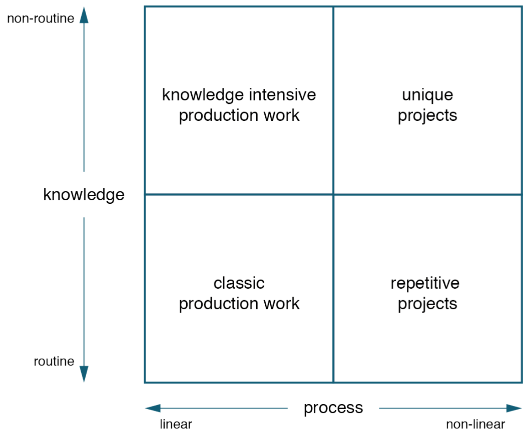

Figure 4.1 I Different types of activities (Amelsvoort & Metsemakers, 2003)

Nevertheless, the enhancement of the design productivity can partly contribute to the enhancement of the overall productivity of a project. For example, by shortening the lead-time of the design process, the overall project lead-time will also be shortened, assuming the design is correctly specified with regard to execution. By shortening the overall project lead-time, the possibility arises to carry out more projects, provided that enough workforces are available, and to earn revenues sooner, as projects are completed in a shorter period of time.

When taking the above considerations regarding the design process into account, the general definition of productivity can be adjusted for productivity in the design process. According to Duffy (1998), design productivity can be defined as:

> *"The efficiency of the production of a design solution, within a business context, that is effective to the overall requirements"*

In which, efficiency relates to the process and effectiveness to a product's development. As no other definitions of design productivity were found in literature, interviews were held in order to gain insight into the perspectives of employees regarding design productivity of construction projects in general. Table 4.1 presents the findings derived from these interviews (see Appendix B.1 for the complete interviews).

Table 4.1 I Overview of the perceptions of design productivity derived from interviews

Interviewee	**Perception of design productivity**
EH	To ensure *clarification* of all aspects at the *beginning of the design* process, so that as much as possible is *designed correctly the first time*. Meaning, *as few wastes as possible* occur during the design process and the *right direction* is followed from the start.
RH	The optimum between *benefits and costs* that is required for the concerned project
TD	To only design what is *required for the decision to be made* and the consideration between *efficiency and effectiveness*.
JV	To come up with the best solution with the deployment of *as few man-hours as possible in the shortest possible timeframe*, in which the best solution corresponds to *meeting client requirements, costs, support and design*.
PM	To design at a level of detail *appropriate to the next design decision to be made* and in *alignment with the support.*
SD	To do as much as possible and making progress in an *efficient* way, by developing smart information flows and communication lines.

By analysing the above perceptions of design productivity, a few aspects can be highlighted, being the ratio between benefits and costs, which equals efficiency, effectiveness, minimal waste, support, design for the next decision to be made, and meeting client requirements. When these aspects are taken into account, the design productivity definition by Duffy (1998) can be adjusted into the following definition:

> *"Design productivity is the efficiency of the production of a design solution, that is effective to the overall requirements and customer needs"*

4.3 Improvement possibilities

In order to gain a first insight into the improvement possibilites of design productivity and the difficulty thereof, McGeorge (1988) has considered the obvious approaches by which design productivity may be increased, which are essentially the following:

1. work harder
2. work smarter
3. increase capital investment

Again, it has to be taken into account that the design aspect in design productivity makes the productivity improvement more difficult. As most of the design activities involve creative thinking, approach 1 is hard to accomplish. Designers and/or engineers can work harder in terms of producing more drawings, but that does not necessarily mean that their design productivity improves. Seeing only the drawings that contribute to achieving the desired objective(s) are perceived as valuable and as a contribution to the design productivity improvement. In contrast, approach 2 and 3 are more feasible and have in fact already yielded several improvements. Approach 2 involves for example the improvement of methods such as standardisation and simplification of representations. In order to achieve approach 2, it might be necessary to also apply approach 3, which for example involves the investment in equipment such as computer aided design (CAD) systems. CAD systems have improved the output capabilities of the draftsman to a large extent. Even though several improvements have already been made, McGeorge (1988) states that designing involves so much more than merely putting lines on paper. Putting lines on paper is only the last step of a much more difficult process, namely that of deciding what to draw. In conclusion, a lot of design productivity progress can be obtained when focussing on deciding what has to be drawn in the first place.

5 INTRODUCTION TO LEAN PRINCIPLES

This research is aimed at improving the design productivity of infrastructural projects by preventing, mitigating and/or eliminating types of waste that occur during the design process. Therefore, it is important to gain insight into the principles of Lean. The reason for this importance is the fact that waste is a fundamental aspect of Lean practices and must thus be taken into account when aiming for waste prevention, mitigations and/or elimination. This chapter will provide an introduction into the Lean principles in section 5.1, by firstly discussing the origin of Lean, the different types of waste and the principles of Lean. Then, section 5.2 will discuss the implementation of Lean in the construction industry. Lastly, section 5.3 will zoom into the design process and discuss which Lean tools and techniques have been established in order to turn a design process into a Lean design process.

5.1 Background information

The origin of Lean can be found in the Japanese Toyota Production System (TPS), which is based on Henry Ford's concept of mass production in factories. In the 1950s, Taiichi Ohno, former executive vice president of Toyota, was given the task of developing an efficient production system for manufacturing Japanese automobiles (Bhuiyan & Baghel, 2005). According to Womack, Jones, and Roos (1990), Ohno used multiple techniques, such as Just-In-Time, quality control and Plan-Do-Check-Act, to develop the TPS, which is now widely known as Lean manufacturing. Nowadays, Lean has become a philosophy and moreover a way of working in which everyone and everything within a company is focused on creating value in all processes and tries to eliminate waste. In line with this philosophy, waste is defined as "any non value adding activity to a product or a service".

Womack and Jones were the first ones who introduced the concept of 'Lean', when describing the practices and philosophy of the TPS. In their book, Lean thinking, Womack and Jones (1996) have established five principles as a framework for Lean thinking, which have been successfully implemented in the manufacturing industry as well as other industries such as the aerospace industry and the health care industry. The five principles can be summarised as follows:

1. **specify value** - as the objective of Lean is to create value and prevent waste, value can only be defined by the ultimate client regarding the product and its capabilities at a predefined time
2. **identify and map the value stream** - in order to differentiate value from waste, the entire value stream should be analysed. For each activity it should be identified whether the activity is value or non-value adding
3. **make value flow by eliminating waste** - after identifying the value adding activities, all wasteful activities in the remaining process steps must be eliminated to make value flow.
4. **respond to customer pull** - only produce what the client actually desires. Meaning, the customer can pull the production in such a way that it is conform their requirements
5. **pursue perfection** - by continuously applying the first four principles, waste can be eliminated once it occurs during the process. By doing so, one can strive for perfection

Since the Lean philosophy relies on the identification and elimination of waste, there should be a clear understanding of the phenomenon of waste. As already stated, waste can be defined as "any non value adding activity to a product or a service" and according to Ohno (1988) and Liker (2004) waste can be divided into eight types of waste. Ohno (1988) identified the first seven types of waste and Liker (2004) added the eighth type of waste, being:

1. overproduction
2. waiting
3. transportation
4. over processing
5. unnecessary inventory
6. movement
7. defects
8. unused employee creativity

5.2 The implementation of Lean in the construction industry

As a result of the successful implementation of the Lean principles in many industries, the construction industry also started implementing the Lean principles. This led to the development of Lean Construction, which is based on three design views. According to Ballard and Koskela (1998) and (Tzortzopoulos & Formoso, 1999) the three views are as follows:

1. **conversion** - this view divides the design process in sub processes that are carried out by a specialist who transforms his/her perception on the client requirements into design decisions
2. **flow** - this view presents design as a flow of information, in which non-value adding activities are visualised
3. **value generation** - this view focuses on achieving the best possible value from the customer's point of view

An elaborate overview and comparison of these three design views can be found in Appendix C.1.

Koskela (2000) combined the three design views, which resulted in the Transformation Flow and Value (TFV) theory. According to Baarends (2015), Lean Construction is based upon the TFV theory and therefore systems that comply with the TFV theory can be viewed as 'Lean Systems'. Ballard et al. (2002) have designed such a Lean system (see Figure 5.1), which is known as the Lean Project Delivery System.

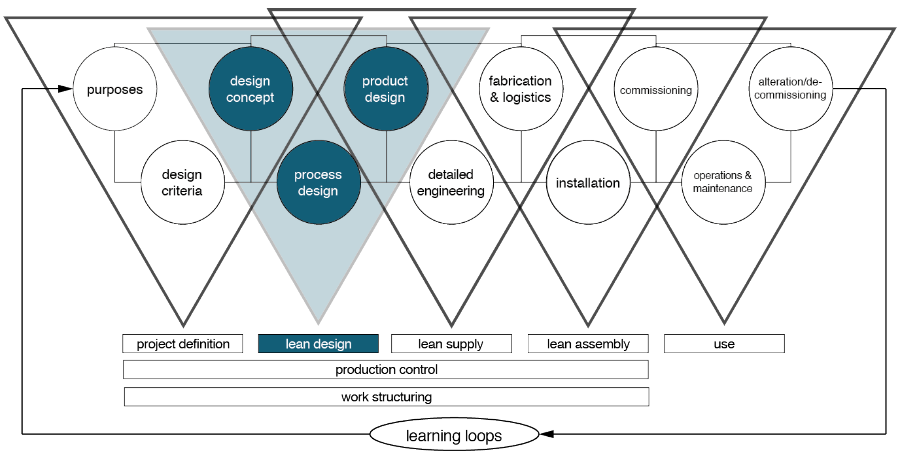

Figure 5.1 I Lean Project Delivery System (Ballard, Tommelein, Koskela, & Howell, 2002)

5.3 Lean design tools and techniques

With regard to the scope and subject of this research, we will zoom in to the Lean Design phase. Freire and Alarcón (2002) argue that the planning and control of the design phase are substituted by anarchy and improvising in design, which results in poor communication with stakeholders, lack of documentation, deficient or missing input information, and a lack of coordination. Therefore, they have developed a Lean Design Process in which both the flow and value view are incorporated, in contrast to the traditional conversion view (see Appendix C.1 for a comparison of the three design views). Ballard and Zabelle (2000) endorse the perspective of Freire and Alarcón and acknowledge the difficulty of reaching a Lean Design. Therefore, Ballard and Zabelle (2000) have developed an overview of tools and techniques for Lean Design which is illustrated by Figure 5.2.

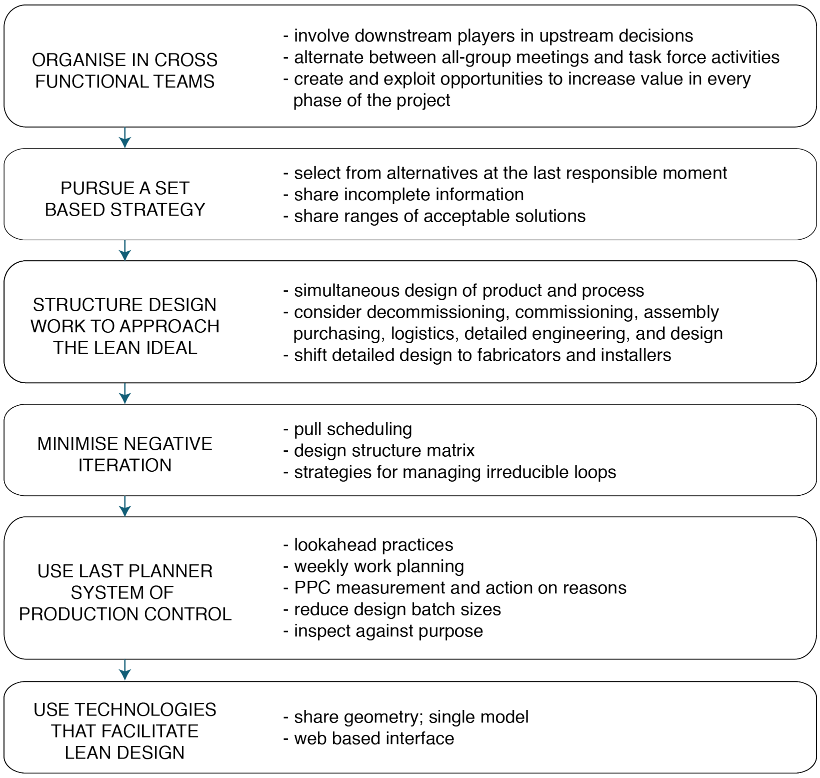

Figure 5.2 I Overview of tools and techniques for Lean Design (Ballard & Zabelle, 2000)

The tools and techniques for Lean Design that are provided in the overview above are taken into account throughout this research and may serve as input for the recommendations on waste prevention, mitigation and/or elimination. Therefore, these tools and techniques will be taken into consideration in the recommendations in Part V.

PART III. RESEARCH

6 WASTE IDENTIFICATION

In order to be able to improve the design productivity, the factors affecting the design productivity, also referred to as *waste*, need to be identified first. Therefore, the first step of the research part entails the waste identification, which is presented in this chapter. The identification of waste contains four different types of input and 12 steps (see Figure 6.1). The different forms of input are a literature study (section 6.1) regarding waste in the design process, an analysis of an earlier conducted research (section 6.2 and 6.3) into waste in the design process, interview results (section 6.4), and the results from a conducted questionnaire (section 6.5). The aim of the waste identification is to determine the top types of waste that occur in the current design process.

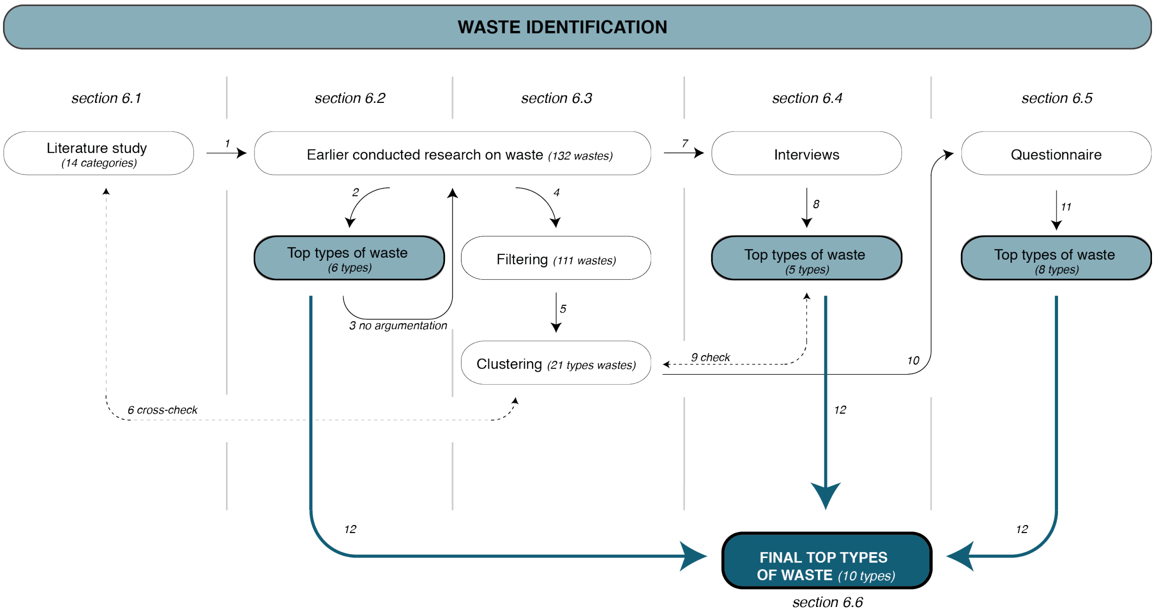

Figure 6.1 I Set-up waste identification (own illustration)

6.1 Literature study

As already mentioned in the introduction, a clear knowledge gap in literature exists when it comes to design productivity and the factors by which it is affected. McGeorge (1988) even states that productivity in the design office has been a neglected field compared with the outpourings of research and theory on productivity in construction or manufacturing activities. And indeed, in literature a large amount of articles can be found that elaborate on inefficiencies that occur at the construction site. Viswanathan (2017) compared several studies that aim at finding causal factors for project delays and budget overruns in the construction industry. The comparison resulted in a list of most frequently identified causes and it concluded that the majority of this list was design-related and could directly be related to the design process. Yet, by analysing the design-related causes it became evident that some of the causes emerge in the execution phase rather than the design phase, i.e. non-availability of design drawings on time, late review and approval of design documents, inaccurate specification of site conditions, and change orders during construction.

Nonetheless, one paper was found in literature regarding factors affecting design productivity. This paper represents the deliberations of the First International Engineering Design Debate held in September 1996 in Glasgow, United Kingdom. This debate was directed at discussing key issues concerning the improvement of the design productivity with a view of deriving a common understanding of the basic factors, problems and potential solutions involved. During the discussion, it became apparent that there are numerous barriers to enhancing design productivity. Some participants of the discussion argued that these barriers, when inverted or aligned to enhance productivity, are themselves elements of productivity. Table 6.1 highlights the barriers that were identified during the discussion.

Table 6.1 I Barriers to enhancing design productivity (Duffy, 1998)

Category	Barriers
Approach	• converge on a design solution too soon • poor selection and use of tools • late consideration of constraints • inadequate documentation, lack of a process model
Communication	• distance, infrastructure • organisation • different language styles
Experiences	• constrained by prior experiences
Expertise	• mismatch
Individuals	• decision making ability • skills • problem solving ability • poor motivation • poor learning ability
Inflexibility	• reluctance to change
Information	• lack of information • incorrect information • too much information • changing information
Knowledge	• lack of knowledge • poor training • inappropriate training • lack of documentation
Management	• process too rigid • poor decision making • lack of focus • poor leadership • bad planning • uncoordinated • untimely decisions
Planning	• poor planning • lack of planning
Product	• designing the wrong solution • unclear specifications • too many conflicting goals • poorly understood goals
Resources	• lack of resources • insufficient funding • wrong or poor tools • lack or unsuitable people • inappropriate allocation
Teamwork	• poor cohesion • lack of focus and direction • "in-fighting" • clash of personalities
Technical	• poor equipment • tools not available

6.2 Earlier conducted research

In the summer of 2015, a group of six Witteveen+Bos employees established a Lean workgroup for Systems Engineering (SE). The aim of this workgroup was to minimise waste in the design process, using the SE process description developed by Rijkswaterstaat. Even though the output of Lean for SE is specifically based on the SE process, it is still used as input for this graduation research. Many findings from the Lean for SE research were perceived to be general waste rather than SE specific waste. Besides, both researches have the same objective of improving the design process (Witteveen+Bos, 2016b).

During a brainstorm session, in which the working group and designers were involved, 132 wastes in the current design process were determined. Based on the impact of the determined wastes and the influence that employees can exert on these, the working group had selected the following six (causes of) waste(s) to be the most important ones in the design process:

- insufficient use of existing knowledge
- ineffective meetings and academic purposes
- overproduction per aspect and/or per phase
- working with the wrong starting points, assumptions, requirements and/or information
- lack of alignment between disciplines
- lack of management

However, no argumentation on the establishment of the above list was found and therefore it was decided that the selection had to be more substantiated. However, the above list will be taken into account when deciding on the final top types of waste in section 6.7. The steps that have been taken in order to come to a more substantiated list are discussed in the following sections.

6.3 Reorganising Lean for SE research

As explained in the previous section, the total list of wastes derived by the working group from the brainstorm session consisted of a number of 132 wastes. In order to establish a list of general types of waste, the waste specifically based on SE were eliminated from the total list. Besides, the list was checked regarding whether every waste was mentioned only once. The elimination of SE specific and double waste resulted in a list with 111 wastes remaining. Yet, due to the amount of wastes it is still hard to determine which of these are the most important and therefore the list was clustered.

The clustering of the list started off with looking for similar topics within the total of 111 wastes. Then, the similar wastes were grouped and several clusters of types of waste were created (see Appendix B.2). The clustering of the wastes thus involved an analysis of all remaining wastes and the set up of different variants of clustering. Eventually one variant of clustering was chosen and then verified by two employees in order to check whether all 111 individual wastes fit the established 21 clusters of types of waste.

The types of waste were also checked crosswise with the findings from literature that are presented in Table 6.1, which can be found in Appendix B.2. From the cross check it was found that all established 21 types of waste could be linked to one of the 14 categories that were found in literature. Therefore, it can be concluded that the established 21 types of waste do not include any company specific types of waste. The 21 established types of waste are listed in Table 6.2.

Table 6.2 I 21 Types of waste

Type of waste
• Insufficient use of existing knowledge
• Gathering external information
• Gathering internal information
• Ineffective meetings and academic discussions
• Lack of management
• Lack of support
• Lack of alignment between disciplines
• Ambiguities regarding the project
• Ambiguities regarding the design process
• Ambiguities regarding the basic specifications
• Working with the wrong starting points, assumptions, requirements and/or information
• Ambiguities regarding the client requirements
• Ambiguities regarding the interfaces
• Ambiguities regarding generating alternatives
• Ambiguities regarding the level of detail
• Insufficient attention regarding verification
• Implicit way of working
• Overproduction per aspect and/or per phase
• Unnecessary design changes
• Client changes
• Solution space too narrow

The 21 types of waste above, will serve as input for the questionnaire in section 6.5.

6.4 Semi-structured Interviews

Now that the types of waste have been verified by literature, the types of waste that are perceived to be important by employees will be taken into account. Firstly, the types of waste that were mentioned during the semi-structured interviews. During the semi-structured interviews, the interviewees were asked to elaborate on the factors that affect the current design process and its productivity. Figure 6.2 illustrates which types of waste have been mentioned during these interviews and the bars show how often each type of waste is mentioned.

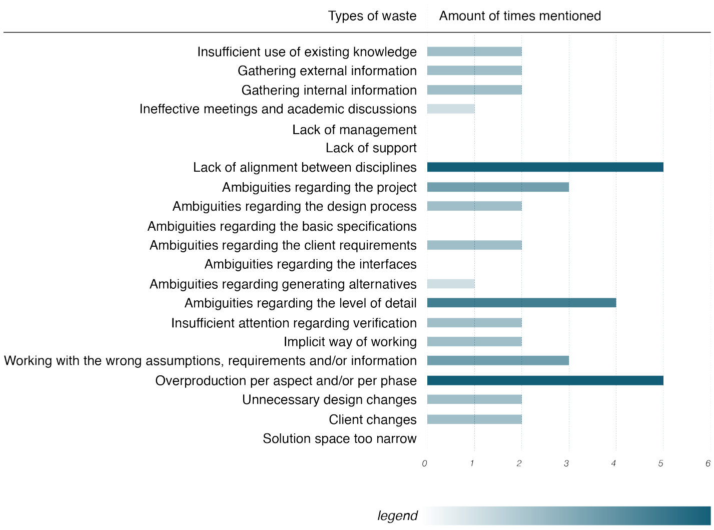

Figure 6.2 I Top types of waste from interviews (own illustration)

By analysing the answers from the interviewees, it can be derived that five of the types of waste were mentioned by at least half of the interviewees. So, based on Figure 6.2, the most common types of waste according to the interviewees can be ranked as follows:

1. Lack of alignment between disciplines
1. Overproduction per aspect and/of per phase
3. Ambiguities regarding the level of detail
4. Ambiguities regarding the project
4. Working with the wrong assumptions, requirements and/or information

As illustrated in Figure 6.1, the top types of waste resulting from the interviews will also be taken into account when deciding on the final top types of waste in section 6.7.

6.5 Questionnaire

The last form of input for the determination of the top types of waste in the design process is the use of a questionnaire. As the top types of waste that resulted from the Lean for SE working group were not substantiated, it was decided that a new selection of most important types of waste should be made. By converting the established list of 21 types of waste, as presented in section 6.3, into a questionnaire, several employees, who have experience with the design process of infrastructural projects, could be asked about their perspectives on the types of waste that affect the design process and its productivity. The aim of the questionnaire is to review each type of waste's presence, impact and the influence employees have to prevent, mitigate and/or eliminate the waste.

Set-up of the questionnaire

The established questionnaire consists of 21 types of waste that have to be reviewed on presence, impact and influence of employees. Meaning, the results would provide insight into:

- the most common types of waste in the design process
- the types of waste with most impact on the productivity of the design process
- the types of waste that can be most influenced by employees

In the questionnaire, the respondents are asked to indicate, on a 5-point Likert scale, to what extent each type of waste occurs in the design process, what impact these wastes have on the design productivity and to what extent employees can influence the prevention of this type of waste. The questionnaire can be found in Appendix B.3. In addition, if the last question for each type of waste regarding the influence of employees was answered with a score > 3, then an explanation is asked on how the waste can be influenced.

Results of the questionnaire

A total of five respondents have filled out the questionnaire, which is a small number of respondents. However, since the input is based on findings from previous research and functions as an extra substantiation, the results are considered to be useful nonetheless. The final results of the questionnaire can be found in Table 6.3 and a complete overview of the results can be found in Appendix B.3. Since the questionnaire has a 5-point Likert scale, the variables are measured on an ordinal measurement level. Therefore, the median instead of the average has been calculated for each type of waste (Scriptium, 2017). The use of a median makes sure that deviant answers will be neglected.

Table 6.3 I Results obtained from the questionnaire

Ranking	Type of Waste	Median presence	Median impact	Median influence
1	Implicit way of working	5,0	4,0	4,0
2	Ambiguities regarding the client requirements	4,0	5,0	4,0
3	Insufficient attention regarding verification	4,0	4,0	5,0
4	Insufficient use of existing knowledge Gathering internal information Ambiguities regarding the level of detail Ambiguities regarding the project Overproduction per aspect and/or per phase	4,0	4,0	4,0
9	Gathering external information Ineffective meetings and academic discussions	4,0	3,0	4,0
11	Lack of management Lack of alignment between disciplines Ambiguities regarding the interfaces Solution space too narrow	3,0	4,0	4,0
15	Working with the wrong starting points, assumptions, requirements and/or information	3,0	4,0	3,0
16	Ambiguities regarding the design process	3,0	3,0	4,0
17	Lack of support Ambiguities regarding the basic specifications Ambiguities regarding generating alternatives Unnecessary design changes	3,0	3,0	3,0
21	Client changes	3,0	4,0	2,0

The ranking of the final results in Table 6.3 is based on the outcomes of consecutively presence, impact and influence. First, it is important to know which types of waste are the most common in the design process. From the remaining types of waste it is important to know which types of waste have a significant impact on the productivity in the design process. Lastly, it is important to know which of the remaining types of waste can be influenced by the employees. When determining the top types of waste from the questionnaire, only the types of waste that score a median > 3 on all three aspects are taken into account. This is decided based on the 5-point Likert scale in which a 3 represent a neutral opinion. So, after ranking the types of waste on the three aspects, the top types of waste resulting from the questionnaire can be listed as follows:

1. Implicit way of working
2. Ambiguities regarding the client requirements
3. Insufficient attention regarding verification
4. Insufficient use of existing knowledge
   Gathering internal information
   Ambiguities regarding the level of detail
   Ambiguities regarding the project
   Overproduction per aspect and/or per phase

As illustrated in Figure 6.1, the top types of waste resulting from the questionnaire will also be taken into account when deciding on the final top types of waste in the next section.

6.6 Discussion of the questionnaire results

As already mentioned, the results from the Lean for SE research could not be conceived as expert judgement and therefore the questionnaire was set up with the aim of reviewing each type of waste's presence, impact and the influence employees have to prevent, mitigate and/or eliminate the waste. When comparing the results of the earlier conducted Lean for SE research with the results from the questionnaire, only two out of six types of waste correspond to one another (see Table 6.4). The corresponding types of waste are insufficient use of existing knowledge and overproduction per aspect and/or per phase. The remaining four top types of waste resulting from the Lean for SE research will be discussed based on the questionnaire results (see Table 6.3) and the interview results (see Table 6.4).

Ineffective meetings and academic discussions - As can be seen from Table 6.3, this type of waste is found to be often present and considered to be impressionable by employees to a large extent, both with a score of 4.0. However, the impact of this type of waste is considered to be neutral, with a score of 3, and therefore not part of the top types of waste resulting from the questionnaire. Also, this type of waste has not been mentioned in the interviews as a common type of waste. Therefore, ineffective meetings and academic discussions will not be taken into account in the final top types of waste.

Lack of management - This type of waste is found to be regularly present with a score of 3.0 and has not been mentioned during the interviews. Therefore this type of waste will also not be taken into account in the final top types of waste.

Lack of alignment between disciplines - This type of waste is also found to be regularly present with a score of 3.0 and are therefore not part of the top types of waste resulting from the questionnaire that are presented in Table 6.3. However, from the interview results the lack of alignment between disciplines is considered to be one of the most common types of waste (see Table 6.4). Therefore, the lack of alignment between disciplines is added to the final top types of waste.

Working with wrong starting points, assumptions, requirements and/or information - This type of waste is also not part of the top types of waste resulting from the questionnaire as shown in Table 6.3, even though the impact of the type of waste is said to be rather high, with a score of 4.0. The reason for this is that the type of waste is regularly present and considered to be neutrally impressionable by employees, both with a score of 3.0. Nevertheless, both previous research and the interviewees consider this type of waste as a common type of waste and therefore working with wrong starting points, assumptions and/or information is also added to the final top types of waste (see Table 6.4).

Table 6.4 I Comparison questionnaire with Lean for SE and interviews

Results of Lean for SE		Results of the questionnaire		Results of the interviews
Insufficient use of existing knowledge	1	Implicit way of working	1	Lack of alignment between disciplines
~~Ineffective meetings and academic discuss~~	2	Ambiguities regarding the client reqs	2	**Overproduction per aspect and/or per phase**
Overproduction per aspect a/o phase	3	Insufficient attention regarding verification	3	**Ambiguities regarding the level of detail**
Working with the wrong sp, ass, reqs, info	4	Insufficient use of existing knowledge	4	**Ambiguities regarding the project**
Lack of alignment between disciplines	4	Gathering internal information	4	Working with the wrong sp, ass, reqs, info
~~Lack of management~~	4	Ambiguities regarding the level of detail		
	4	Ambiguities regarding the project		
	4	Overproduction per aspect and/or phase		
	9	...		
	10	...		

6.7 Conclusion

Now that the results from the earlier conducted research, interviews and questionnaires are obtained and discussed, the final top types of waste can be determined. By taking into account the comparison of the three forms of input, as illustrated in Table 6.4, the following ranking of top types of waste has been determined:

1. Implicit way of working
2. Ambiguities regarding the client requirements
3. Insufficient attention regarding verification
4. Insufficient use of existing knowledge
4. Gathering internal information
4. Ambiguities regarding the level of detail
4. Ambiguities regarding the project
4. Overproduction per aspect and/or phase
9. Lack of alignment between disciplines
10. Working with the wrong starting points, assumptions, requirements and/or information

In this ranking the average of all medians is 4.0, in which only the last two types of waste have an average median that is below average. Lack of alignment between disciplines and working with the wrong starting points, assumptions, requirements and/or information have an average median of respectively 3.7 and 3.3. Nevertheless, these types of waste are taken into account as these were mentioned both in the interviews and in the previous research, to commonly occur in the current design process.

The determined list of top types of waste will serve as input in the matrix in chapter 8, in which the interfaces between the types of waste and design methods will be analysed. In order to do so, the possible design methods will be explored first in the next chapter.

7 DESIGN METHOD EXPLORATION

Now that the top types of waste are identified, several design methods can be explored that might present a solution to prevent or mitigate the identified types of waste in order to contribute to improving the design productivity. The origin of the design methods that are explored can be found in different industries, but all methods have interfaces with the improvement of productivity. The elaboration on each design method firstly provides a brief introduction of the design method. Then, the definition is presented followed by the objective(s). Thereafter, the characteristics and the limitations of implementing the design method in the construction industry are discussed. The characteristics of each design method will serve as input for the matrix in the following chapter, which will discuss the most suitable design method regarding the identified top types of waste.

7.1 Concurrent Engineering

Concurrent Engineering (CE) is a management philosophy originating from the manufacturing industry and also commonly known as Simultaneous Engineering or Parallel Engineering. Smith (1997) argues that CE is not totally a radically new set of ideas as many aspects of the CE principles have been mentioned in previous literature. However, total realisation of CE as a whole concept was only made in the late 1970s. When applying CE, all life cycle stages of a product or project are considered simultaneously during the design process, from the conceptual design stage through detailed design stage (Kusiak, 1993).

According to Syan and Menon (1994), a now widely accepted definition of CE was given in the report of the Institute of Defence Analysis (IDA) in 1986 and is as follows:

> *"A systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from concept through disposal, including quality, cost, schedule, and user requirement"*

Objectives

The CE approach to manufacturing aims to reduce product development time, have better customer orientation, improve product quality, but also lower development costs (Mohamad, 1999; Prasad, 1995; Stalk & Webber, 1993). According to Love and Gunasekaran (1997) CE seeks continuous process improvement by:

- increasing organisational efficiency and effectiveness
- the elimination of non-value adding activities (waste)
- continuous optimisation or refinement of the entire system, which includes design, manufacturing, production and marketing for an improved productivity and quality

The CE approach to the construction industry prescribes how to realign the traditional way of work processes based on a fragmented and sequential process into a new paradigm of integrated life cycle process using a multidisciplinary teamwork approach (Mohamad, 1999). CE is considered to be a feasible option that can be adapted in the construction industry as the goals and principles are appropriate to the challenges that the construction industry is facing. De La Garza, Alcantra, Kapoor, and Ramesh (1994) argue that CE can be used as a strategy to generate diverse knowledge in the design development by incorporating all different specialists in the design phase. Furthermore, Evbuomwan and Anumba (1997) argue that CE enhances team work and provides a suitable framework to identify client requirements at outset and utilise IT tools to further improve the industry efficiency in cross functional teams (CFTs) communication and information sharing.

Characteristics

Jo, Parsaei, and Sullivan (1993) stated that CE comprises of four basic elements, being increased consideration of manufacturing process in product design, formation of cross functional teams to accomplish the development process, the focus on customers during the development process, and the use of lead time as a source of competitive advantage. Mohamad (1999) adapted these basic elements and presented those within the context of the construction industry:

- **consideration of project life cycle requirements in the design process** - When applying CE in the construction industry, all project life cycle requirements such as planning, construction, client requirements, end user requirement, constraints by contractors and sub-contractors, etc. need to be simultaneously considered during the design development phase. Also input from the expertise of various project members and stakeholders has to be considered in the design from outset. In other words, CE entails an integral design process.

- **teamwork** - The teamwork approach based on the CE philosophy is the so-called Cross Functional Teams (CFT). The most important and relevant differences between the traditional teamwork and CFT are the removal of the functional boundaries, the team is formed at the inception stage of the project, the team is given adequate authority to make important decisions, the team may comprise of a wider range of members including the client, sub-contractors, suppliers, etc., and the main objective is to enable project members to contribute in the design phase. Every team member is deemed to have knowledge and information regarding how downstream issues can influence the design process, which is a fundamental advantage in reducing the amount of redesigning and both design time and costs.

- **focus on the client requirements** - As stated above, the client will be involved in the project team throughout the project lifecycle. However, due to the complexity of most construction projects and the lack of experience of most clients, their needs may not always be properly addressed. Kamara (1999) argued that the client requirements must therefore be thoroughly understood and analysed to ensure they are clear and unambiguous. In order to achieve this, there must be a formal framework to process client requirements. Such a framework should provide effective procedures and techniques for precise establishment of the client requirements and ensure traceability of the requirements during the design process. Moreover, the requirements must be analysed and prioritised in order to avoid conflicts.

- **reduce development time** - Reduction of development time can be achieved by simultaneously considering all life cycle requirements in the design development. This will enable to reduce the length of iterative design loops and the time needed to rectify design error and rework. It also enables to carry out project tasks in parallel as project members are involved in the process earlier and this ensures the ability to share project information across the functional boundaries.

Limitations regarding implementation in the construction industry

The fragmented structure of the construction industry obstructs the consideration of the downstream requirements during the design phase. As the construction process is developed based upon the separation of the design and construction phases, other parties such as contractors cannot participate in the design phase. So, the CE approach cannot be fully implemented if the traditional process structure persists. However, the arrival of the integrated contract (Dutch: UAV-GC) does offer possibilities in the field of implementing CE. An important characteristic of this kind of contract is the merging of tasks and responsibilities within construction process into one contracted party. The client continues to fulfil the role of the initiator of the project and the contractor is responsible for the design and execution of the project (Projectbureau B.V., 2015).

The nature of construction projects is mostly one-of-a-kind and project-based. Due to this, the construction industry is generally comprised of relatively small, independent operators that come together on a one-off basis to procure a construction project. Meaning that a typical construction project consists of a temporary multi-organisation (TMO), in which members have divergent goals and objectives (Cherns & Bryant, 1984). Moreover, participants seldom gain the chance to work with each other on more than one occasion due to the one-off projects. Consequently it is difficult for the members to learn how to cooperate, communicate and integrate with one another effectively throughout the project development process.

Overall, the success of the implementation of CE in the construction industry highly depends upon the construction industry to eliminate the fragmented structure of the traditional process and the corresponding cultural, behavioural, organisational and institutional barriers that currently exists between the project members.

7.2 Systems Engineering

The origin of Systems Engineering (SE) can be found in the 1940s, when the complexity of systems increased and more and more disciplines with interrelationships were involved in projects. The need for SE first emerged when it was realised that the combination of components did not necessarily lead to the desired system, even though the individual components were satisfactory (Schlager, 1956). SE was first implemented in the telephone sector as a means of achieving operability between the various parts of the telephone system. During the Second World War, Bell Telephone Laboratories implemented SE in order to solve the occurring problems with the national telephone network (ProRail, 2015).

During the 1950s, the NASA and the US Department of Defence also began to apply the SE method. Since then the SE method was further developed into a more general application. The process was developed in parallel in the aerospace industry, the defence industry, and the commercial sector, as these various sectors considered SE to be a suitable method to address increasingly complex problems (ProRail et al., 2013).

In 1990, after SE had developed into a well-known and accepted method, a number of companies and government agencies in the United States founded the National Council on Systems Engineering (NCOSE) as a first professional platform for SE. The aim of NCOSE was to further develop and gain knowledge regarding SE. The growing international interest in SE led to the changing of the name into International Council on Systems Engineering (INCOSE) in 1995 (ProRail et al., 2013).

As SE can be applied in several disciplines, various definitions exist. According to INCOSE (2015) SE can be defined as follows:

> *"An interdisciplinary approach and means to enable the realisation of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem. SE integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs"*

Objectives

The aim of SE is to enhance productivity and quality, and to cope with the design of increasingly complex systems (Systems Engineering and Management, 2016). According to ProRail (2015) these objectives can be achieved, as SE:

- is an interdisciplinary approach to create a well-functioning system
- focuses on customer demand and translates this into functionality, early in the system development
- documents requirements
- asks for validation of the whole system throughout its life cycle
- incorporates both business objectives and stakeholders' needs and translates these to system requirements
- has the ultimate goal to realise a product that meets the needs of the system user

Characteristics

ProRail et al. (2013) have established the following five principles for SE in the construction industry:

- **system thinking** - SE is based on system thinking. In addition, a system, depending on its intended purpose, is to distinguish within the overall reality sets of elements (including organisations and processes) that have mutual relationships. Each system is part of a larger whole. System thinking keeps organisations aware of the complete system, life span and all parties involved in the chain.

- **customer needs** - Projects that use SE analyse the problems and opportunities, related to customer needs. Through specification the customer needs are translated into customer requirements and intended use. These customer requirements are documented in a Customer Requirements Specification (CRS). During system development the system is continuously being aligned with the current needs. With SE, the best solution to the problem is designed based on the customer needs within the given solution space.

- **life cycle optimisation** - Concept, development, realisation, (re-)use, maintenance and demolition are the phases of each system in the life cycle. SE transcends the various phases of the life cycle and focuses on optimising the system in all its phases and in interdependence throughout the life cycle. The focus on one phase usually results in sub-optimisation. For example, a high quality coating can be a relatively expensive investment in the realisation phase. However, if this coating generates considerable savings in the maintenance phase, then the costs over the entire life cycle will decrease.

- **working explicitly** - Documenting information well and explicitly by all various stakeholders is a prerequisite for SE. During the life cycle of systems, different teams and parties are involved and transfers between teams and locations are regular. This asks for cooperation and transmission of information between all different parties. Therefore, clear and unambiguous documentation is needed in order to make choices and information traceable as well as transferable. Important supporting processes include verification and validation (V&V). Verification shows that a solution meets the requirements objectively and explicitly. Validation shows that a solution is suitable for the intended use.

Limitations regarding implementation in the construction industry

In the meantime, SE has been implemented in the Dutch construction industry for more than 15 years, however practice has proven that the implementation of SE in the civil engineering sector is rather hard. This is experienced by both contractors and engineers (Witteveen+Bos, 2010). For this reason, Rijkswaterstaat (RWS) has drawn up a process description in order to clearly and unambiguously define the SE method, as applied at Rijkswaterstaat.

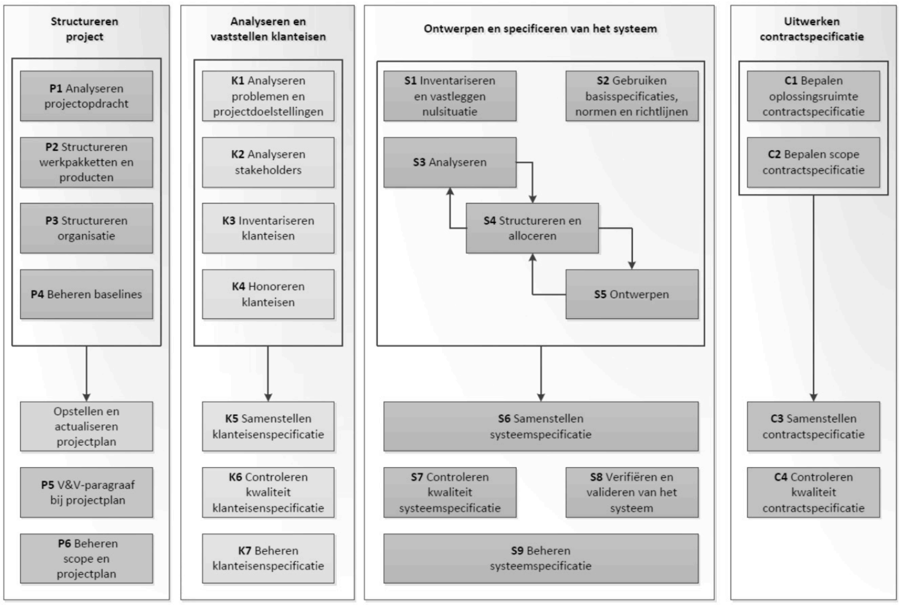

Figure 7.1 I Process description systems engineering for RWS (Rijkswaterstaat, 2016)

Moreover, the process description gives insight into and an overview of the cyclic process that is being carried out during the development process (Rijkswaterstaat, 2016). The process description of Rijkswaterstaat divides the process into four steps: structuring the project, analysing and determining the customer requirements, designing and specifying the system, and developing the contract specification (see Figure 7.1).

7.3 Open Design

Open Design is part of the Quality-oriented Construction Management (QCM) and originates from the industrial research and development (R&D) industry. Industrial R&D is aimed at creating a strategic advantage over the competition through uniqueness. Such strategic uniqueness is achieved by offering quality in a product or service, which is valued by the end user and which is hard to get from others.

In order to cope with quality, a classification is needed to distinguish various quality aspects. One of the classifications that can be used is proposed by van Gunsteren (1995), in which quality is defined as "fitness for purpose", meaning quality is a perception and related to a subjective purpose. The classification as proposed by van Gunsteren (1995) states that quality can be:

- relevant or irrelevant
- realised or not realised in the product or service
- specified or not specified in specifications

Figure 7.2 shows that combinations of these aspects yield seven categories of quality. Quality specifications will never cover exactly all quality that is relevant to the end user. Therefore, relevant quality that is covered by specifications is labelled *crucial quality*, because it is absolutely crucial to realise this type of quality in the product or service.

Relevant quality that is not specified is called *service quality*, because this quality has to be delivered as a service if the end user's needs are to be properly satisfied. Specified quality that does not serve any purpose of the end user is labelled *cosmetic quality*. In case cosmetic quality is realised but not relevant, it is labelled as *ritual quality*. Whereas, in case it is neither realised nor relevant, it is labelled as *excuse quality*. Quality realised in the product or service will also never cover exactly what is relevant and/or specified. Realised quality that is neither relevant nor specified is labelled *wasted quality*, as it serves no true purpose.

The mainstream of literature on quality is focused on getting execution in line with design specifications, rules and regulation, which is in contrast to the QCM approach. According to van Gunsteren (2013), QCM can be defined as follows:

"Quality-oriented Construction Management is an approach that is not focussed on getting the execution in line with the specifications, but getting execution and specifications as much as possible in line with the desirable quality defined as fitness for purpose"

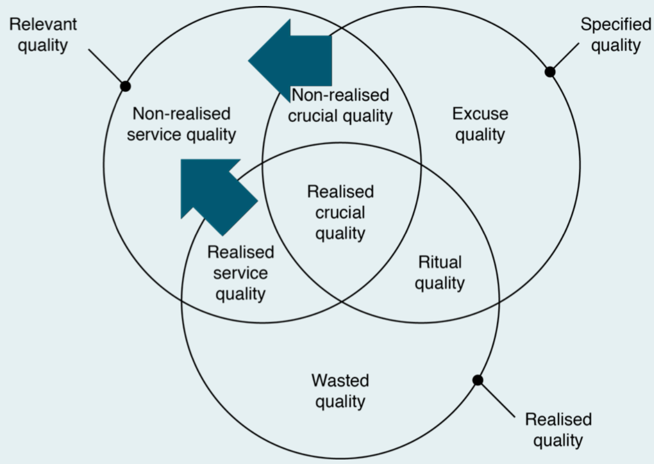

Figure 7.2 I Visualisation of the purpose of quality-oriented construction management (van Gunsteren, 2013)

Objectives

The QCM approach aims to improve product quality by designing what is fit for purpose. This involves reducing the wasted and excuse quality. The change of mind-set from focussing on contract specifications and control towards fitness for purpose and stakeholder involvement is a fundamental aspect of QCM. According to (van Gunsteren, 2013) QCM can provide significant competitive advantages for any engineering company in the short term by:

- reducing or even removing wasted and excuse quality
- timely involvement of stakeholders
- enhancing multi-criteria-decision-making
- enhancing project scheduling through probabilistic network planning with mitigations on the run

In the longer term, the engineering company can acquire the reputation of delivering the quality that the end user needs rather than merely complying with contract specifications, rules and regulations. This is done by providing additional service quality, which is essential for fitness for purpose (van Gunsteren & Binnekamp, 2016).

Characteristics
Based on the various literatures of van Gunsteren and van Loon (1995, 2000, 2013, 2016) the following characteristics can be identified:

- **fitness for purpose** - As already elaborated, the QCM approach aims to get the realised quality as well as the specified quality as much as possible in line with the relevant quality in order to provide "fitness for purpose" with regard to the client.

- **stakeholder involvement** - The demands of stakeholders can be seen as quality specifications which the final design has to satisfy. Therefore, it is important that stakeholders are involved in the process, preferably as early as possible.

- **complex project management practices (PII management practices)** - The QCM approach requires best management practices that are particularly suited for complex projects. According to Binnekamp, van Gunsteren, and van Loon (2006), best management practices for complex and unpredictable projects can be labelled PII practices, whereas best management practices for straightforward and predictable projects are labelled as PI practices. PII management practices should only be applied to projects that can be characterised by uncertainty, unpredictability, and a multitude of stakeholders with conflicting interests.

- **use of open design** - The purpose of open design is to generate a design in which the interests of all stakeholders are reflected in an optimal way. The classical approach to a design problem is to consult an expert or limited group of experts. These experts provide a solution that often does not reflect the wishes of all stakeholders. To prevent dissatisfaction of the involved stakeholders, the aid of process experts is called in. However, this often leads to a sub-optimal design in which a lot of stakeholder wishes are still left unfulfilled. The open design approach avoids these conditions of sub-optimality by giving equal weight to experts and laymen having an interest in the outcome of the design process.

Limitations regarding implementation in the construction industry
The required change of mind-set from contract specifications and control to fitness for purpose and stakeholders involvement requires reflection-in-actions. This means learning by doing and developing the ability for continued learning and problem solving throughout the professional's career (van Gunsteren & Binnekamp, 2016). This change of mind-set can only be successfully implemented if the higher management agrees upon it and provides the project managers and the employees with both the freedom and the support to do so.

7.4 Parametric Design

Parametric Design (PD), also known as Constraint Design, is a way of thinking that designers may find alien, as the first requirement is to explicitly express and explore relationships. Typically, designers address complexity by relying on experience and the use of design heuristics. However, the specificities of each context can undermine the relevance of such an approach. In this regard, the use of Computer Aided Design (CAD) has increased over the past years. Currently, there is an increasing demand of flexible tools for CAD. PD seems to be a good response seeing as PD is being more and more used in order to make variations in the design process less difficult (Hernandez, 2006).

Some of the very earliest design systems were parametric and the defence, marine and automotive industries have built parametric models for many years (Woodbury, Williamson, & Beesley, 2006). PD introduces the new idea of relating parts together and defer to the system the task of keeping parts related. Embedded in this method of exploration is the idea of capturing design history and returning it in an editable form. With PD, early design models become conceptually stronger than conventional CAD models and less constrained than building information models, as parameters express the concepts contained in the model and give interactive behaviour to components and systems. An important aspect of design is change and PD represents this change. By using PD, new capabilities in adapting to the context and contingency can be explored. By supporting designers in explicitly stating intentions, parametric modelling systems engender exploration of new possibilities (Woodbury, 2010; Woodbury et al., 2006).

According to Woodbury (2010) and Wassim (2013), PD can be defined as follows:

> *"Parametric design is a process based on algorithmic thinking that enables the expression of parameters and rules that, together, define, encode and clarify the relationship between design intent and design response. Parametric design is a paradigm in design where the relationship between elements is used to manipulate and inform the design of complex geometries and structures"*

Objectives

The aim of PD is to allow for a flexible design that can adapt to the context by using parameters within the design. According to Woodbury (2010), Aish and Woodbury (2005), Monedero (2000), Nembrini, Samberger, and Labelle (2014), and Woodbury et al. (2006) this objective can be achieved, seeing as PD:

- enables the exploration of a great number of alternatives and variations
- enhances the search for designs better adapted to context
- can facilitate discovery of new forms and kinds of form-making
- can reduce the time and effort required for change and reuse
- can yield better understandings of the conceptual structure of the artefact being designed
- maintains relations while modifying their parts independently
- allows designers to model classes of design and parts of the editing process

Characteristics

Based on various literature with regard to PD, the following characteristics have been identified:

- **parametric models** - PD is carried out with the aid of parametric models, which are computer representations of a design constructed with geometrical entities that have attributes that are fixed and other that can vary. There are two types of parametric modelling systems, being the propagation-based and constraint-based systems. The propagation systems compute from knowns to unknowns with a dataflow model, whereas constraint systems solve sets of continuous discrete constraints (Woodbury et al., 2006).

    - **parameters** - The variable attributes in the parametric models are the so-called parameters, which can at any given time to search for different possible solutions. The parametric model responds to the changes by adapting or reconfiguring to the new parameter values without erasing or redrawing (Hernandez, 2006).

    - **constraints** - The fixed attributes in the parametric models are the so-called constraints (Hernandez, 2006). The constraints in itself can also be either geometric constraints or physical constraints (Monedero, 2000).

    - **design families** - Parametric models imply design families. By varying inputs to a model, different specific designs are produced. Exploring the resulting design space is one of the challenges for future parametric modelling research (Hernandez, 2006).

    - **variations** - Parametric models have a strong potential for generating and exploring early design variations. Variations are a fundamental part of the design process in the search for solutions to the design problem at hand. Variations support improvement of the design, which in turn improves the quality of the final design artefact (Hernandez, 2006; Nembrini et al., 2014).

- **relations** - Besides choosing an entity, marking its position and assigning dimensions to it, it must be specify the relation that it shall keep with other entities in the model (Monedero, 2000).

- **iterative process** - PD is a continuous and iterative search process of variations of a design idea, in which designers constantly go back and forth between different alternatives of possible solutions. It is very likely to revisit a previously abandoned solution and rework it (Hernandez, 2006).

- **working explicitly** - A crucial aspect of PD it the fact that nothing can be created in a parametric model if the designer has not explicitly exemplified the relevant conceptual and constructive structure of the design (Aish & Woodbury, 2005).

Limitations regarding implementation in the construction industry

One of the limitations of PD is that the use of PD may introduce negative consequences such as the additional effort and the corresponding time consumed. Additional effort is needed from the designers as the numbers of items to pay attention to increases by the use of PD (Aish & Woodbury, 2005). Also, the set-up of PD can be time consuming as it is difficult to define physical information regarding the design in an early stage (Hernandez, 2006; Nembrini et al., 2014).

Another limitation of PD is that the current PD modelling tools are considered to be unsatisfactory (Monedero, 2000). This is substantiated by the fact there is a lack of appropriate instruments to modify the model interactively once it has been created. However, the ability of interactively modifying the model is a fundamental aspect in a design activity as the designer is constantly going back and forth, re-elaborating some particular aspects of the model or even re-elaborating a solution that had been temporarily abandoned in a previous phase. Moreover, a fundamental problem in the current CAD-systems is that it is difficult to make intuitive knowledge explicit. An example of this is formulating 'common sense' such as the fact that the floors of a building are always horizontally placed.

Furthermore, the unpredictable nature of the design process may be a limitation. When using PD, the designers use declared parameters to define the form. This way of designing requires accurate thinking in order to build a refined geometrical structure, which is flexible enough to produce variations. So, the designer must anticipate to which kinds of variations he/she wants to explore in order to determine the kinds of transformations that the parametric model should be able to make. However, this anticipation is very hard due to the unpredictable nature of the design process.

Lastly, traceability may be a limitation when using PD. Even though the exploration and comparison of alternative designs is considerably eased through parametric design, the approach currently mainly relies on visual programming tools. Therefore, the level of complexity is limited in traceability (Nembrini et al., 2014).

8 MOST SUITABLE DESIGN METHOD

In this chapter, the findings of the waste identification and the design method exploration will be brought together in order to analyse the interfaces between both findings. The aim of this chapter is to determine which of the explored design methods or a combination of methods addresses the identified types of waste in the current design process best. First, a brief clarification on the matrix will be provided in section 8.1. Then the analysis will be elaborated in section 8.2 per design method. Lastly, section 8.3 concludes which design method is the most suitable.

8.1 Matrix clarification

As already stated, the identified top types of waste are ranked based on their presence in the design process, the impact on the design productivity and the influence that employees may have on preventing or mitigating the type of waste. Therefore, the interfaces do not have equal weight. The weighing of each interface is illustrated by Table 8.1.

Table 8.1 I Weighing factor explanation

Ranking of type of waste	Weight
1	10
2	9
3	8
4	7
5	6
6	5
7	4
8	3
9	2
10	1

The matrix that is presented in Table 8.2 incorporates the ranked top types of waste that have been identified in chapter 5 horizontally and the characteristics of the design methods that have been explored in chapter 6 vertically. The interfaces between the types of waste and design method characteristics are visualised by ticking the corresponding cell.

The total interface score per design method characteristic is calculated by assigning the corresponding weight to each ticked cell and then summing up all weights. The total interface score per design methods is subsequently calculated by adding up all individual characteristic interface scores. The design method with the highest total score represents the design method that addresses the identified types of waste in the current design process best.

8.2 Matrix analysis

The analysis of the matrix entails an elaboration per design method on the interfaces between the characteristics and corresponding types of waste based on Table 8.2. The interfaces are determined based on the studied literature regarding the specific design methods.

Table 8.2 I Waste vs Design method Matrix

ranking	type of waste	weight	concurrent engineering (Mohamad, 1999)				systems engineering (ProRail et al., 2013)				open design (Van Gunsteren, 1995)				parametric design (Woodbury et al., 2006; Monedero, 2000; Hernandez, 2006; Aish & Woodbury, 2005)			
			project life cycle requirements	cross functional teams	focus on the client requirements	reduce development time	working explicitly	focus on customer needs	life cycle optimisation	systems thinking	fitness for purpose	stakeholder involvement	complex project management practices	use of open design	use of parametric models	use of relations	iterative process	working explicitly
1	implicit way of working	10					x											x
2	ambiguities regarding the client requirements	9	x	x	x		x	x		x	x	x	x	x	x			x
3	insufficient attention regarding verification	8					x			x	x						x	x
4	insufficient use of existing knowledge	7					x											x
4	gathering internal information	7	x	x			x											x
4	ambiguities regarding the level of detail	7	x				x		x	x	x							x
4	ambiguities regarding the project	7	x				x			x	x		x					x
4	overproduction per aspect and/or per phase	7							x		x				x			
9	lack of alignment between disciplines	2		x		x	x								x	x		x
10	working with the wrong starting points, assumptions, requirements and/or information	1					x				x	x	x		x	x	x	x
	total score per characteristic		30	18	9	2	58	9	14	31	39	10	17	9	19	3	9	58
	total score per design method		84				102				75				89			

Concurrent Engineering

The characteristics of CE address several of the identified top types of waste. Especially the consideration of project life cycle requirements and the use of CFTs are able to contribute to preventing, mitigating and/or eliminating multiple types of waste.

Consideration of project life cycle requirements - By considering all project life cycle requirements in the design process, the ambiguities regarding the client requirements, level of detail and the project itself are likely to be reduced. This is due to the fact that the expertise of various project members and stakeholders are considered from the outset. The involvement of various expertises from the outset is also likely to ensure better gathering of internal information.

Cross Functional Teams - The ambiguities of client requirements will also be reduced by the use of CFTs, as all members contribute to the design process including the client itself. The internal information flow will also be improved, as all knowledge regarding the project and the requirements is present within the team from the outset. The formation of the CFTs from the outset also ensures that the lack of alignment between disciplines will reduce. The knowledge of each team member regarding how downstream issues can influence the design process can be used to align the disciplines.

Focus on the client requirements - Focussing on the client requirements will of course reduce the ambiguities regarding the client requirements. However, this will only be the case if the client is supported in the establishment of their requirements, by means of a framework for example.

Reduce development time **-** The reduced development time is achieved through carrying out project tasks in parallel. In concurrent engineering it is possible to work in parallel, as all project lifecycle requirements are considered simultaneously. This allows for project members to share project information throughout the whole duration of the project and is likely to contribute to reducing the lack of alignment between disciplines. When information regarding a certain aspect of a discipline is needed by another discipline, there is no barrier of not being able to sort it out yet. All aspects can be sorted out from start and no consecutive order is appointed.

Systems Engineering

The characteristics of SE have even more interfaces with the identified top types of waste than CE. Especially the characteristics system thinking, working explicitly and working from abstract to concrete are able to contribute to preventing, mitigating or eliminating multiple types of waste.

System thinking - By perceiving the whole project as a system and taking into account all aspects of the system including all parties involved throughout its life span, the existing ambiguities are likely to be reduced. In this case being the ambiguities regarding the client requirements, the level of detail and the project. Moreover, system thinking also contains a framework for the verification of the system.

Customer needs - As the customer requirements, also known as client requirements, are documented in a client requirement specification and continuously aligned during the project according to the current needs, the ambiguities regarding the client requirement will be significantly reduced. Moreover, SE consists of explicit verification and validation and by verifying the design continuously, the client requirements will be discussed on a regular basis.

Life cycle optimisation - SE focuses on optimising the system in all its phases. Meaning, the level of detail needed per phase will be determined from outset. By taking into account all project phases, it is likely that the ambiguities regarding the level of detail will be reduced. By reducing these ambiguities, the overproduction will also be reduced as a positive consequence.

Working explicitly - The use of a SE equals working explicitly and thus eliminates the implicit way of working. Working explicitly can have a positive influence on many types of waste, as the aim is to avoid ambiguities. Meaning, the ambiguities regarding the client requirements, level of detail and project will likely be reduced. Also, working with the wrong assumptions, requirements and/or information will likely be reduced as every input is documented explicitly and therefore tractable. The traceability and explicitness of documents information and documents eases the gathering of internal information as well as the alignment of disciplines and the verification of the design.

Working from abstract to concrete - Working from abstract to concrete involves an iterative design process in which the specified client requirements are evolving from abstract needs to a translation of the needs into a concrete solution. The aim of this way of working is to ensure that the level of detail of the design corresponds with the abstraction of the stage the design is in and should contribute to reducing overproduction. It also allows for adjustment of the assumptions, requirements and/or information on which the design decisions are made. The iterative nature of the design process also allows better alignment of the disciplines, as all client needs are firstly specified and decomposed in an iterative way. In order to decompose accurately, the input of all disciplines is demanded. The specification and decomposition is likely to result in a concrete solution in which all disciplines are incorporated.

Open Design

One of the characteristics of OD, fitness for purpose, has several interfaces with the identified top types of waste, meaning this characteristic is able to contribute to preventing, mitigating and/or eliminating several types of waste. The other characteristics only address one or two types of waste.

Fitness for purpose - The aim of OD is to achieve as much relevant quality as possible. In order to comply with the relevant quality, it is important to have a clear understanding of the project, the relevant client requirements and the level of detail needed. Therefore, one of the focus points will be on reducing the ambiguities thereof. Overproduction can be categorised as wasted quality and the purpose of fitness for purpose entails preventing wasted quality as much as possible. However, overproduction can also be categorised as realised service quality. Meaning, the overproduction is intentionally and in line with the fitness for purpose approach, which is supported by OD. Seeing as the purpose of fitness for purpose also entails the shift from the specified quality towards the relevant quality, it is likely that working with the wrong assumptions, requirements and/or information will be reduced. This shift namely involves creating specifications that correspond to the relevant quality rather than designing what is specified. Moreover, by continuously wondering whether the project is still fit for purpose, verification also takes place continuously. Meaning, more attention is paid with regard to verification when applying OD. Furthermore, an important finding from the interviews as well as the value analysis sessions is that it is in the Witteveen+Bos employees' nature to always put in a little more effort than needed. In order to prevent that this leads to overproduction, the principle of fitness for purpose may be a valuable addition, seeing as the extra effort will be put in offering more added value to the client and/or end user.

Stakeholder involvement - The early involvement of stakeholders within the design process can have a positive influence on two types of waste. Namely, ambiguities regarding the client requirements and working with the wrong assumptions, requirements and/or information. Due to the stakeholder involvement, both types of waste can be verified by the stakeholders from outset and throughout the process, which will result in a reduction of the type of waste.

Complex project management practices - As already explained, PII management practices are intended for complex and unpredictable projects. The bigger infrastructure tasks, involving a great amount of stakeholders and environmental issues can be categorised as a complex project. The ambiguities regarding these complex projects and the corresponding ambiguities regarding the client requirements can be prevented, mitigated or eliminated by applying the PII management practices. Moreover, PII management practices suit projects in which uncertainties are common. This characteristic matches the type of waste of working with the wrong assumptions, requirements and/or information, as this involves a lot of uncertainty. Especially the assumptions made during the design process, but also the requirements that are commonly adjusted during the process or even added.

Use of open design - By the use of open design, equal weight is given to the interests of experts and laymen. This may ensure a better translation of the client requirements into a design solution.

Parametric Design

One of the characteristics of PD that can contribute to preventing, mitigating and/or eliminating several types of waste is working explicitly, which is the same as one of SE's characteristics. Besides, the use of parametric models is the only characteristic of the explored design methods that addresses the insufficient use of existing knowledge. PD's other two characteristic only contribute to one or two types of waste.

Use of parametric models - In order to be able to set up the parametric model, all the requirements need to be clear. These requirements are used to determine the parameters and constraints regarding the design, which will then result in multiple variations. So, the ambiguities regarding the client requirements will likely be reduced when using a parametric model. The same accounts for working with the wrong assumptions, other requirements and information. All requirements and information needs to be complete before the model can be composed and the assumptions should be somewhat correct, however as the model is aimed at adapting to changes, the use of wrong assumptions, requirements and/or information is incorporated. Moreover, the use of a parametric model allows for generating many variations. As the parameters and constraints regarding the design are incorporated this ensures only suitable variations. Meaning overproduction is less likely. Also, by using a model the disciplines are more easily aligned to one another and conflicts are detected more easily. Furthermore, design errors are less likely as parametric models make use of standardised designs and methods in which standards and guidelines are incorporated and thus make use of existing knowledge.

Relations - By specifying relationship of one entity to another, the lack of alignment between disciplines will be reduced. Adjusting a certain entity will immediately show the consequences for and possible clashes of the related entities and so the different disciplines can be better aligned. The relations between entities will also have a positive influence on working with the wrong assumptions, requirements and/or information. It will not ensure that the assumptions for example are more likely to be correct with the use of PD. However, it will ensure that the adjusting of wrong assumptions is carried out more easily and the subsequent consequences are also adjusted more easily.

Iterative process - An iterative design process enables the possibility of verification and adjusting the wrong assumptions, requirements and/or information. As an iterative design process consists of design loops, the end of every loop may be comprised with a verification session followed by adjusting the incorporated assumptions, requirements and/or information before starting a new design loop.

Working explicitly - The use of a PD goes hand in hand with working explicitly. The explicit way of working can have a positive influence on many types of waste, as already explained in the discussion of SE.

8.3 Conclusion

Based on the interfaces that are indicated in the matrix, SE appears to have most interfaces with the identified types of waste at first sight, followed by CE and PD, and lastly OD. However, it is not only important which of the design methods has the most amount of interfaces. The ranking of the types of waste that a certain design method addresses is also of great importance.

As explained, the types of waste are ranked according to the outcomes of the questionnaire, in which each type of waste is reviewed and scored based on their presence, their impact and the employee's influence of preventing, mitigating and/or eliminating the type of waste. Due to the fact that the types of waste are ranked, each interface has a weight incorporated and the sum of all weighted interfaces results in a final score. As can be seen in Table 8.2, SE does not only have the most interfaces but also has the highest total score. Meaning that SE is supposed to be the most suitable solution to addressing the identified top types of waste.

Even though SE is perceived to be the most suitable solution, it does not necessarily mean that the implementation of SE will prevent all top types of waste from occurring. For example, no interface is found between the characteristics of SE and the insufficient use of existing knowledge. Yet, SE does have characteristics that can support the use of existing knowledge. For example, working explicitly can increase the traceability of information and knowledge, which in turn increases the chance of using the existing knowledge. Besides, working explicitly also provides the possibility of setting up a database containing existing knowledge, which in turn provides for more sufficient use of existing knowledge. Moreover, it has to be noted that none of the other design methods, except for PD, consists of a characteristic that does directly address the insufficient use of existing knowledge. Based on the fact that PD is the only design method that does address the insufficient use of existing knowledge, it may be useful to look into the implementation of a combination of design method characteristics as well.

Furthermore, the outcomes of the matrix are based on theory regarding the characteristics of the design methods. Meaning that SE might be perceived as the most suitable in theory but not in practice, as the identified types of waste occur in a certain context and thus the context has to be taken into account as well. Therefore, the next chapter will look into the implementation of SE in practice.

PART IV. CASE STUDIES

9 CASE STUDY SESSIONS

Now that SE is determined to be the most suitable design method to address the identified types of waste, case studies have been performed in order to gain insight into how successful SE is implemented in practice with regard to preventing, mitigating and/or eliminating waste. A total of three infrastructure projects, in which SE has been used in the first two projects during the design process, have been selected for these case studies. Furthermore, each of the three projects has a different scale and a different client. Altogether, it is assumed that the three projects are representative for the projects that an engineering company, such as Witteveen+Bos, carries out. First, each project will be discussed separately by providing a short introduction into the concerning project and discussing the design process, the waste identified during the process and the control measures that have been applied or might be applied in future projects. Then, a cross case analysis will be performed in order to analyse both the similarities and differences in types of waste and corresponding control measures between the three projects. The output of the case studies and cross case analysis serves as important input for the recommendations.

Figure 9.1 I Case study projects (1) A9 Badhoevedorp-Holendrecht (2) Oosterweelverbinding (3) VR view of Zaanenstraat (Witteveen+Bos, 2017)

9.1 A9 Badhoevedorp - Holendrecht

Part of the Schiphol-Amsterdam-Almere (SAA) program is the widening of the A9 at Amstelveen. In the original route decision (Dutch: TB) of 2011 a tunnel was designed. However, due to the financial crisis and the changing real estate market, the contribution from the municipality of Amstelveen to the tunnel was no longer justified. In 2012, Rijkswaterstaat spent three months designing a new solution in which it was decided to deepen the A9 (Witteveen+Bos, 2016d). Amongst the results of this internal design process were factsheets containing hazardous aspects, which form the basis for the project. Witteveen+Bos obtained the project based on BVP. Since 2014, Witteveen+Bos has been responsible for the integral design, planning and plan study of this TB for the A9, which was signed in March 2017 (Witteveen+Bos, 2017a). Rijkswaterstaat was responsible for calculating the costs of the project, as Witteveen+Bos was not responsible for drawing up the contract. The aim of the project is to robustly design an achievable, feasible and licensable TB that the future contractor can design in further detail (JR, personal communication, November 9, 2017). The project concerns the highway between the interchanges Badhoevedorp and Holendrecht (Witteveen+Bos, 2014). The concerning road section will be expanded from 2x3 lanes to 2x4 lanes and an additional switch lane. The extra lanes will ensure improvement of the traffic flow and with that the accessibility of the northern Randstad. Furthermore, the highway will be recessed over a length of 1.3 kilometres including two large roof constructions and alongside the highway 12 kilometres of new acoustic barriers will be built. By this, the quality of life in the area will be increased as noise nuisance will be reduced and the air quality in the surrounding area will be improved (Witteveen+Bos, 2017a).

The design process

The design process of the A9 consists of three design loops, being risk-driven design (Dutch: RGO), concept integral design (Dutch: cIPO), and integral design (Dutch: IPO). In this case study, only the first loop of the design process has been analysed, which is the RGO loop. The aim of this loop is to determine any disruptions in the design made by RWS by identifying the current client requirements.

The design of the A9 is subdivided into three different parts, being roads, infrastructural works, and integration. In the context of the design process, four design ateliers have been established. A design atelier consists of employees from Witteveen+Bos, employees of Rijkswaterstaat and environmental stakeholders. The design ateliers entail a consultation with approximately 15-20 people of the three aforementioned parties. Every 2 weeks, a consultation was held in which the design ateliers discussed all three design parts. The result of such a consultation was a variant note without any considerations regarding the design. Witteveen+Bos did provide Rijkswaterstaat with notes consisting of aspects that Rijkswaterstaat could take into consideration when deciding on the design.

Waste identification

During the case study session, several types of waste were mentioned that occurred in the design process of the A9 Badhoevedorp - Holendrecht, being:

- gathering external information
- ambiguities regarding the project
- ambiguities regarding the interfaces
- client changes
- overproduction per aspect and/or per phase
- solution space too narrow

The most important findings will be discussed in the following section and a more detailed elaboration of each of these types of waste can be found in Appendix B.4.

The main finding from this session is that there were a lot of ambiguities regarding the project, which subsequently resulted in many other types of waste. The reason for the ambiguities regarding the project could be traced back to the fact that the client itself, Rijkswaterstaat, did not know the exact aim and scope of the project at first. A clear example of this is that Rijkswaterstaat put a lot of focus and effort on the highway part at Amstelveen, whereas the concerning project area of the TB that was to be designed was supposed to focus on Badhoevedorp - Holendrecht. Because of the ambiguities regarding the project, the exact client's request needed to be explored first, which eventually led to an increase in project scope. Because of this increased project scope, Witteveen+Bos had to deal with many client changes and thus had to file many requests for change (Dutch: VTW) accordingly. Besides, politics as well as the environment also had major influence on the project, which also led to client changes that did not add value to the design itself. For example, the TB of 2011 consisted of three parts of which the middle part had to be revised in the project A9 Badhoevedorp - Holendrecht. However, the demarcation lines of the three parts were not feasible in practice, as certain infrastructural works that were part of the adjacent parts, being outside the project's scope, needed to be incorporated in order to be able to come up with a feasible solution. Thus, the project scope needed to be expanded to incorporate the important infrastructural works. However, during the design of the TB of 2011 one of the stakeholders, Ouder-Amstel, showed considerable resistance regarding the concerning area developments but eventually agreed upon the TB. Therefore, Rijkswaterstaat advised to change as little as possible in the revised TB regarding Ouder-Amstel's interests. But due to the scope increase, it was unavoidable to make changes to the area that Ouder-Amstel had already agreed upon. Therefore, Witteveen+Bos decided to design a new crossroad in order to persuade Ouder-Amstel into the process. This may be seen as a clear example of overproduction, but in this case it is rather a part of stakeholder management, as the concerning stakeholder might oppose to other aspects otherwise.

Another important finding is that the project members of Witteveen+Bos were overloaded with information from Rijkswaterstaat. However, the approximate 1000 documents were neither structured nor complete. According to the project members, 90% of the information was redundant, not up-to-date, of poor quality, lacking the right references or containing different versions. This led to checking every document one-by-one, which took a disproportionate amount of time compared to the information that actually turned out to be of use. Besides, the incompleteness of information led to requesting the documents from Rijkswaterstaat, which took a lot of extra waiting time.

Control measures

As the ambiguities regarding the project were found to be the cause of many other occurring types of waste, the control measures regarding this type of waste will be explained in more detail. Witteveen+Bos has applied clear control measures regarding the mitigation of project ambiguities with regard to the unclear aim and scope of the client. A project member of Witteveen+Bos was appointed to attend the project management team meetings of Rijkswaterstaat in order to be involved at a higher level. This way, weekly feedback could be given to Rijkswaterstaat on the design progress of Witteveen+Bos and the difficulties that were faced could be immediately discussed with Rijkswaterstaat. This control measure was experienced by the project members to be of value due to the relatively direct contact and communication with Rijkswaterstaat. This way, difficulties and further ambiguities regarding the project could be discussed with the client directly.

The other control measures that have been applied during the design process in order to mitigate the occurring types of waste are listed in Table 9.1 and elaborated in more detail in Appendix B.4. As can be seen from Table 9.1, no control measure was applied for the gathering of external information, which was the other important finding.

Table 9.1 I Overview of control measures per type of waste (A9 Badhoevedorp - Holendrecht) (own illustration)

Type of waste	Applied control measures	Proposed control measures
Ambiguities regarding the project	• Use of design loops • Appoint a project member at a higher management level • Appoint a BVP manager	• Get to know the client • Learn from previous projects (database)
Ambiguities regarding the interfaces	• Use of design ateliers	
Client changes		• Be flexible to adjust own process
Overproduction per aspect and/or per phase	• "What is best for project?" • Define own design levels beforehand • Use experience and common sense in early design phase	

9.2 Oosterweelverbinding

The Oosterweelverbinding is currently one of the largest European infrastructure projects. This project involves closing the Ring around Antwerp and improving the flow and integration of the existing Ring. The Oosterweelverbinding is an important part of the 2020 Master Plan, which provides additional road infrastructure, public transport projects, extra cycle paths and water-related infrastructure works among other things. For this project, Witteveen+Bos has united with Sweco (formerly known as Grontmij) in THV ATLAS. Commissioned by Beheersmaatschappij Antwerpen Mobiel (BAM), THV ATLAS has conducted studies regarding the realisation of the Oosterweelverbinding right bank. In June 2015, THV ATLAS was also granted the project for the left bank of the Oosterweelverbinding (Witteveen+Bos, 2015). The total assignment comprises three sub-projects that contribute to the closure of the Antwerp Ring:

- The realisation of the infrastructure projects on the left bank, including the adaption of the northern junction (E34/R1), the southern junction ((E17/R1), access and exit complexes and parts of the underlying road network
- A new Scheldt tunnel, which will be built as an immersed tunnel. The tunnel will be about 1.8 kilometres long, with three lanes in each direction, and a separate tube for cyclists and pedestrians
- Construction of a construction dock in Zeebrugge, where the individual tunnel elements are prefabricated. Then they will be towed to Antwerp to be immersed at the construction site.

This case study focuses on the sub-project Scheldt Tunnel, which has been tendered 2.5 years ago. The aim of the project is to provide the client with a feasible final design (Dutch: DO) regarding the design and the cost estimate. However, in Belgium the definition of a DO differs from the Dutch definition. This is due to the fact that the Belgian culture is more old-fashioned compared to the Dutch culture. The Belgians still work with detailed and prescriptive specifications (Dutch: bestekken). So, in the perspective of the client the definition of a DO is a complete contract. The scope of the project does not involve stakeholder management. At the end of January 2018, the contract will be put out for tender.

The design process

The design process of the new Scheldt tunnel is very different from other projects. This may be due to the fact that this project has already been put out for tender before. Witteveen+Bos has received the former design and used it as a base design. This base design needed to be adjusted to the current situation and then the new design needed to be specified into an Engineering & Build contract.

The design process is subdivided into two design loops, being the preliminary design (Dutch: VO) and the final design (Dutch: DO). During the first design loop, the project team analysed the base design in order to see if they had any questions regarding certain elements of the design. For example, the bicycle tunnel next to the car tunnel was very steep, which was determined by the project team to be a safety risk. However, due to political commitment, the design had to consist of both a tunnel for cars and a tunnel for bicycles and thus the client did not agree to change this design part. After the analysis of the base design, the preliminary design was made. The preliminary design was also analysed in order to identify the bottlenecks and all bottlenecks were then discussed with the client. Thereafter, the final design was made, which consisted of approximately 6 to 7 iterations as there were many ambiguities regarding the requirements and the project itself. The development of the final design lasted almost a year. During the whole design process, the main question in every step was "What is required in this step with regard to the final level of detail?" Also, design notes that contain the considerations have been made throughout the design process.

Waste identification

During the case study session, several types of waste were mentioned that occurred in the design process of the Oosterweelverbinding. Moreover, in this project a new type of waste is introduced, namely cultural clash. As Belgium and The Netherlands have a different culture, several inefficiencies can be traced back to the cultural differences. The types of waste that were mentioned are as follows:

- lack of support
- lack of alignment between disciplines
- ambiguities regarding the basic specifications
- ambiguities regarding the level of detail
- working with the wrong assumptions, requirements and/or information
- culture clash

The most important findings will be discussed in the following section and a more detailed elaboration of each of these types of waste can be found in Appendix B.4.

Three main findings can be derived from this session, of which the first is that the cultural differences between Belgium and The Netherlands have played an important part in the design process of the Oosterweelverbinding. Belgians make use of basic specifications, which is referred to in Dutch as *bestekken*. These specifications consist of enormous documents containing many duplications and references to other specifications or specification documents. Many different specifications such as roads and rivers exists and each specification is elaborated in a lot more detail than Dutch people are used to. Meaning, Dutchmen may have trouble determining what is stated exactly and what has to be done subsequently. Due to the strict specifications, the Belgian infrastructure is very much interwoven with politics. Therefore, Belgians are not used to thinking 'out-of-the-box". Besides, certain terms are defined differently in Belgium than in The Netherlands. For example, different definitions on the Engineering&Build contract existed and therefore both parties had to agree on the definition first. Witteveen+Bos has presumed that the contract would be a Design&Build contract with solution space for the contractor. However, the client presumed that the contract would be according to the classical Belgian basic specifications.

The second main finding is that Witteveen+Bos' project team has been working with the wrong assumptions, requirements and/or information even though they had observed and communicated some of them in the early design phase. However, the client did not want to adjust the design and neglected the observations of Witteveen+Bos. Later on in the design process, those aspects eventually did come to the client's attention and had to be adjusted nonetheless. Moreover, new client and stakeholder requirements were taken into account in the design, but were not included in the cost estimations, leading to budget overruns. Also, no comprehensive risk analysis was conducted, due to the fact that the project team was under-staffed.

The third main finding is that the client made some odd decisions, which resulted in a lack of alignment of disciplines. For example, the client decided to procure two different contracts for both the civil part of the project and the installation part of the project. According to one of the project members, this is a recipe for disaster, especially when these two parties do not work together. The same accounts for the designers of the projects. Next to Witteveen+Bos, a Belgian architect and Zwarts&Jansma Architects were also involved in the design process. However, all three parties worked and designed individually and did not collaborate until the end of the design phase. Which is bound to cause problems regarding the alignment of different elements of the design.

Control measures

As Witteveen+Bos had carried out projects in Belgium before, it is likely that they can implement the learning experiences obtained during these previous projects. However, the project members state that it is rather hard to learn from previous projects as team members shift in both parties. Therefore, it is important to report and structure the lessons learned from each projects. This has not been done properly in the past and therefore lessons learned could not be implemented during this project. In order to cope with the cultural differences between the Belgian client and Dutch employees of Witteveen+Bos, an intermediate has been introduced into the design process in order to take care of the communication and solve the issues between the two parties.

No specific control measures have been applied with regard to working with the wrong assumptions, requirements and/or information during this project. The project members did communicate their observations during the early design phase to the client, nevertheless the client decided to neglect this. Meaning, Witteveen+Bos started designing with the wrong assumptions and requirements. The project members proposed the use of set-based design as a possible control measure to this type of waste, as iteration is needed to come to the most suitable design and this way the possibility arises to come to the solution by a more structured method.

With regard to the lack of alignment, also no specific control measures have been applied during this project. However, the project members did propose two control measures that might have led to better alignment of the different disciplines. The first one is to interrupt the process when issues occur. By interrupting the process, the opportunity will be created to discuss the issue and come to an agreement with all parties involved before continuing the process in the wrong direction. The second control measure is to include evaluation sessions within the design process in order to evaluate the work that has been carried out and aligning the work regularly instead of at the very end of the design process.

The other control measures that have been applied during the design process in order to mitigate the occurring types of waste are listed in Table 9.2 and elaborated in more detail in Appendix B.4.

Table 9.2 I Overview of control measures per type of waste (Oosterweelverbinding)

Type of waste	Applied control measures	Proposed control measures
Lack of alignment between disciplines	• Interrupt process and make agreements first	• Include evaluation sessions • Maintain process flow by creating larger teams • Select teams based on profile and expertise
Ambiguities regarding the level of detail	• Verification and validation	• Determine the ratio time/quality in advance • Use risk-driven design loops • Defined time limit
Working with the wrong assumptions, requirements and/or information	• Use of letter to the higher management	• Use set-based design • Sufficient project members
Cultural clash		• Report and structure lessons learned • Use previous lessons learned • Introduce intermediate in case of bad relationship with the client

9.3 Zaanenstraat

The municipality of Haarlem has taken the next step with regard to the maintenance of the city. From May 17, 2017 all major maintenance projects will be carried out by permanent contract partners. In the preparation of these projects, Witteveen+Bos will be one of the supporting contract partners. This new way of working must ensure that the major maintenance projects are carried out more efficiently through more intensive cooperation. Also, the partners will make an innovative contribution to the circular economy and sustainability objectives of the municipality of Haarlem. Witteveen+Bos is the permanent partner in the Haarlem-West area, meaning that in the next four years all preparations for major maintenance projects west of the Spaarne will be carried out by Witteveen+Bos (Witteveen+Bos, 2017c).

This case study focuses on the Zaanenstraat, which is one of the ca. 80 projects that will be carried out in the Haarlem-West area. Within the Zaanenstraat, two different projects were acquired by Witteveen+Bos, being the sewerage model and the redevelopment of the public space. In the project regarding the sewerage model, the existing measures that were designed in 2012 needed to be verified with regard to the current situation. The results of this project needed to be implemented in the redevelopment of the public space, meaning that both projects are interrelated.

The design process

The design process of the Zaanenstraat differs from other projects. In order to explain both projects, Figure 9.2 illustrates both design processes on a timeline. As can be seen from the figure, two interrelated projects are carried out in parallel. However, at first the projects were carried out without knowing of the existence of the other project.

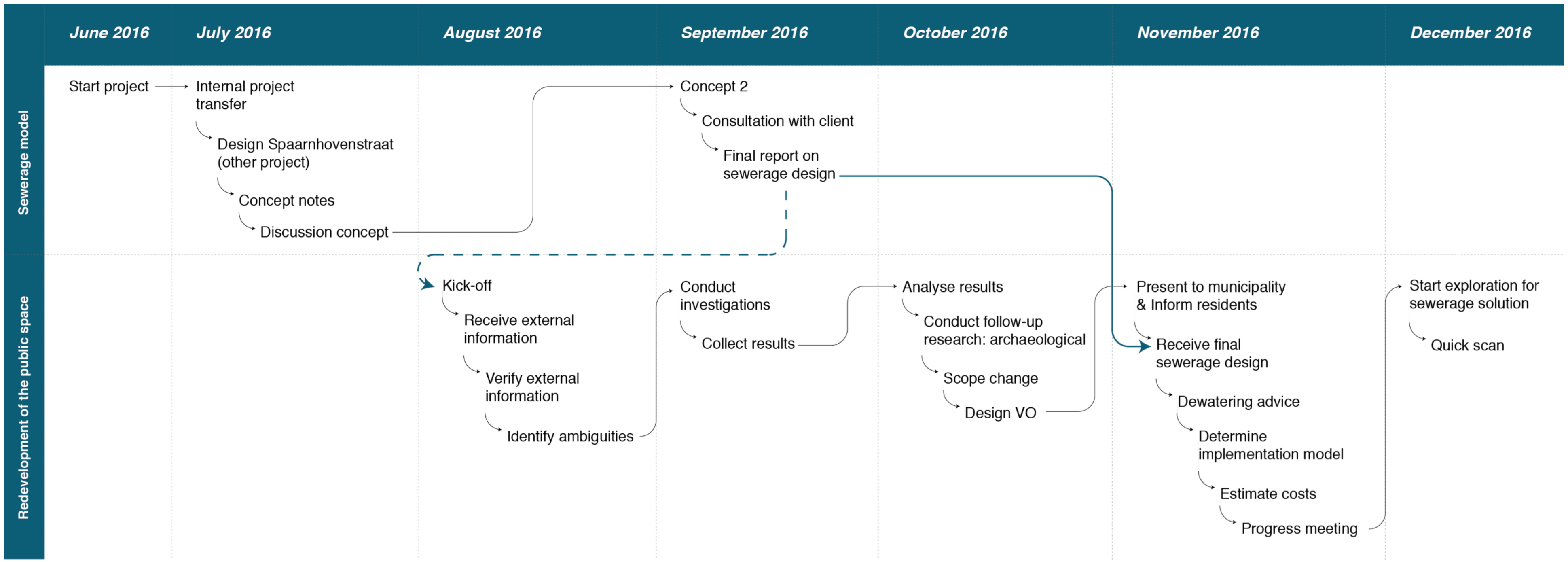

Figure 9.2 I Parallel design processes of the Zaanenstraat (own illustration)

The process that is illustrated first is the sewerage model design process. This project started in June 2016 and the final report on the sewerage design was completed in September 2016. The final report is part of the input for the redevelopment of the public space. However, the process design of the redevelopment of the public space started in August 2016 already (see dotted blue line). Yet, it can be derived from Figure 9.2 that the final report was not received by the project team of the redevelopment until November 2016 (see blue line).

Waste identification

During the case study session, several types of waste were mentioned that occurred in both the design processes of the Zaanenstraat. The two project will be seen as one big project concerning the Zaanenstraat, as many types of waste concern both projects. The types of waste that were mentioned are as follows:

- insufficient use of existing knowledge
- gathering external information
- lack of alignment between disciplines
- working with the wrong assumptions, requirements and/or information
- unnecessary design changes

The most important findings will be discussed in the following section and a more detailed elaboration of each of these types of waste can be found in Appendix B.4.

A total of three main findings can be derived from this session. Firstly, the lack of alignment between disciplines. As already mentioned in the explanation of the design process, both teams were not aware of the existence of the other team and thus of the other project in the same project area. Therefore, the sewerage model was not incorporated correctly in the redevelopment of the public space. So, when it became clear that Witteveen+Bos was carrying out both projects and the redevelopment team received the sewerage model of the sewerage team, the output of the sewerage team did not match the vision of the redevelopment team. Moreover, the realisation costs would be doubled in case the redevelopment team would adjust their design according to the sewerage model. The fact that the teams did not know of each other's existence may be due to poor internal communication, but it can also be attributed to the client for not notifying the teams of it.

The second main finding is the insufficient use of existing knowledge. Due to change of personnel on both Witteveen+Bos' side and the client's side several losses arose. On one hand the loss of project specific information and on the other hand the loss of knowledge and experience on the process acquired during the design process.

The last main finding is that the both design teams have been working with the wrong assumptions, requirements and/or information during the design process. The sewerage team has started their design based on the wrong requirements. The project members stated that this was due to the fact that the client requirements were vaguely described, but also admitted that they have not been sufficiently critical with regard to the client requirements. Moreover, the analysis of the redevelopment team showed that the total replacement of the sewerage model, which was the client's requirement, was not feasible and thus the scope had to be changed. After the scope change, the redevelopment team started designing the VO even though they had not received the output report of the sewerage team yet. This led to the redevelopment team designing based on assumptions, which could only be verified after receiving the output report of the sewerage team.

Control measures

As the explanation of the two parallel design processes took quite some time, there was not enough time left to discuss the applied control measures regarding all types of waste that occurred during the design process. The control measures that have been discussed are regarding the first two main findings, being lack of alignment between disciplines and insufficient use of existing knowledge.

No specific control measures have been applied during the design process with regard to the prevention or mitigation of the loss of expertise, knowledge and/or information. Nonetheless, the project members did propose possible control measures that could be applied in future projects. In case personnel is transferring projects or leaving the company, it is important to engage the specific person to stay available by telephone or provide back office work for a determined period of time, to keep the appointed substitute up-to-date throughout the process and/or work in parallel during the transfer period of the new team member. With regard to the transfer of expertise and knowledge, it is important to ensure that the essence is documented explicitly, to use the back-to-back principle as an example and/or make use of decision and transfer lists.

With regard to the lack of alignment, the project team applied two control measures. First of all, the two project teams decided to merge both projects into one big project instead of two separate projects, seeing these two projects are highly interrelated. Besides, the project teams started to attend each other's design meetings. This way the two projects could be aligned more directly by immediately discussing the issues when they are observed.

Table 9.3 provides a short overview of the control measures that have been applied during the design process and that are proposed by the project team for future projects.

Table 9.3 I Overview of control measures per type of waste (Zaanenstraat)

Type of waste	Applied control measures	Proposed control measures
Insufficient use of existing knowledge		• Engage personnel to stay available or provide back office work for a determined period of time • Keep appointed substitute up-to-date throughout the process • Document the essence explicitly • Use back-to-back principle • Use decision and transfer lists
Lack of alignment between disciplines	• Attend each other's design meetings	• Perceive separate projects as one big project

9.4 Cross case analysis

Based on the three case studies, three main conclusions can be drawn. First of all, the use of SE in the design process is not as efficient in practice as it is stated in theory. This conclusion can be drawn as theory states that SE is supposed to prevent or mitigate the types of waste that have occurred in the case study projects nonetheless. This may be due to the fact that SE as a method is not as satisfactory in practice as theory describes or the fact that SE is not implemented correctly in practice, which may be due to all different kinds of difficulties.

Next to that, it became clear that each of the three case study projects has experienced its own types of waste and has applied control measures accordingly. Some of the types of waste that occurred in the case study projects were similar, such as the lack of alignment between disciplines, which occurred in both the Oosterweelverbinding and the Zaanenstraat. However, the control measures that were applied are different in both projects. The Oosterweelverbinding proposed to interrupt the design process in order to make agreements on the observed issues first and to include evaluation sessions regarding the design as well as the alignment of the disciplines within the design. Whereas in the Zaanenstraat project, the different disciplines have been attending each other's design meetings in order to allow for direct communication and discussion regarding the observed issues, which is believed to result in better alignment between disciplines. So, it appears from the case studies, that every project addresses each type of waste differently even though all projects are carried out while using the SE method. However, it is not clear which of the applied control measures is better than the other, as no explicit documentation is available regarding the applied control measure and the influence of the control measure on the design process and its efficiency.

Lastly, the issues that arose during the design processes of the case studies are not only and specifically related to technical complexity, but rather to organisational and environmental complexity. This conclusion can be endorsed by the research of Bosch-Rekveldt (2011) into managing project complexity. Bosch-Rekveldt (2011) has developed a framework that consists of a total of 47 elements, the so-called TOE framework (see Appendix C.2), that indicates either technical, organisational or environmental complexity. Table 9.4 lists the issues derived from the case studies and the corresponding type of complexity with regard to the TOE framework.

Table 9.4 I Categorisation of issues regarding the TOE-framework

Issue	Type of complexity
Client does not know the exact aim and scope of the project	Technical
Information overload (incomplete and unstructured information)	Environmental
Culture clash	Organisational
Bad relationship with client	Organisational
Not used to the level of detail and amount of the basic specifications	Technical / Environmental
Negligence of client	Environmental
No comprehensive risk analysis	Organisational
Separate contracts	Organisational
No collaboration between different involved parties	Organisational
Poor internal communication	Organisational
Client did not notify important information	Environmental
Change of personnel	Organisational / Environmental
Vaguely described requirements	Technical
Engineering company not sufficiently critical on requirements	Organisational
Designing without output of the other discipline	Technical / Organisational

In short, the following conclusions have been drawn from the case studies:

- Several types of waste are still occurring even though SE is implemented. Meaning that SE is not as efficient in practice as stated in theory and thus needs be complemented by other methods or SE is not implemented correctly and one should focus on better implementation of the SE theory.
- Different control measures are used of which it is unclear what the best measure is and what the impact of each method is on the productivity of the design process. Meaning that best practices and lessons learned should be documented (more) explicitly.
- The issues that have arisen are rather organisational and environmental complex than technical complex. Therefore, more attention should be paid to these elements of complexity in order to improve design productivity.

PART V. ADVICE

10 PROPOSED RECOMMENDATIONS

Based on the interfaces of the explored design methods and the identified top types of waste, SE was determined to be the most suitable design method to address the types of waste occurring in the current design process. By applying SE to the current design process, the identified types of waste should be addressed by means of preventing, mitigating and/or eliminating them. However, the results of the three case studies show that waste still exist regardless of the implementation of SE. Moreover, it became apparent that the waste in the current design processes is rather due to organisational and environmental complexity instead of the technical complexity that engineering companies are aimed to focus on. Based on the results and findings from the case studies three recommendations will be provided in this chapter of which the first is a generic recommendation and the other two are specific recommendations. The specific recommendations are derived from the generic recommendation and are regarding the two most important types of waste that were found from the case studies, being working with the wrong assumptions and the lack of alignment between disciplines.

10.1 Project evaluations and lessons learned

One of the most important findings of the case studies was that many different control measures are applied during the design process, even though the same design method is used and the same types of waste arise. Of all the various applied control measures, no explicit information or documentation is available stating the effect of the applied control measure to preventing, mitigating and/or eliminating the occurred type of waste. As this cannot be traced back, no comparison can be made in order to decide which method is the most effective or to determine what the requirements of the issue should be in order for the control measure to be applied. A possible solution to unify the approach to waste in the design process is the set-up of a database that contains all best practices and lessons learned. This solution is consistent with the type of waste of insufficient use of existing knowledge, more specifically knowledge regarding the process rather than project specific knowledge.

The interviews and case study sessions have shown that projects are not always properly evaluated and/or documented. In addition, the current system is experienced as difficult to understand and use and therefore it may be difficult to find best practices and lessons learned by yourself. Besides, no database focusing on learning experiences from the design process exists within Witteveen+Bos to this date. This is remarkable seeing Witteveen+Bos is a design and consultancy company and the design process is one of the primary processes. Nevertheless, employees often physically pass by colleagues to ask them to share their knowledge and experiences. However, transferring personal experiences and knowledge verbally is more difficult than it seems, especially when it is asked unexpectedly. Therefore it is also important to find and maintain a structured way to document experiences and knowledge with the aim of sharing it with others.

SE can contribute to this aim by explicitly documenting the experiences and knowledge gained during a certain process. Nonetheless, it is of more importance to find a way that simplifies and structures the evaluation of the obtained knowledge and experiences from completed projects. In addition it is of importance to provide for a method or tool that increases the usability and accessibility of consulting the evaluated projects.

According to Groot (2005), best practices and lessons learned are examples of intellectual capital, as it documents experiences (human capital) in a description (structural capital), which is then converted into actions (human capital) and thus a suitable way of acquiring experience and transferring knowledge. A best practice can be defined as "a description of a method that has proven to be the most efficient method in a given context". According to Bertrams (1999) and Molier (2008), every best project must contain the following components:

- a clear description of the problem or process
- a description of the specific context
- the goal and result
- the reason(s) why the project was successful
- the competencies and method(s) with which the major problems have been conquered

In addition, according to Gamble and Blackwell (2001), Weggeman (2000) and Molier (2008), it is important that a best practice meets the following requirements:

- proven and value-adding method (based on the experience gained)
- useful for other departments/branches (regardless of the context)
- transferable for potential users (explicitly and clearly documented)
- adaptable (based on new experiences)
- supported by tools (figures, tables, checklists, etc.)

So, first of all, it is important that every project is evaluated and that this evaluation is then explicitly documented as best practice. For the documentation as best practice, the aforementioned list of Bertrams (1999) and Molier (2008) can be used as a format. In addition, it is important to check whether the best practices meet the requirements set by Gamble and Blackwell (2001), Weggeman (2000) and Molier (2008). To make the best practices more accessible, setting up a separate database, focused on the learning experiences from the design process, can be a valuable addition to the organization. This database will not only be valuable in the design process, but also during the tender process. An interview showed that during the tender process Verifiable Performance Indicators (VPIs) are used, which refer to previous (successful) projects. By linking the best practices to VPIs in the database, a more targeted search can be carried out in the database and the best practices will also be found more easily. Moreover, not all best practices fit one on one on another project; so using VPIs can identify multiple best practices that can be of value while designing the current project. Moreover, all best practices and lessons learned need to be continuously monitored in order to monitor the effectiveness of each best practice and lesson learned. If a new measure turns out to be more efficient, then the new measure should be included in the database.

10.2 Assumption management

The interviews and case studies have shown that the employees are often aware of the fact that they have to wait until all information is complete and correct before commencing the design. Yet, they always seem to find a way that is considered to be good enough to start designing nonetheless. One of these reasons may be the fact that a (conceptual) design is needed to gain more insight into certain aspects. For example, to verify whether client requirements are understood and interpreted well by the designer(s). This results in designing based on assumptions in order to maintain the design process flow. Assumptions are therefore inevitable and thus a solution must be found to deal with these assumptions as well as possible.

SE supports working with assumptions to a certain extent, as explicitly documenting and evaluating the assumptions during the design will ensure that the assumptions can be monitored and controlled. However, a complementary method needs to be implemented to deal with the assumptions more effectively and efficiently.

Turbit (2005) has developed a method to deal with assumption within projects. The essence of this method is that the assumptions must be regarded as the flipside of a risk. This means that not the assumption itself, but the risk that the assumption turns out to be wrong has to be incorporated in the risk management plan. When considering risks within a project, the risks are generally measured on the basis of a probability/impact matrix. The result of the measurement is a risk priority number (RPN), which allows for prioritisation of the risks. The risks with a high RPN have a higher priority to be prevented, reduced or even eliminated. Turbit (2005) has developed a rating for assumptions that is comparable to the rating of risks, so that these assumption ratings can be incorporated in the risk management plan as well. The following parameters are considered:

1. **certainty** - how sure are we that the assumption is correct?
2. **lead time** - how long before we can prove or disprove the assumption?
3. **impact** - if the assumption proves incorrect, how much rework is involved?

Figure 10.1 shows the assumption assessment matrix in which the ratings are visualised. A more elaborate explanation on the ratings can be found in Appendix C.3.

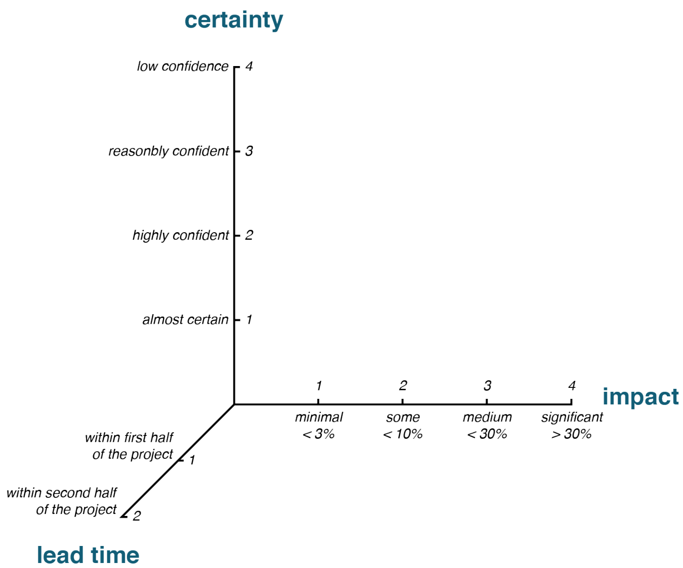

Figure 10.1 | Assumption assessment matrix (Turbit, 2005)

When all parameters have been assessed, the assumption priority number (APN) can be calculated by adding all the ratings. Subsequently, the results of these APNs can be used as input for the risk management plan and the associated mitigation plan. The priority of the assumptions can be assessed as follows:

- 9 - 10 Critical
- 7 - 9 High
- 5 - 7 Medium
- 3 - 4 Low

So, first of all, it is important that all assumptions are explicitly documented at the beginning of the design process and then continuously evaluated during the design process. In this way, it can be monitored which assumptions have changed in the meantime and can thus be evaluated as proven or disproven and which assumptions are still assumptions. In addition, new assumptions can also be added during the design process, which must then be documented and evaluated in the same way. In order to monitor the assumptions in a structured way, it is important that actions are linked to each assumption and that an employee is also responsible for monitoring and validating each assumption. This way of explicitly documenting and linking actions is very similar to the possibilities and working methods of Relatics, a software program that is already being used within Witteveen+Bos and would therefore be a valuable addition to the program.

10.3 Lean principles

The interviews and value analysis sessions have shown that there is often a lack of alignment between the disciplines. Even though enough means of communication are available and regular consultations take place in which the various disciplines are involved. One of the reasons that was mentioned is that the project teams are often spread over different work locations. In the interviews, an often proposed solution therefore was to work at the same location as much as possible. At the same time it was noted that this may be difficult to achieve given that all employees work on several projects simultaneously, which are located at different locations. Another reason for the lack of alignment that was mentioned is that disciplines do not know exactly what the other person needs, when he/she needs it and which level of detail is needed. There is no insight into each other's role within the project and the associated activities and how this relates to the own activities. In order to achieve better alignment, it is therefore important that:

- disciplines know what the other disciplines need and when they need it
- disciplines gain insight into each other's activities and associated problems
- disciplines meet regularly

SE can contribute to the alignment of disciplines by working explicitly and working from abstract to concrete. By explicitly documenting which activities are performed by each discipline and which input of the other disciplines is needed, the alignment between the disciplines is likely to improve. However, it has been found in the case studies that there is still a lack of alignment when using SE. Therefore additional measures need to be taken. The use of parametric models may have a positive influence, but this will only be the case if there is enough in-house knowledge and experience. Another option is the implementation of Lean principles as an addition to SE.

A method that according to the graduation project of (Schonk, 2013) can contribute to increasing mutual coordination and communication between the designing parties is the so-called Last Planner Method (LPM), also known as the Lean Planning (LP). This planning system assumes that not the project managers, but rather the people who carry out the tasks, are responsible for the planning. They are also called the Last Planners (Ballard, 1994). The difference between the traditional planning process and the Last Planner planning process is that the traditional process is a push process while the Last Planner process is a pull process. A push process introduces aspects, such as information, into a process while a pull process approaches the process from the end goal and only allows those aspects into the process that can be dealt with (Ballard, 2000). The traditional process takes into account which activities are planned (should), then resources are linked to these activities (resources) and afterwards the activities that have been done are examined (did). While the Last Planner process first takes into account which activities should be carried out (should), then these activities are linked to activities that actually can be carried out (can), and then a Last Planner takes responsibility for what will be carried out (will)

(Ballard, 2000). The activities that are categorised as 'can' are, for example, activities that can be carried out based on available resources or output of already completed activities. The total Last Planner Method can be divided into four parts, which relate to each other in an increasing degree of detail (see Appendix C.3). For the preparation of each planning it is important that all disciplines are present or adequately represented, in order to ensure sufficient commitment per discipline. The four plans can be divided as follows:

- central planning
- phase planning
- look ahead planning
- weekly planning

To take this even one step further, Daily Standup Meetings (DSMs) can be introduced, which contributes to regular meetings of the project team. The objective of a DSM is to discuss the activities and possible obstacles that disciplines may face on a daily basis, in order to gain insight into other discipline's activities and progress. When an obstacle is likely to occur that affects multiple disciplines or that requires support from other disciplines, a more extensive team meeting can be scheduled (Schwaber, 2004). The three questions that need to be answered during a DSM are:

1. What have I achieved since the previous DSM?
2. What am I going to achieve today?
3. Do I expect any obstacles, and can other disciplines support me with it?

Another Lean principle that can contribute to gain insight into each other's activities and associated problems, according to Merholz and Skinner (2016), is the use of CFTs. In CFTs, different disciplines work together to such a high extent, that disciplines are almost able to carry out each other's activities. The idea behind this is that people think further than their own discipline and therefore also think about the consequences of their own activities on the activities of other disciplines.

So, three recommendations can be provided with regard to the lack of alignment between disciplines:

Last Planner Method - The use of LPM can contribute to aligning what the other disciplines needs and when. When applying the Last Planner Method, it is important that the project manager implements it at the beginning of the design process and that this will be continued throughout the design process. Involving an external person who leads the planning sessions can be of added value, because the focus during this session will be fully on the planning and no other project specific issues will be discussed. In addition, the use of Percent Plan Complete (PPC), part of the Last Planner Method, can add extra value, since a root cause analysis is performed when tasks in the weekly planning are not 100% performed. For example, the root cause analysis can show that information from another discipline was not available yet and as a result the disciplines can be reconciled and better aligned. In addition, the root cause analysis can also identify a lack of or erroneous information and with this result and follow-up actions contribute to reducing working with the wrong starting points, assumptions, requirements and / or information.

Daily Standup Meetings - Introducing DSMs can contribute to better alignment of the daily activities of the various disciplines. At the same time, problems and obstacles can be identified that affect individual disciplines and for which the assistance of other disciplines is desirable. The advantage of a DSM is that it takes little time, 15 minutes a day, and that no external persons are needed. However, involving an external person in the initial phase may help to get acquainted with the method. Subsequently, leading the meeting and monitoring the time can, preferably, be done by a different discipline every day. This will ensure that the disciplines will inform each other what their current activities are instead of informing the project leader. This aims to ensure that all disciplines will be more focused on other people's planning and activities.

Cross Functional Teams - The composition of and working with CFTs can contribute to gaining a better understanding of the activities of other disciplines and the associated problems. This is mainly caused by the close cooperation between the various disciplines. It is therefore important to physically bring the various disciplines together at the same location on a regular basis.

11 VALIDATION

The proposed recommendations that are discussed in the previous chapter have been validated by using expert judgement. Three experts with experience in the design process of infrastructural projects were consulted during a validation session. The experts were asked to elaborate on the feasibility of the proposed recommendation and the willingness to implement the proposed recommendations. This chapter will first provide a brief explanation in section 11.1 on the validation session that has been carried out. Then the outcomes of the validation session are discussed per proposed recommendation in section 11.2 - 11.4. The output from the validation has been taken into account and processed, which has then resulted in the final recommendations that are discussed in chapter 12. The complete overview of the validation session can be found in Appendix B.5.

11.1 Validation session based on expert judgement

For the validation session, experts needed to be selected that had not been involved in the research yet in order to ensure that they did not have any influence on the proposed recommendations and may therefore be biased. It was chosen to select experts based on their involvement in an on-going project, so that the proposed recommendations, when considered appropriate and valuable, may be directly implemented or taken into account in the on-going project. In total, three experts who are involved in the Innova58 project have been selected for the validation session. Two of them are part of the core project team and responsible for project management and project control and the other one is concerned with the performance indicators of the project. It has to be noted that the Innova58 project is a rather exceptional project within Witteveen+Bos, because in terms of process it is quite ahead of other processes. Preceding the discussion on the proposed recommendations, a concise introduction into the research has been provided to the experts as well as the research goals and outcomes. Then each of the three recommendations was presented to the expert, after which the experts were asked to give their opinion on the proposed recommendation and their perspective on the feasibility of the proposed recommendation and willingness of employees to implement the proposed recommendation. The validation session lasted in total approximately 1.5 hours.

11.2 Project evaluations and lessons learned

The expert panel states that every completed project is evaluated in many different and sometimes multiple forms, such as evaluation sessions, KPI measurements, audits, etc. However, the expert panel confirms that currently too little is done with the output of the various evaluations that are performed by the organisation. All the outcomes of the evaluations are documented in separate notes and reports. Then, these documentations are read by the PMC leaders, but no specific and uniform actions are linked to the evaluations.

The Central Quality Team (CQT) of Witteveen+Bos also acknowledged that a lot more could be obtained from the evaluations than is currently being done and therefore decided to look into the possibilities of setting up a quality database. At the moment, the CQT is carrying out the first step, being the set up of the database in which all findings from the different forms of evaluations are assembled. The CQT is going to review all the evaluations and determine which lessons can be learned from each of them; What lessons have been learned and how could these lessons be used in future projects? The lessons learned will also be documented in the database. The next step would be to provide insight into these findings and lessons learned for all employees. The ultimate intention is for employees to be able to feed their knowledge and expertise into the database directly after for example an evaluation session of a recently completed project.

Feasibility

Currently, different forms of evaluation are being applied, but the explicit documentation and subsequent use of these evaluations in follow-up projects is still lagging behind in practice. According to the panel, setting up a database in which all these evaluations are structurally elaborated and documented, can be the first step into stimulating the use of the evaluations in new projects. Especially when concrete lessons learned are derived from the evaluations.

Linking the lessons learned to the VPIs perceived as a valuable recommendation by the expert panel. Moreover, the expert panel is confident that it might also be feasible in practice. The panel thinks that linking the VPIs to the database with best practices and lessons learned can contribute to bring clarity to the considerations. Meaning that it can be checked with each consideration what it has delivered in the past, what the conditions are for a certain approach, etc.

However, the panel does indicate that a database alone will not be the solution to the problem. They indicate that the discussion during an evaluation also has an enormous added value and is therefore at least as important as having a database. In addition, it is important that the person who consults the database also has insight into who he/she can turn to for further questions or explanation regarding a particular lesson learned.

Willingness

The fact that actions have been set up within Witteveen+Bos to work with databases shows that there is a willingness, at least among certain employees, to get more out of the current evaluations. Without the databases, there is little chance that the findings will find its way to the other employees, because the PMC leaders are currently the only ones, apart from individual exceptions, who read the evaluations.

The willingness to link the evaluations to VPIs is clear from this validation session when it is indicated by the expert panel that it is a good idea to look at the extent to which may already be possible. Within the CQT it will be examined whether it is possible to link every lessons learned to one or more VPIs.

Conclusion

The recommendation of the set up of a database with best practices and lessons learned is perceived as a first step into stimulating the use of evaluations in new projects and therefore validated as a valuable recommendation. In addition, the expert panel states that it is important that each lesson learned also has an owner incorporated by means of a contact person who can be consulted for further information. Also, the expert panel argued that the discussion of the evaluation session itself is perceived as highly valuable as well. Therefore, they highly recommend to not replace the evaluation sessions by the database, but to use the outcomes of the evaluation session as input to feed the database with.

Moreover, the link between the lessons learned and VPIs are perceived to add value to the database. However, as the set up of the VPI database is still in progress, the expert panel recommends to continue setting up both databases separately and to link them afterwards. This way it can be figured out to what extent the link between the VPIs and lessons learned is feasible first.

11.3 Assumption management

The expert panel recognises the urge to start designing even when the assumptions are not clear yet. They therefore confirm the finding from the research that working with assumptions is necessary to start the design process and make communication possible. The Innova58 project core team knew in advance that working with assumptions could lead to enormous waste, regarding both waste of effort and talent and the loss of job satisfaction. For these reasons, a lot of attention has been paid within the project to getting the assumptions clear before the designing is commenced.

The Plan of Approach (Dutch: PvA) of the Innova58 formed the basis from which starting points and research principles were formulated. Subsequently, working hypotheses were formulated on the most critical parts. For example, the driveline of the main roadway is always very important for an infrastructure project. This has therefore been recognised as the most important assumption. Subsequently, a discussion took place about the impact that this assumption may have on both the planning and the costs of the project if the assumption proves to be incorrect. The certainty of this assumption is also important, because many other aspects are derived from this assumption. Implicitly, assumptions are therefore placed along the axes of the proposed APN, but this is not explicitly documented. Another example is a certain intersection of which the project team knows that the assumption is unstable. On the proposed certainty axis of Turbit (2005) this assumption would therefore be scaled to low confidence with a score of 4. Because this assumption is highly uncertain, it was decided to monitor and control this assumption from risk management.

Feasibility

The expert panel indicates that the recommendations are certainly feasible and they are convinced of this because the recommendations are, to a certain extent, already implicitly applied within the Innova58. The explicit prioritisation is seen as a valuable extra step, which has not been taken until now. By explicitly prioritising the assumptions, an estimate can be made for which assumptions it is important to quickly be converted to a fixed starting point. Linking action holders is not yet explicitly done, but this is also seen as valuable recommendation. By making action holders responsible for specific assumptions, the assumptions can be continuously monitored and adjusted until it is evaluated to a fixed starting point. This way, it is clear to everyone what they are doing and who is responsible for which assumption. This could be documented and monitored in Relatics or, if Relatics is not yet suitable for this, in a simple Excel file.

The expert panel also indicated that there are a number of conditions for implementing the recommendations. First of all, the team should not be conflict avoiding, but rather move towards the conflict. In addition, the team must include sufficient senior consultants who can assess the uncertainty level of an assumption. For this assessment, experience and expertise at the right level is required, because with little information one has to be able to fathom the core of the problem. Finally, sufficient persuasiveness was mentioned. It is important that the project (management) team has sufficient persuasiveness to substantiate the importance of patience when working with assumptions and convince the client of this.

Willingness

The expert panel states that the willingness within Witteveen+Bos for the recommendations with regard to the application of assumption management is high. Especially because the implicit form of assumption management, as applied within the Innova58 project, is perceived as positive. A learning experience that is imparted from the Innova58 process is that the environmental process must be initiated earlier in the process in some way or another, for example by communicating a rough outline of the design to the environment. A major disadvantage of working with assumptions is that the environment will be involved in the design process later, because they are often dependent on visual translations. When working with assumptions, the visualisations will be dealt with later in the process, because first of all you will have to get all the assumptions clear before you even design them. How the environment can be involved in better or earlier in the process is something that needs to be further considered and researched.

Conclusion

The recommendation of the implementation of assumption management is validated as a valuable and feasible recommendation. In order to implement the recommendation successfully, it is of great importance that all APNs are documented explicitly in for example Relatics and that an action holder is linked to each assumption. The action holder is then responsible for the continuous monitoring and controlling of the assigned assumption. Besides, the expert panel brought up two additions to the proposed assumption management method. The first is the requirements regarding the team composition. According to the expert panel, the assumption management method requires a non-conflict-avoiding team with sufficient senior consultants and sufficient persuasiveness. Secondly, when the assumption management method is implemented it has to be borne in mind that the environmental parties should be involved in the design process at an early stage to prevent resistance. However, no solutions are found on how to do this yet, so this requires further research.

11.4 Lean principles

The expert panel confirms that coordination between different disciplines is one of the biggest challenges in all major projects, certainly in infrastructure projects. Therefore, all sorts of methods and tools have already been applied to contribute to a better alignment between the different disciplines. However, no ultimate solution has been found yet.

Within the Innova58, the project management consciously managed the cooperation and alignment between the various disciplines. This has been done by constantly making use of changing work methods, so that the disciplines always enter into dialogue with each other in different ways. For example, every two weeks there is an integration meeting, in which every discipline discusses their activities. In addition, the entire project team works together one or two days a week at the same location. This will not automatically ensure that the alignment will be improved, but bringing all disciplines together is seen as a first step in the right direction. Moreover, a design week is planned, in which all disciplines work closely together on the design for a whole week. In addition, a mix of tools and instruments is also used, such as parametric design and review moments, to identify different types of interfaces at different levels.

Feasibility

The expert panel indicates that the recommendations are certainly good examples of measures that can contribute to better coordination between disciplines, but that this is only a small part of the required amount of measures in order to achieve complete design integrity. Nonetheless, the recommendations that have been made are confirmed as valuable recommendations, since all recommendations are applied to varying degrees within the A58 project and all have a positive effect.

Especially the LPM is seen as a very good and valuable planning method. Within the A58 project this has already been applied a number of times. By applying the LPM, a planning can be set up in a relatively short lead time, but especially the conversation that takes place contributes to improving the coordination between the disciplines. Despite the fact that the Innova58 project team does not involve external staff during the planning sessions, the sessions have generally proved to be effective. The expert panel therefore believes that the LPM can also be applied without an external.

Within the A58 project the communication lines are short and therefore no use is made of DSMs but of weekly stand up meetings (WSMs). This method is seen as a good method to catch up and the fact that it is a standing consultation contributes to the effectiveness and efficiency of the consultation. The stand-up meetings thus appear to be feasible within Witteveen+Bos and the frequency of the meetings depends on the mutual communication within the team. The shorter the communication lines, the lower the frequency of the meetings.

The use of CFTs as presented in the literature, in which disciplines take over each other's roles so to speak, is not realistic according to the expert panel. Nevertheless, attempts are being made to create as many close collaborations as possible, for example by designing in pairs from different disciplines. In addition, the core team consists of different disciplines, but in order to reach depth and production, specialisation is also required. So at a high level there is certainly a CFT, but the lower you come from the project organisation, the more specialised it becomes.

Willingness

Based on the fact that the recommendations are already being applied within the Innova58 and the positive experiences with it, it can be said that Witteveen+Bos is certainly willing to implement the recommendations to a certain extent in other projects.

As already indicated in the feasibility of the DSMs, the communication of the project in question depends on how often the stand up meetings take place. In addition, working with CFTs is not entirely feasible due to the specialisms required for each project, but the successful application of different work forms means that the willingness to work closely with other disciplines is present.

The use of the Percent Plan Complete is not yet applied, but was seen as a good and efficient way to keep track of which activities have been carried out and the possible cause of the fact that a planned activity has not yet been fully implemented. However, an easy-to-use tool or method must be found here to prevent employees from seeing this as an extra administrative task.

Conclusion

According to the expert panel, only one of the three proposed lean principles is perceived as a feasible and valuable recommendation, which is the Last Planner Method. This method has been applied multiple times by the expert panel and has had a positive effect on the alignment of the disciplines. This statement can be substantiated by an example from practice in which the rough planning, which was made by the core team, was adjusted based on the input of the last planners, being the disciplines itself. The core team would not have been able to make these adjustments themselves as they do not have sufficient insight into the activities of each discipline. So, the LPM planning method ensures a better planning as well as better alignment between disciplines. However, the PPC tool of the LPM method is argued to need further research in order to make the tool more easy-to-use. Currently, the tool is seen as a more administrative task rather than an efficient way of keeping track of the on-going activities and possible obstacles.

The DSMs are argued to be infeasible as every project member, with the exception of the core team, carries out multiple projects at a time. Meaning, that the project members are not working on the same project every day. Therefore, the expert panel recommends weekly stand up meetings, which corresponds to their way of working in the Innova58 project. The weekly planning is incorporated in the LPM as well, but the organisation of weekly stand up meetings needs further research in order to be able to organise them in an efficient way.

The CFTs are also argued to be infeasible, as infrastructural projects involve so many different specialities. Due to the specialised knowledge and expertise of each individual project member, it is not feasible to carry out activities of other disciplines.

12 FINAL RECOMMENDATIONS

In this chapter, the final recommendations will be presented, which are the result of the adjustment of the proposed recommendations. The adjustments are based on the feedback that has been obtained from the expert panel during the validation session. Per section, the three final recommendations will be presented. It has to be noted that the implementation of the two specific recommendations needs to be documented, monitored and evaluated in order to determine their effectiveness. If they prove to be effective measures, they need to be incorporated in the database as discussed and recommended in section 12.1.

12.1 Project evaluations and lessons learned

In order to be able to carry out the design process more efficiently, it is important to make use of best practices and lessons learned from previous projects. However, this can only be done when these best practices and lessons learned are explicitly documented and stored. Nevertheless, to this date no database containing the best practices and lessons learned exists even though every project and its process is evaluated after completion.

Therefore, it is recommended to set up a database in which all best practices and lessons learned are explicitly documented and stored. After storing the best practices and lessons learned, it is of great importance to continuously monitor the effectiveness and efficiency of the best practices and lessons learned, in order to update the database. The best practices and lessons learned can be obtained from the evaluation sessions that are held after the completion of each project. During the evaluation sessions, the best practices and lessons learned will be discussed and documented. The discussion in itself will also be valuable and contribute to gaining knowledge on someone else's experiences.

In addition, each best practice and lesson learned needs to have an owner assigned, who can be consulted in case someone is in need for further explanation or information regarding the best practice or lesson learned.

In the near future, VPIs might be linked to the database containing the best practices and lessons learned. On one hand, the link with VPIs may increase the traceability of lessons learned. On the other hand, the link may also be valuable for other processes such as the tendering process. However, further research regarding the set up of a VPI database is required first.

12.2 Assumption Management

In order to start a design process or to take the next step within a design process, one has to work with assumptions. However, the assumptions can have a major impact on the design and the design process if turns out to be a wrong assumption later on in the process. Therefore, it is of great importance that the assumptions that are made during the design process are carefully monitored and controlled throughout the process. In order to do so, the assumption management method developed by Turbit (2005) is recommended. Currently, the assumptions are implicitly measured along the three axes as shown in Figure 10.1, but the recommendation is to do this explicitly. Each assumption needs to be documented explicitly, in a program such as Relatics, at the beginning of the process or immediately when a new assumption arises. After the documentation, an APN as well as an action holder needs to be assigned to each assumption. The APN can be determined based on the assumption management matrix as discussed in chapter 10. The action holder is responsible for continuous monitoring and controlling of the assigned assumption.

In order to be able to successfully implement the assumption management, it is of great importance that the composition of the team meets the following requirements:

- **non-conflict avoiding team** - clarifying assumptions in an early stage of the process requires team members that move towards possible conflicts in order to solve them
- **consists of sufficient senior consultants** - it requires expertise and experience to assign APNs to assumptions in an early stage of the process
- **sufficient persuasiveness** - it takes a certain degree of persuasiveness to convince the client, or other stakeholders, that the assumptions need to be clear before the design process can begin

Another aspect that needs to be borne in mind when implementing assumption is the involvement of environmental parties. This research has not looked into the possible strategies or methods with regard to the involvement of environmental parties, however working with assumptions may lead to environmental resistance. So, further research in possible solutions need to be conducted.

12.3 Lean principles

One of the biggest challenges in all major projects and certainly in infrastructure projects is the alignment between different disciplines. Three aspects that are important when aiming for better alignment, which may be achieved by the implementation of Lean principles are:

- gaining insight into other disciplines' activities and associated problems
- gaining insight into other disciplines' input, output and planning
- meeting regularly

A Lean method that can be implemented in order to achieve the above is the Last Planner Method (LPM). Witteveen+Bos has been implementing this method for a couple of years now, however it has never been documented and measured explicitly. The advantage of the LPM is illustrated by Figure 12.1, which shows that the LPM takes into account which activities should be carried out (should), then these activities are linked to activities that actually can be carried out (can), and then a Last Planner takes responsibility for what will be carried out (will) (Ballard, 2000). The activities that are categorised as 'can' are, for example, activities that are can be carried out based on available resources or output of already completed activities.

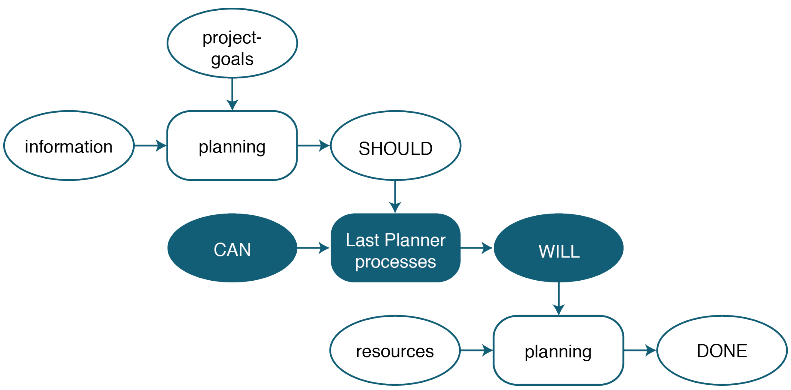

Figure 12.1 I Last Planner Method (Ballard, 2000)

As the LPM consists of four types of planning, each with a different detail level, the regular meetings can also be provided by the implementation of LPM. Since one of the different planning types is the weekly planning, the project team comes together at least one time a week. Further research into the execution of weekly stand ups need to be conducted, however it should be aimed to make the meetings as efficient as the DSMs. DSMs are however not feasible in an engineering company such as Witteveen+Bos, as multiple projects are carried out at a time by every employee.

In addition, the use of Percent Plan Complete (PPC), part of the Last Planner Method, can add extra value, since a root cause analysis is performed when tasks in the weekly planning are not 100% performed. For example, the root cause analysis can show that information from another discipline was not available yet and as a result the disciplines can be reconciled and better aligned.

So, the LPM method ensures a better planning as well as better alignment between disciplines. However, further research is needed regarding the implementation of efficient weekly stand ups and the implementation or establishment of an easy-to-use PPC tool. Furthermore, the implementation of LPM alone is not enough in order to achieve complete integral design. However, it is a first step into achieving the complex challenge of integral design.

PART VI. CONCLUSIONS & RECOMMENDATIONS

13 CONCLUSIONS

This report contains an exploratory research into the factors affecting the current design process of infrastructure projects. This research was conducted to discover which (combination of) design method(s) address these factors in order to be able to advice on the possible enhancement of the design productivity. The main research question of the research therefore was:

"Which (combination of) design method(s) contributes to the enhancement of the design productivity of Dutch infrastructure projects?"

Based on the findings from both literature study and field research, a matrix was established in which four design methods were matched with the identified top 10 types of waste. From the weighted matrix it was found that Systems Engineering was the theoretically most suitable design method to address the identified top types of waste that occur in the current design process.

In order to analyse the implementation of SE in practice, three case studies have been conducted. The conclusion that was drawn from the case studies was that the implementation of SE is not as satisfying as described by theory, since several types of waste still occurred even though SE was implemented. This may be due to the fact that SE is not implemented correctly and the implementation should be improved or it may be due to the fact that SE is not as efficient as theory argues and should thus be complemented by (an)other method(s).

Moreover, from the case studies it was also found that the most important type of waste is the insufficient use of existing knowledge, more specifically process-based knowledge. Within the three cases, many similar types of waste occurred. However, in every project different control measures were applied of which it is unclear what the best measure is and what the impact on the design process of each method was. The conclusion that can be drawn based on this finding, is that there is no uniform way of coping with best practices and lessons learned from previous projects. The recommendation of the set up of a database containing best practices and lessons learned with regard to the design process, may in turn prevent, mitigate and/or eliminate other types of waste as well. For example, the lack of alignment between disciplines is another important type of waste of which the case studies also showed that different control measures are applied. When a database can be consulted on how to deal with this type of waste, on what can be learned from previous projects, and on which control measure is the most effective, it is highly likely that the lack of alignment will at least be mitigated and may be even eliminated.

Furthermore, another important finding that resulted from the case studies is the fact that the issues that arise and the wastes that occur in the design process are not related to technical complexity, which is the main focus of all engineering firms. The complexity within the design process of the infrastructure project is rather related to organisational complexity and environmental complexity, which brings us back to the client-designer-user triangle that was introduced in chapter 3, in which engineering companies operate. In order to enhance the design process and subsequently the design productivity, an engineering company should not solely focus on the technical complexity of the project, but also on the organisational and environmental complexity. In order to do so, more research must be conducted into these complexities and possible methods and/or strategies to deal with the complexities.

So, based on all findings throughout this research, it can be concluded that Systems Engineering is a suitable method to contribute to the enhancement of the design process. However, it should be either complemented with other methods or more aligned with theory in order to be more effective and thus enhance the design productivity, as waste still occurs in projects even though SE is implemented. A valuable and highly recommended addition to SE is the set-up of a process-based database containing best practices and lessons learned from previous projects. This database is continuously updated, as all measures need to be monitored, evaluated and documented, so that the most effective measures will be incorporated in the database. The database addresses one of the most important identified types of waste, being insufficient use of existing knowledge. Besides, it also contributes to mitigating other important types of ways as the database provides for insight into efficient ways, methods, strategies and tools to deal with types of waste, based on learning experiences from previously completed projects.

Two specific recommendations have been provided regarding how SE can be complemented by other methods. The assumption management method from Turbit (2005) is perceived to be valuable with regard to working with the wrong assumptions and the implementation of the Last Planner Method, which is part of the Lean Philosophy, is perceived to be valuable with regard to the lack of alignment between disciplines. However, the effectiveness of these methods has not been proven yet. Therefore, once these methods are applied, their effectiveness needs to be monitored, evaluated and documented in order to determine whether the methods are the most effective methods with regard to the corresponding types of waste.

Although it cannot be quantitatively concluded that SE contributes to the enhancement of the design productivity in practice and to what extent, valuable recommendations have been provided in order to take the first step into enhancing the design productivity. Moreover, valuable lessons have been obtained from this research that result in recommendations for further research. Besides, through this research a list has been established of the identified types of waste, which can be seen as a contribution to bridging the knowledge gap with regard to improving the design productivity.

14 LIMITATIONS & REFLECTION

This chapter will shortly reflect upon the limitations of the method that has been used in section 14.1 and on the recommendations for further research in section 14.2.

14.1 Method

Of all the methods used in this research, the questionnaire involves the most limitations. First of all, in order to be able to set up the questionnaire, the list of 132 wastes that was obtained in an earlier conducted research had to be clustered. The clustering was carried out alone and involved analysis and variations. Only the last variant was checked by two employees, in order to verify whether the clusters were sufficient and covered all different wastes. However, if the clustering was done in collaboration with other employees, who can be perceived as experts with regard to the design process, other variations might have resulted. Also, if the check of the clusters was carried out by two different or even more employees, the clusters may also be different. Moreover, the amount of respondents to the questionnaire was low. In order to establish a more reliable ranking of types of waste, more respondents are needed to fill out the questionnaire and the set-up of the questionnaire should be more substantiated.

14.2 Further research

The findings that are presented in this thesis provide a basis for improving the design process and thereby, if efficiently implemented, the design productivity of Dutch infrastructure projects. However, these findings are only a small step in the achieving the major objective of achieving the productivity objective of the Bouwagenda. Further research regarding the enhancement of the design productivity can be carried out in several ways. A few recommendations that arose during this research will be named:

- more elaborate and quantitative study into the factors affecting the design productivity
- quantitative research regarding applied control measure in and the successes thereof
- research into the set-up of a database with best practices and lessons learned
- research into organisational complexity and environmental complexity and possible methods and/or strategies to deal with these
- research into the set up of a VPI database (link with best practices database)
- research into methods that contribute to achieving integral design

My recommendation for a future graduate student would be to focus his/her research on either and/or both the organisational complexity and the environmental complexity that has to be dealt with during the design process of infrastructural projects. During my research, this turned out to be a major issue during these kinds of projects, but unfortunately I did not have sufficient time to carry out more research with regard to this topic.

Moreover, research into methods to monitor and evaluate the applied measures may also be highly valuable seeing as my main conclusion is that we need to learn more of what we have already done and implemented in previous projects.

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A COMPANY INFORMATION

This appendix provides company specific information, consisting of an organisational chart of Witteveen+Bos and the integral design approach developed by Witteveen+Bos.

A.1 Organisational chart

Figure A.1 provides a part of the overview of the organisational chart of Witteveen+Bos. The figure shows the four business lines and the corresponding product market combinations in the Netherlands and the other continents. For a complete organisational chart visit http://www.witteveenbos.nl/nl/organisatiestructuur, containing also information regarding the offices and different departments within the Netherlands and the other continents.

Witteveen+Bos

DIRECTIE	NEDERLAND		AFRIKA, EUROPA EN AMERIKA	CIS-LANDEN	MIDDEN-OOSTEN	ZUID OOST-AZIË EN AUSTRALIË
BUSINESS LINE GEBOUWDE OMGEVING	PMC Gebiedsontwikkeling	PMC Planstudies en procesmanagement	PMC Resilient infrastructures UK		PMC Water en stedelijke ontwikkeling Dubai	
	PMC Gebouwen	PMC Stedelijke ontwikkeling				
	PMC Omgevingsrecht en vergunningen					
BUSINESS LINE DELTA'S, KUSTEN EN RIVIEREN	PMC Ecologie	PMC Kusten, rivieren en landaanwinning	PMC Water en infrastructuur Letland	PMC Water en infrastructuur Rusland		PMC Water en infrastructuur Indonesië
	PMC Havens en scheepvaartwegen	PMC Waterbouwkundige constructies en geotechniek				PMC Water en infrastructuur Singapore
	PMC Hoogwaterbescherming en landinrichting	PMC Watermanagement				
	PMC Internationale technische assistentie					
BUSINESS LINE ENERGIE, WATER EN MILIEU	PMC Afvalwater	PMC Drinkwater	PMC Environmental Solu- tions and Industry Belgium	PMC Water en milieu Kazachstan		PMC Water en milieu Vietnam
	PMC Assetmanagement	PMC Industrie en energie				
	PMC Bodemgebruik, ondergrond en reststoffen	PMC Informatietechnologie				
BUSINESS LINE INFRASTRUCTUUR EN MOBILITEIT	PMC Geïntegreerde contracten	PMC Ondergrondse infrastructuur	PMC Infrastructuur en milieu België			
	PMC Infra constructies	PMC Smart Infra Systems				
	PMC Kunstwerken railinfra	PMC Verkeer en wegen				

Figure A.1 I Organisational chart (Witteveen+Bos, 2017)

A.2 Integral design approach

Witteveen+Bos has developed a design approach, which is the *integral design* approach. As projects are getting bigger and more complex, the financial risks involved are also greater. In order to comply with the scope and complexity of the projects, Witteveen+Bos developed the integral design approach as a new design method, which is implemented in more and more projects nowadays (Witteveen+Bos, 2016). In the integral design approach an iterative, cyclical design process is assumed rather than the traditional linear design process. As indicated in Figure A.2, five steps can be distinguished within one design loop:

1. problem analysis
2. system analysis
3. functional analysis
4. technical design
5. effect study and assessment

The results of each design loop are documented in a so-called baseline report, consisting of a design document with drawings and explanatory notes and an impact report with an estimation of costs and environmental effects. These reports are used to provide the client with important choices and to enter into a dialogue with environmental parties. The results of these dialogues are then used as input for the upcoming design loop. Experience has shown that most design processes require three formal design loops. The first loop focuses on identifying the major dilemmas and risk in the design brief. The next loop focuses on the elaboration of the design dilemmas and the elaboration of the reports to the desired level of detail. The last loop focuses on elaborating the details and making the final products that need to be delivered.

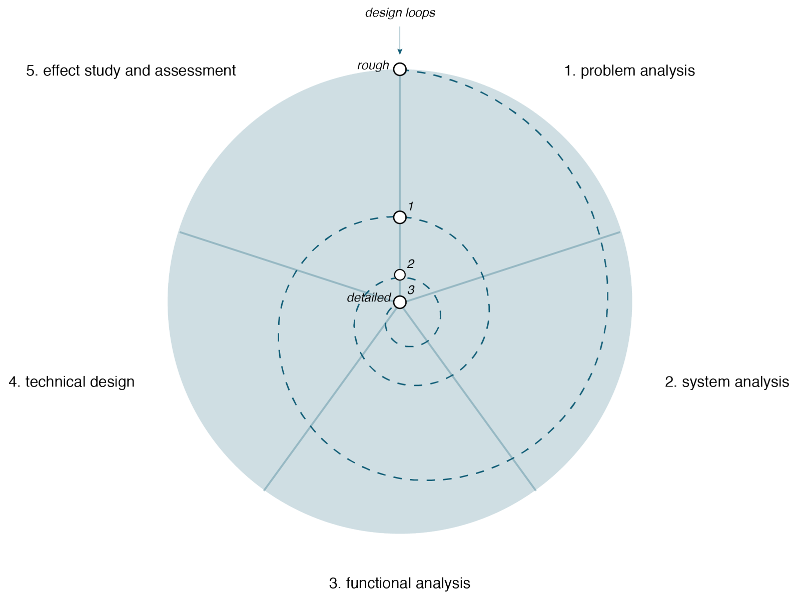

Figure A.2 | Integral design approach (Witteveen+Bos, 2016)

B FIELD RESEARCH

This appendix provides additional information and findings on the field research and is subdivided into four parts, being interviews, previous research, questionnaire, and value analysis sessions.

B.1 Interviews

First, additional information and findings regarding the interviews are provided, consisting of a complete overview of the semi-structured interview questions, a summary of the findings from the interviews and the visualisations of the design process of the discussed project.

B.1.1 Overview interviewees

A total of six interviews are carried out, in order to gain insight in the three subjects as explained above. Five out of six are employees at Witteveen+Bos and have had a managing role in the projects upon which the interview questions are based. By interviewing employees in a managing function, a broader view of the design process can be obtained compared to when a designer of a specific aspect of the design would be interviewed regarding the design process. The sixth interviewee is a system integrator within Witteveen+Bos. No specific project is used during this interview, as TD has not been a project leader or manager, unlike the other interviewees. However, he has a lot of interest in the subject matter and was therefore asked to provide input regarding the definition of design productivity and the factors affecting the current design process in general, also by means of validation. Table B.1 provides an overview of the interviewees, their years of experience, background, reference project, and their role in the concerning reference project.

Table B.1 I Overview of interviewees

Interviewee	Background	Years of experience	Reference project	Role
EH	Civil Engineering	26 years	Afsluitdijk	TM/IOM
RH	Civil Engineering	20 years	Beatrixsluis	TM
JV	Civil Engineering	31 years	Blankenburgverbinding	TM/IOM
PM	unknown	unknown	Afsluitdijk	PM/CM
SD	Civil Engineering	24 years	Zuidasdok	IOM
TD	Civl Engineering & Management	10 years	-	SI

B.1.2 Semi-structured interview

The following list of Dutch questions is merely used as a guideline during the interviews and are based upon three main subjects, being design productivity, design process, and types of waste and control measures.

Ontwerpproces

1. Kun je een korte beschrijving geven van het project?
2. Wat is jouw rol geweest in dit project?
3. Uit welke grove stappen bestaat het ontwerpproces dat doorlopen is?

Ontwerp productiviteit

4. Wat is jouw definitie van '*productiviteit'* in het ontwerpproces?
5. Op basis van welke indicatoren beoordeel je de productiviteit?
6. Hoe beoordeel je de productiviteit van het ontwerpproces van dit project? (1-10)

Mogelijke verspillingen en beheersmaatregelen

7. Welke verspillingen ben je tegengekomen tijdens het ontwerpproces?
8. Hoe is er in dit project gestuurd op productiviteit van het ontwerpproces?
9. Op welke manier zou de productiviteit in een gelijksoortig project in het vervolg verhoogd kunnen worden?

B.1.3 Interview results

The findings of the interviews are summarised in four tables that follow the structure of the semi-structured interviews. The tables consecutively regard project information, design productivity, design process, and types of waste and control measures.

Table B.2 I Project information findings

	Project	Projectdoel(en)	Projectfase	Rol
EH	Afsluitdijk	• Dijk versterken • Schut- en spuisluizen aanpassen	Planfase (SO & VO)	Technisch Manager / Integraal Ontwerp Manager
RH	Beatrixsluis	• Dijk- en sluisverlegging • Zo snel mogelijk tot een goedgekeurd ontwerp Tracébesluit komen tegen minimale kosten	Ontwerp faciliterend aan planstudie (toets tussen huidige en toekomstige situatie)	Technisch Manager
TD	(Zuidasdok)	n.v.t.	n.v.t.	Systeemintegrator (opstellen SYS en VSE)
JV	Blankenburgverbinding / Oosterweel	• Maakbaarheid van de referentieoplossing aantonen • Ontwerp op DO niveau	Planstudiefase (VO & DO) + Technisch deel van het contract	Technisch Manager / Integraal Ontwerp Manager
PM	Afsluitdijk	• Dijk versterken • Waterafvoercapaciteit vergroten	Planstudiefase	Project Manager / Contract Manager
SD	Zuidasdok	• Bestaande snelweg uitbreiden • Aanleg tunnel • Aanpassing station • Herinrichting omgeving • Zo veel mogelijk functioneel specificeren	Planstudiefase + Voorbereiden contract	Integraal Ontwerp Manager

Table B.3 I Design productivity findings

	Definitie productiviteit	Indicatoren
EH	Zo veel mogelijk in één keer goed doen, zodat je zo min mogelijk verspillingen hebt en 'de verkeerde paadjes in loopt'.	• Value Stream Mapping
RH	Het optimum tussen opbrengsten en kosten dat nodig is voor het desbetreffende project	• Kosten • Manuren • Rechtszekerheid • Voldoet het voor het Tracébesluit?
TD	Alleen ontwerpen wat nodig is om een besluit te kunnen nemen + Afweging tussen efficiëntie en effectiviteit	• Productie • Voldoende kennis/informatie/detail om besluit te nemen
JV	Met zo min mogelijk inzet van mensenuren in een zo kort mogelijke tijd komen tot de beste oplossing, waarin beste betekent voldoen aan klanteisen, kosten, draagvlak en vormgeving.	• Doorlooptijd • Draagvlak beoordeling van het eindresultaat • Manuren • Tijd
PM	Ontwerpen op een detailniveau passend bij het volgende ontwerpbesluit en in afstemming met het draagvlak	• Acceptabele effecten • Kosten • Manuren • Risico's • Voldoende kennis/informatie/detail om besluit te nemen
SD	Zoveel mogelijk goed doen en voortgang boeken op een efficiëntie manier, door slimme informatielijnen uit te zetten en goed te communiceren met elkaar.	• Informatielijnen • Tijd • Voldoende kennis/informatie/detail om besluit te nemen • Voortgang

Table B.4 I Design process findings

	Ontwerpstappen
EH	1. Uitgangspunten, randvoorwaarden en klantwensen 2. Brainstormsessie met een aantal deskundigen 3. Eerste (aftastende) ontwerpslag 4. Kansrijke alternatieven 5. Tweede ontwerpslag 6. Voorkeursalternatief 7. Derde ontwerpslag + effectenstudies 8. Optimalisaties 9. Plan procedureel vastleggen: Rijksinpassingsplan
RH	1. Opgave volgens BVP 2. Grove ontwerpslag o.b.v. expert judgement 3. Eerste assessment effectenstudies 4. Eisen ophalen/aanscherpen 5. Gedetailleerde ontwerpslag 6. Effectenstudies 7. 'Puntjes op de i' ontwerpslag
TD	n.v.t.
JV	1. Basisontwerp van RHDHV 2. Analyse huidige situatie + Ophalen nieuwe eisen 3. Ontwerpslag I 4. Variantenstudie 5. Afweging varianten 6. Nieuw ontwerp
PM	1. Project management plan 2. Varianten genereren 3. Varianten trechteren 4. Overgebleven varianten uitwerken 5. Varianten afwegen 6. Voorkeursalternatief 7. Draagvlak toetsen 8. Voorkeursvariant uitwerken 9. Vastleggen in Rijksinpassingsplan 10. In detail uitwerken 11. Functioneel specificeren
SD	1. Referentieontwerp 2. Varianten genereren 3. Varianten trechteren 4. Value Engineering sessie 5. Voorkeursvariant uitwerken 6. Aspecten vastleggen in VSE

Table B.5 I Types of waste and control measures findings

	Cijfer	Type verspillingen	Beheersmaatregelen
EH	7	(1) Bestaande kennis onvoldoende gebruiken (7) Gebrek aan afstemming tussen disciplines (13) Onduidelijkheden genereren varianten (14) Onduidelijkheden uitwerkingsniveau (16) Werken met verkeerde uitgangspunten, aannames, eisen en/of informatie (17) Overproductie per onderdeel en/of fase (20) Te hoog uitwerkingsniveau	• Directe aansturing (ontwerp stopzetten, gedetailleerd genoeg) • Evalueren • Point-based ontwerkeuzes omschrijven naar set-based design methode
RH	8	(7) Gebrek aan afstemming tussen disciplines (15) Impliciet werken (17) Overproductie per onderdeel en/of fase (22) Te weinig aandacht voor verificatie	• Duidelijke doelen en verwachtingen vaststellen per fase (nieuwsbrief en instructie aan het begin van elke fase) • Mogelijkheid scheppen om fysiek bij elkaar te zitten
TD	-	(2) Externe informatie achterhalen (3) Interne informatie achterhalen (7) Gebrek aan afstemming tussen disciplines (9) Onduidelijkheden ontwerpproces (14) Onduidelijkheden uitwerkingsniveau (16) Werken met de verkeerde uitgangspunten, aannames, eisen en/of informatie (17) Overproductie per onderdeel en/of fase (18) Onduidelijkheden project (20) Te hoog uitwerkingsniveau	• Verificatieformulieren • Vooraf redeneerlijn afstemmen • Vooraf uitwerkingsniveau afstemmen • Voortgangsrapportages
JV	7	(7) Gebrek aan afstemming tussen disciplines (11) Onduidelijkheden klanteisen (14) Onduidelijkheden uitwerkingsniveau (15) Impliciet werken (16) Werken met verkeerde uitgangspunten, aannames, eisen en/of informatie (17) Overproductie per onderdeel en/of fase (18) Onnodige ontwerpaanpassingen (20) Te hoog uitwerkingsniveau	• Directe aansturing (plan om product een stap verder te krijgen/af te ronden) • Inspelen op aanvullende/nieuwe eisen (cyclisch ontwerpen en parallel studies) • Mogelijkheid scheppen om fysiek bij elkaar te zitten • Pilotproducten leveren • Vooraf uitwerkingsniveau afstemmen • Voortgangsrapportages
PM	5 > 8	(1) Bestaande kennis onvoldoende gebruiken (2) Externe informatie achterhalen (3) Interne informatie achterhalen (4) Ineffectief overleg en academische discussies (7) Gebrek aan afstemming tussen disciplines (8) Onduidelijkheden project (11) Onduidelijkheden klanteisen (17) Overproductie per onderdeel en/of fase (20) Wijzigingen opdrachtgever (22) Te weinig aandacht voor verificatie	• Externe review • Gezamenlijke database opzetten/gebruiken • Goede kwaliteitsborging • Inspelen op aanvullende/nieuwe eisen (eisen categoriseren op abstractieniveau) • Integraal ontwerpen • LEAN plannen • Risico-gestuurd ontwerpen • Vooraf redeneerlijn afstemmen
SD	8	(8) Onduidelijkheden project (9) Onduidelijkheden ontwerpproces (14) Onduidelijkheden uitwerkingsniveau (18) Onnodige ontwerpaanpassingen (19) Wijzigingen opdrachtgever	• Externe procesmanager als tussenpersoon • Inspelen op aanvullende/nieuwe eisen (werken met baselines) • Klant intensief bij het proces betrekken • Mogelijkheid scheppen om fysiek bij elkaar te zitten • Risico gestuurd ontwerpen • Voortgangsrapportages

B.2 Previous research

As explained in the main text, findings from LEAN for SE have been used as input for this graduation research. The following section will first provide an overview of the clusters of types of waste that have been established and then show the findings from the cross check regarding the literature and research findings.

B.2.1 Clustering of types of waste

Table B.6 provides an overview of the clusters that have been established by grouping the wastes that were identified in the brainstorm session of the previous research, LEAN for SE.

Table B.6 I Clusters of types of waste based on findings of previous research

Nr	Type verspilling	Voorbeelden
1	Bestaande kennis onvoldoende gebruiken	• Het wiel opnieuw uitvinden bij elk project • Senior kennis ontbreekt bij start van het project • Ervaringen uit het verleden ontbreken
2	Externe informatie achterhalen	• 'Richtlijnen van derden' achterhalen op inefficiënte wijze • Basis sets worden onvoldoende geüpdatet door Rijkswaterstaat
3	Interne informatie achterhalen	• De KES analyseren op een inefficiënte wijze • Informatie wordt aangeleverd in slechte kwaliteit
4	Ineffectief overleg en academische discussies	• Intern wordt te veel overlegd over het project • Academische discussies voeren over - basisprincipes - raakvlakken - aspecten - categorisering - vormgeving analyse - formuleren van systeemeisen uit bovenliggend niveau
5	Gebrek aan aansturing	• Ontwerpproces wordt onvoldoende gestuurd • Onvoldoende werken van grof naar fijn • Onvoldoende borgen van besluiten per niveau • Analyse van informatie en eisen ontbreekt • Structuur van informatie en eisen is onevenwichtig • Focus op de functionele baseline ontbreekt • Rework a.g.v. het ontbreken van een goede functieanalyse
6	Gebrek aan draagvlak	• Draagvlak wordt niet getoetst • Resultaat komt niet overeen met verwachting • Verschillende belangen
7	Gebrek aan afstemming tussen disciplines	• Verwachtingen zijn niet gelijk • Disciplines zien zichzelf als 'belangrijkste discipline' • Gebrek aan overeenstemming over het decomponeren van het systeem • Rework a.g.v. - het gebrek aan afspraken over de structuur, status en doorwerking van brondocumenten voor het afleiden van systeem eisen - het gebrek aan overeenstemming over de prestaties van bovenliggende eisen voor het opstellen van meetbare eisen - onvoldoende afstemming tussen disciplines

Table B.5 I Clusters of types of waste based on findings of previous research (continued)

8	Onduidelijkheden project	• Geen eenduidig doel hebben • De weg om het doel te bereiken niet weten • Vraagstelling niet tijden genoeg scherp hebben • Zonder contractstrategie beginnen • De (interne) klantvraag gaat dieper dan de vraag vanuit de aanbieding
9	Onduidelijkheden ontwerpproces	• Het proces is niet omschreven • De redeneerlijnen zijn niet vooraf vastgesteld • Het doel is onscherp per fase • De criteria voor het ontwerpproces ontbreken • Het beoordelingskader voor de varianten is niet vastgesteld • Varianten worden gegenereerd zonder overeenstemming over de ontwerpruimte • De ontwerper en opdrachtgever zitten niet samen aan tafel
10	Onduidelijkheden basisspecificaties	• Het gebruik van welke basis sets is vooraf niet duidelijk • Het omgaan met dubbelingen uit ontwerpnormen is vooraf niet duidelijk
11	Onduidelijkheden klanteisen	• Klanteisen zijn onduidelijk en vrij te interpreteren • Klanteisen passen niet bij het uitwerkingsniveau van de fase • Dubbele en/of onduidelijk eisen worden te lang meegenomen • Klanteisen passen niet bij het uitwerkingsniveau • Rework a.g.v. conflicterende eisen
12	Onduidelijkheden raakvlakken	• Raakvlakken zijn niet SMART • Raakvlakken worden niet geanalyseerd op een gestructureerde wijze
13	Onduidelijkheden genereren varianten	• Het definiëren van varianten gebeurt niet systematisch • De hoeveelheid effort in 'out of the box' varianten is onduidelijk • Worst case varianten worden vaak niet beschouwd • Het genereren van te weinig varianten • Het genereren van te veel varianten • De keuze tussen relevante en niet-relevante varianten wordt te laat gemaakt
14	Onduidelijkheden uitwerkingsniveau	• Definitie SO, VO en DO is niet eenduidig • De benodigde beslisinformatie is niet duidelijk • Onderbouwing van ontwerpkeuzes is ongelijk t.o.v. andere projectonderdelen • Onderbouwing niet eenduidig • Geen balans in het nauwkeurigheidsniveau
15	Te weinig aandacht voor verificatie	• Verificatieplan ontbreekt of te laat opgesteld • Te weinig tijd voor ingeruimd • Onvoldoende controles/reviews • Onvoldoende kritische review • Uitgevoerd door de verkeerde mensen • Achteraf worden er vinkjes gezet als formaliteit

16	Impliciet werken	• Het is een gewoonte: “We doen het altijd zo”
		• De analyse van de KES wordt niet vastgelegd
		• De onderbouwing van de klanteisen wordt onvoldoende vastgelegd
		• Het beoordelen van bestaande systeemeisen wordt niet expliciet vastgelegd
		• De onderbouwing van keuzes wordt achteraf gedaan
		• De onderbouwing van keuzes wordt niet expliciet vastgelegd
		• Rework a.g.v.
		  - het verliezen van informatie die bijdraagt aan de herleidbaarheid van eisen
		  - onduidelijke afspraken over het categoriseren van eisen

Table B.5 I Clusters of types of waste based on findings of previous research (continued)

17	Werken met verkeerde uitgangspunten, aannames, eisen en/of informatie	• Vooraf niet goed nadenken over randvoorwaarden, uitgangspunten, risico's en eisen • Onduidelijk hoe er om moet worden gegaan met voortschrijdend inzicht van de klant/ontwerper • Ontwerpbeslissingen worden gemaakt o.b.v. ongecontroleerde vuistregels (en later ter discussie gesteld) • Rework a.g.v. - aannames die niet meer blijken te kloppen - het onderbrengen van eisen in de systeemspecificatie in een te vroeg stadium - ontwerpen met de verkeerde informatie - ontwerpen zonder de benodigde informatie - gewijzigde meetbare eisen
18	Overproductie per onderdeel en/of fase	• Alle problemen in één keer willen oplossen • Onnodig werk verrichten dat niet bijdraagt aan de vraag • Geen keuzes durven maken • De onderbouwing van ontwerpkeuzes te ver uitwerken • Het hele ontwerp tot een bepaald detailniveau uitwerken i.p.v. risicogestuurd • Onderdelen te ver uitwerken die onder de vrijheid van de ontwerper vallen • Het genereren van te veel varianten • Niet trechteren van varianten • Varianten te lang meenemen die steeds op onderdelen worden afgekeurd • Varianten uitwerken o.b.v. verkeerde/onvoldoende gelezen randvoorwaarden, uitgangspunten en eisen
19	Onnodige ontwerpaanpassingen	• Te laat beoordelen van bestaande systeemeisen • Niet vaststellen van ontwerpmarges • Te laat vaststellen van marges • Ontbrekende eisen worden niet expliciet vastgelegd • Het uitvoeringsontwerp levert nieuwe eisen • Input van derden komt pas als het ontwerp gereed is
20	Wijzigingen opdrachtgever	• Het herhaaldelijk aanpassen van basisspecificaties door Rijkswaterstaat • Politiek gestuurde ontwerpkeuzes zijn niet per se 'best for project' • Wijzigingen in de nul-situatie • Rework a.g.v. te late melding van wijzigingen in de opdracht
21	Te hoog uitwerkingsniveau	• Varianten uitwerken met nog te veel onzekerheden in de eisen • Te ver in detail uitwerken voor de betreffende fase • De connectie met het besluit per fase verliezen • Het ontwerp is te ver gevorderd om optimaal aan te passen aan de aanvullende eisen
22	Te weinig oplossingsruimte	• Onvoldoende breed kijken • Te veel detailniveau • Te veel denken in variant i.p.v. oplossingsruimte

B.2.2 Cross check

From literature 14 categories are derived that are experienced to be a barrier to enhancing the design productivity. From the field research, 21 types of waste have been identified that are experienced to affect the design process. Figure B.1, shows the cross check of the identified types of waste from the field research with regard to the categories found from literature.

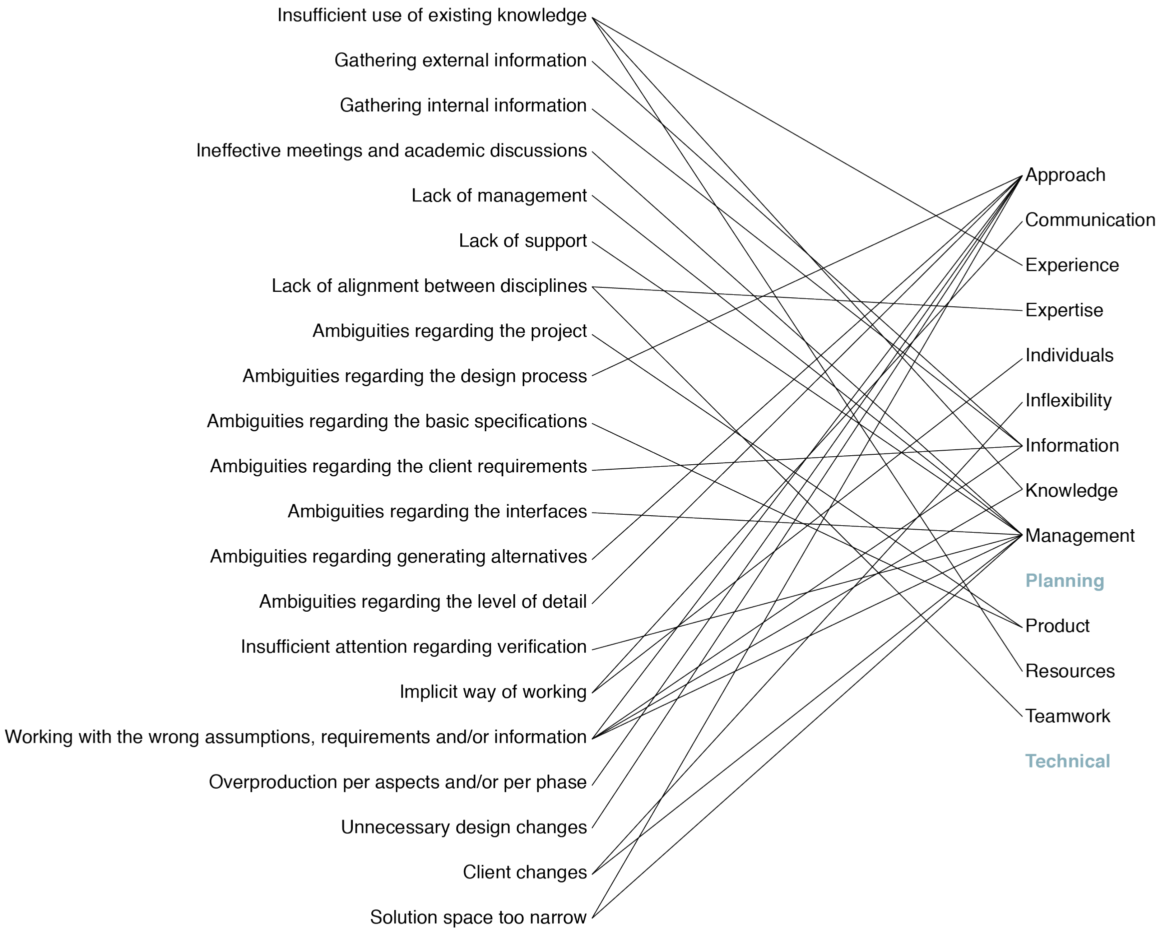

Figure B.1 | Cross check literature vs field research

B.3 Questionnaire

First, the set-up of the questionnaire is shown followed by the results obtained from the respondents.

B.3.1 Questionnaire set-up

The questionnaire consisted of an accompanying text explaining concisely how the questionnaire was set up, what the aim of the questionnaire was and what was asked from the respondent. The Dutch accompanying text of the questionnaire was as follows:

> Beste Witteveen+Bos'er,
>
> In het kader van LEAN for SE heeft er op 11 maart 2016 een brainstormsessie plaatsgevonden, waarbij 111 verspillingen in het ontwerpproces zijn benoemd. Deze verspillingen zijn door mij geclusterd in 21 types van verspilling. Deze questionnaire is opgesteld om erachter te komen welke verspillingen:
>
> - het meest voorkomen in het ontwerpproces van projecten
> - de meeste impact hebben op de productiviteit van het ontwerpproces
> - het meest beïnvloedbaar zijn door Witteveen+Bos'ers (lees: invloed om de verspilling te voorkomen)
>
> In deze questionnaire wordt u gevraagd om aan te geven in welke mate de verspilling voorkomt in het ontwerpproces van projecten (1=nooit, 2=soms, 3=regelmatig, 4=vaak, 5=altijd), wat voor impact deze verspillingen hebben op de productiviteit van het ontwerpproces (1=zeer klein, 2=klein, 3=neutraal, 4=groot, 5=zeer groot) en in welke mate Witteveen+Bos'ers invloed kunnen hebben op het voorkomen van deze verspilling (1=zeer klein, 2=klein, 3=neutraal, 4=groot, 5=zeer groot).
>
> Daarnaast wordt u, indien u de laatste vraag heeft beantwoord met een score van 4 of 5, gevraagd onder 'Beheersmaatregelen' toe te lichten hoe de verspilling beïnvloedt kan worden. Alvast enorm bedankt voor de input!

Figure B.2 illustrates an example of the questionnaire. Per type of waste three questions are asked to the respondents, as explained in the accompanying text, regarding presence of the type of waste, the impact of the type of waste on the design productivity and the influence that employees have on preventing, reducing and/or mitigating the type of waste.

nr	Verspilling	Aanwezigheid?	Impact?	Beïnvloedbaar?	Mogelijke beheersmaatregel(en)
1	Bestaande kennis onvoldoende gebruiken	○○○○○ 1 2 3 4 5	○○○○○ 1 2 3 4 5	○○○○○ 1 2 3 4 5	Invullen indien beïnvloedbaar

Figure B.2 I Example of the questionnaire

B.3.2 Questionnaire results

Table B.7 provides an overview of the obtained results from the questionnaires, structured per question. For each type of waste the median is calculated per question in order to be able to determine which of the types of waste are most common.

Table B.7 I Questionnaire results

		presence						impact						influence					
		EH	RH	TD	JV	SD	MEDIAN	EH	RH	TD	JV	SD	MEDIAN	EH	RH	TD	JV	SD	MEDIAN
1	Insufficient use of existing knowledge	5	3	4	4	4	**4,0**	5	4	3	4	4	**4,0**	5	4	4	4	4	**4,0**
2	Gathering external information	5	3	4	3	4	**4,0**	5	3	2	3	4	**3,0**	5	2	4	4	3	**4,0**
3	Gathering internal information	5	4	4	4	4	**4,0**	5	4	4	3	4	**4,0**	5	4	4	5	4	**4,0**
4	Ineffective meetings and academic discussions	5	4	3	5	3	**4,0**	5	3	2	3	3	**3,0**	5	4	4	5	3	**4,0**
5	Lack of management	4	3	5	2	3	**3,0**	4	4	3	4	3	**4,0**	5	5	4	4	3	**4,0**
6	Lack of support	4	3	2	3	3	**3,0**	5	3	2	5	3	**3,0**	5	4	2	2	3	**3,0**
7	Lack of alignment between disciplines	5	3	3	3	4	**3,0**	5	3	4	4	4	**4,0**	5	4	3	5	4	**4,0**
8	Ambiguities regarding the project	5	3	4	3	4	**4,0**	5	3	3	5	4	**4,0**	4	5	4	4	3	**4,0**
9	Ambiguities regarding the design process	3	2	4	3	4	**3,0**	3	3	4	3	4	**3,0**	3	5	4	4	5	**4,0**
10	Ambiguities regarding the basic specifications	3	2	5	2	4	**3,0**	2	3	3	3	4	**3,0**	3	3	2	3	2	**3,0**
11	Ambiguities regarding the client requirements	5	4	4	3	5	**4,0**	5	4	4	5	5	**5,0**	5	4	5	4	3	**4,0**
12	Ambiguities regarding the interfaces	5	2	3	3	4	**3,0**	5	4	3	4	4	**4,0**	5	4	4	4	4	**4,0**
13	Ambiguities regarding generating alternatives	5	3	2	2	3	**3,0**	4	3	3	3	3	**3,0**	4	4	3	3	3	**3,0**
14	Ambiguities regarding the level of detail	4	2	4	5	4	**4,0**	4	3	4	3	4	**4,0**	5	3	4	2	4	**4,0**
15	Insufficient attention regarding verification	4	4	4	4	4	**4,0**	5	4	4	3	4	**4,0**	5	5	5	5	4	**5,0**
16	Implicit way of working	5	5	4	5	5	**5,0**	5	4	4	3	4	**4,0**	5	4	4	4	4	**4,0**
17	Working with the wrong assumptions, requirements and/or information	4	2	3	2	4	**3,0**	3	5	4	5	4	**4,0**	3	3	3	4	4	**3,0**
18	Overproduction per aspect and/or per phase	5	4	2	4	4	**4,0**	5	4	3	2	4	**4,0**	5	5	4	4	4	**4,0**
19	Unnecessary design changes	3	3	3	4	3	**3,0**	3	5	2	2	3	**3,0**	3	5	3	3	3	**3,0**
20	Client changes	-	3	3	3	5	**3,0**	-	4	4	3	5	**4,0**	-	3	1	2	2	**2,0**
21	Solution space too narrow	4	2	4	2	3	**3,0**	4	5	4	3	3	**4,0**	4	5	4	3	3	**4,0**

B.4 Value analysis sessions

This section is structured per value analysis session and discusses the identified types of waste and applied control measures.

B.4.1 A9 Badhoevedorp - Holendrecht

From the value analysis session regarding the A9 Badhoevedorp - Holendrecht, the following types of waste have been identified:

- gathering external information
- ambiguities regarding the project
- ambiguities regarding the interfaces
- client changes
- overproduction per aspect and/or per phase
- solution space too narrow

Gathering external information

At the start of the project, Rijkswaterstaat provided Witteveen+Bos with a huge amount of information. However, the approximate 1000 documents were neither structured nor complete. According to the project members, 90% of the information was redundant, not up-to-date, of poor quality, lacking the right references or containing different versions. This led to the fact that all documents needed to be checked one by one, which took a disproportionate amount of time compared to the information that actually turned out to be of use. Besides, as not all information was complete, several documents needed to be requested from Rijkswaterstaat, which also took a lot of extra waiting time.

Ambiguities regarding the project

For Witteveen+Bos it was quite unclear what the client, Rijkswaterstaat, wanted with the project. This was due to the fact that Rijkswaterstaat itself did not know exactly what the aim of the project was. This led to misunderstanding of what the client meant. For example, Rijkswaterstaat put a lot of focus on Amstelveen, whereas the TB to be designed was supposed to focus on Badhoevedorp-Holendrecht. Besides, the project was tendered according to best value procurement (BVP). However, the technical manager on the client's side did not work according to BVP.

Ambiguities regarding the interfaces

The interfaces of both the project and the project area contained lots of ambiguities. Regarding the project, all the factsheets resulting from Rijkswaterstaat's design had certain cohesiveness, but it was not clear how these were connected to one another. Also, the soil has a pivotal role in infrastructure projects, but in this case the soil research was conducted separately from this research. Moreover, the project entails several infrastructural works of which the criteria were unclear. This led to exploring the exact client's request, which eventually meant that the project has to be viewed more broadly. Regarding the project area, the TB of 2011 consisted on three parts, of which the middle part had to be revised. However, these hard demarcation lines were not feasible in practice. This may cause difficulties in itself, but in this case another difficulty was involved. During the TB of 2011, the stakeholder Ouder-Amstel showed resistance and therefore as little as possible should be changed in the revised TB regarding their interests.

Client changes
As already mentioned, the client did not exactly know what they were asking for. This had led to many client changes and causing the scope to become increasingly larger. Because of the increasing scope, Witteveen+Bos had to file many requests to change (Dutch: VTWs), which are conceived as inefficiencies in the process. Furthermore, politics as well as the environment have had a lot of influence on the project, also leading to client changes that did not add value to the design itself.

Solution space too narrow
The fact that the project experienced many client changes may be due to the fact that Rijkswaterstaat used a point-based approach. By using a point-based approach instead of a set-based approach, the solution space is less broad and less flexible as the direction is already determined in advance. According to the project members, the client's request should have been broader from the start, as the request also left little room for a suitable solution.

Overproduction per aspect and/or per phase
As in almost every project, certain aspects of the design were elaborated too far. In this project the risks were not determined yet, but the client was already asking for drawings. Therefore, drawings have been made that may not even be needed when taking the actual risks into account. Another example of overproduction in this project is that new products were added to the scope. For example, a crossroad was designed in order to persuade a stakeholder into the process. This may be a clear example of overproduction, but in this case it has added value to the process as the stakeholder might oppose to other aspects otherwise.

The control measures that have been applied during the design process of the A9 Badhoevedorp - Holendrecht, in order to mitigate the occurring types of waste and waste in general are discussed below per type of waste.

General
Designing with design loops is experienced to be very positive with regard to the design process, as the project is discussed from front to back and back to front. This way it is more certain that all elements are taken into account. Adding the design ateliers to the design loops turned out to be very valuable regarding the solutions in this project. Also because the most important stakeholders were directly involved in the design process. Besides, the project members stated that in every design process it is important to first realise whomever you are working with or for. Getting to know your client and collaborating parties is really important, because you can adjust your approach based on this knowledge. Moreover, it has been stated that it is valuable to learn from every project, so reporting the things that have gone wrong and, maybe even more important, the things that were successful. Within Witteveen+Bos the best practices are reported and taken into account in new plans of approach (Dutch: PvA). The PvAs are written by juniors and this way the knowledge is

transferred to other employees. Nevertheless, one has to bear in mind that every project is different and thus every new project may need lessons learned from multiple best practices.

Ambiguities regarding the project
Two clear control measures are taken concerning the project ambiguities. The first one is with regard to the BVP approach. An environmental manager was appointed, who was responsible for managing the process regarding BVP, this was conceived by all parties as valuable. The second control measure is regarding the fact that the client did not know yet what the actual focus of the project was. A project member from Witteveen+Bos was appointed to attend the project management team meetings in order to be involved at a higher level and this way weekly feedback could be given to Rijkswaterstaat.

Ambiguities regarding the interfaces
The establishment of the design ateliers also had a positive influence on the ambiguities regarding the interfaces. Within the design ateliers all three elements of the project are discussed and designed and expectations of all parties could be discussed, so this way all interfaces as well as interests are taken into account. However, in retrospect, four consultations would also be sufficient seeing as the last two consultations did not contribute to the design.

Client changes
It is rather hard to think of control measures regarding client changes, as client changes are categorised as unforeseen circumstances. However, the project members did try to respond to client changes as much as possible. By being flexible and adjusting your own process you can ensure to mitigate the waste resulting from these client changes. This way value can still be added even though the design process is disrupted by the client.

Overproduction per aspect and/or per phase
In order to ensure as little overproduction as possible it is important to keep asking the question "What is best for project?". This includes thinking of the needed level of detail for each decision to be made. In this project for example, the remarks on the cIPO were not processed into a revised cIPO, but taken into account during the next design phase being the IPO. Also, it is important to produce variants as minimal as possible. This may be seem unfeasible, but according to the project members filtering based on experience and common sense in the early design phase overproduction can reduce overproduction to a large extent.

B.4.2 Oosterweelverbinding

From the value analysis session regarding the Oosterweelverbinding, the following types of waste have been identified, including a newly introduced type of waste:

- lack of support
- lack of alignment between disciplines
- ambiguities regarding the basic specifications
- ambiguities regarding the level of detail
- working with the wrong assumptions, requirements and/or information
- cultural clash

Lack of support

The client and Witteveen+Bos have the same project goal, however, their interests differ. Witteveen+Bos has a fixed payment and a fixed timeframe and therefore has to consider the ratio between quality delivered/time spent. Also, Witteveen+Bos may be an expert on BVP projects, they still depend on the client's assessment and the client only focuses on the quality delivered of the final design. Also, a number of stakeholders fiercely oppose the design, but the client is responsible for stakeholder management. However, the client is not very experienced with stakeholder management and thus Witteveen+Bos has to deal with these opposing stakeholders even though they will not get paid for it.

Lack of alignment between disciplines

A few reasons for the lack of alignment between disciplines may be accurate for most projects, such as employees being involved in multiple projects at the same time and a long duration per project causing shifting of employees. However, in this project the client has made some odd decisions. For example, the client procured two contracts separately, one concerning the installation part and one regarding the civil part. According to a project member, this is a recipe for disaster, especially when these two parties do not work together. The same accounts for the designers of the project, being three different parties. Next to Witteveen+Bos, a Belgian architect and Zwarts & Jansma Architects were also involved in the design process. All three parties worked individually for as long as possible.

Ambiguities regarding the basic specifications

The basic specifications are referred to in this type of waste are the specifications that the Belgians use (Dutch: basisbestekken). These specifications consist of enormous documents containing many duplications and references to other specifications or specification documents. In order to be able to efficiently work with these specifications, you should know all the documents by heart. Meaning, as a Dutchman you can have trouble determining what is exactly stated and what exactly you have to do. Moreover, there are many different specifications, for example specifications regarding roads or rivers but also very specific elements such as how the grass has to be sown. Compared to the Netherlands, the Belgian specifications are described in a lot more detail.

Ambiguities regarding the level of detail

Immediately at the start of the project there was ambiguity regarding the level of detail. The client asked for an Engineering & Build contract, however the client and Witteveen+Bos had different definitions of the concerning contract. Both parties managed to agree on the definition, however the level of detail regarding the final product has never been completely clear. Throughout the project, the design has remained the same for approximately 90% and the other 10% entailed the scope changes. However the time spent on the 10% scope changes was way more than 10% of the total timeframe. According to the project member, a disproportionate amount of time has thus been spent on the smallest details such as bolts and nuts. In this case, the 80/20 rule can be applied regarding the time use.

Working with the wrong assumptions, requirements and/or information
As explained in the design process of the project, an analysis was carried out regarding the base design. During the analysis a few trivial aspects were noticed and communicated to the client. However, the client did not want to adjust the design and therefore did not pay attention to the trivial aspects right away. Later during the design phase the aspects eventually did come to the client's attention and had to be discussed, which sometimes led to design changes as well. Moreover, new client or stakeholder wishes were taken into account in the design, but were not included in the cost estimations, leading to budget overruns. Also, no comprehensive risk analysis was conducted, as the project team was under-staffed. It has to be borne in mind that working with the wrong assumptions, requirements and/or information for too long can cause the so-called loss effect according to the project member. Meaning that at a certain moment you have already invested so much that it creates resistance if any changes are initiated. However, in this project a change of management occurred. The new management reorganised and restructured the whole project and came upon a costs clash. This led to new design changes as the project had to be carried out within budget as much as possible.

Cultural clash
The last but probably most important type of waste in this project was the cultural clash. As already mentioned, the Belgian culture differs a lot from the Dutch culture. Witteveen+Bos has carried out projects in Belgium before, but it is hard to learn from previous projects, as the teams on both sides are never the same. This results in Dutchmen reinventing the Belgian wheel during every project. In the Netherlands, projects are usually described in a functional way and therefore performance-oriented with solution space for the contractor, whereas in Belgium everything is described in specifications, which is out-dated and dogmatic. Moreover, Belgian infrastructure is very much interwoven with politics due to the strict specifications, Belgians are not used to thinking "out of the box". All these aspects led to a difficult relationship with the client in this project.

The control measures that have been applied during the design process of the Oosterweelverbinding in order to mitigate the occurring types of waste and waste in general are discussed below per type of waste.

General
Design processes generally take more time than expected. However, tenders are almost always carried out within the given timeframe and may therefore be used as an example. In order to carry out the project within the given timeframe, a team is needed with sufficient project members and a predefined time limit, just like the tender procedure. Another control

measure is the use of a letter to make the higher management aware of the issues regarding the project. When delays occur, ambiguities arise, etc. a letter can be sent to the higher management of the project to help figuring things out. Most of the time, the higher management has no idea what is going on in the projects as the projects are managed by another layer of managers. By involving the higher management, the project management of the client's side is to a certain extent pressured to solve the issues in cooperatively.

Lack of alignment between disciplines
Two specific control measures are discussed regarding the lack of alignment between disciplines. The first one is regarding the lack of alignment and the second is regarding the composition of the project team. In order to mitigate or reduce the lack of alignment, it is stated that processes need to be interrupted in order to be able to make good agreements before continuing in the wrong direction. Another measure is to include evaluation sessions in the design process in order to evaluate the work and the alignment of the work. In order to compose a more efficient project team, it is stated that larger teams are needed in order to be able to maintain the process flow. Also, project members should be selected based on their profile and expertise instead of availability.

Ambiguities regarding the level of detail
When discussing control measures for ambiguities regarding the level of detail, it became clear that the most important control measure is to determine in advance how much time will be spent on each element within the design and what quality will be delivered. By making use of design loops, you start working with the existing information regarding the current design and then go further step-by-step. A project manager aims to finish as soon as possible, but it is really important to keep questioning whether the right things are being designed.

Working with the wrong assumptions, requirements and/or information
In an ideal situation the project is amplified in order to make a good design at once, however iteration is needed in order to reach the best design. This is based on set-base design. Rough concepts are needed in order to adjust according to all the requirements involved. By using Systems Engineering, the possibility arises to better navigate through the entire project.

Cultural clash
As already stated, Witteveen+Bos has already carried out Belgian projects before. However it is rather hard to learn from previous projects as team members shift within both parties. Therefore, it is important to report and structure the lessons learned from each project. The bad relationship with the client, which may arise from the cultural clash, has been mitigated in this project by introducing an intermediate.

B.4.3 Zaanenstraat

From the value analysis session regarding the Zaanenstraat, the following types of waste have been identified:

- insufficient use of existing knowledge
- gathering external information
- lack of alignment between disciplines
- working with the wrong assumptions, requirements and/or information
- unnecessary design changes

Insufficient use of existing knowledge

Two main causes for the insufficient use of existing knowledge can be pointed out. The first one is the fact that both teams were not aware of the existence of the other team and thus of the other project in the same project area. The team responsible for the redevelopment of the public space found out about this at their third meeting with the client. Moreover, the preliminary research regarding the sewerage model was also carried out by Witteveen+Bos. However, this was also not known by the current sewerage model team. The underlying cause for this may be poor internal communication. The second cause with regard to the insufficient use of existing knowledge is the change of personnel during the project. Both the client as Witteveen+Bos had to deal with this several times. The change of personnel may lead to a loss of information, as the information may not be stored explicitly. Also, the experiences already acquired during the project will be lost, as it is hard to transfer this kind of knowledge.

Gathering external information

At the start of the project not all documents were available yet and it took quite a long time before the information was complete. For example, the Statement of Requirements (Dutch: PvE) and Handbook Layout Public Space (Dutch: HIOR) were not final at the start of the project and Witteveen+Bos kept receiving newer versions throughout the project, leading to overproduction as well. Also, at some aspects the client deviated from the PvE or HIOR without explicitly stating this. Moreover, in order to gather external information the information portal of the client needed to be consulted. However, the portal did not contain all information needed for certain aspects.

Lack of alignment between disciplines

As both project teams did not know of the existence of the other team until third meeting, the sewerage model was not incorporated correctly in the redevelopment of the public space. So, when it became clear that Witteveen+Bos was carrying out both projects and the redevelopment team received the output from the sewerage team, the output did not match the vision for the redevelopment. Moreover, the realisation costs would be doubled in case the redevelopment would be adjusted to the sewerage model.

Working with the wrong assumptions, requirements and/or information

The sewerage team started designing with the wrong starting points and also optimised their design with regard to these wrong starting points. According to a member of the sewerage team, the starting points were vaguely described in the client requirements and therefore they had to design with regard to their own interpretation of the starting points. The redevelopment team members also stated that they have not been sufficiently critical regarding the client requirements. Moreover, after the analysis of the redevelopment team it became evident that total replacement of the sewerage, which was the client requirement, was not feasible. Therefore, a scope change had to be made. The redevelopment team started designing the VO, but did not have the output report from the sewerage team yet. This led to the redevelopment team designing based on assumptions. Seeing as the assumptions made the design unstable, the redevelopment team decided to diverge their design solution instead of converging it. Moreover, the presentation of the VO of the redevelopment to the client was scheduled before the residents meeting. In the short timespan between those meetings the VO was developed further without knowing whether the client agreed on the design.

Unnecessary design changes
As already mentioned, the redevelopment team started designing the VO before they had all the information that was needed available. By doing this, a lot of unnecessary design changes and rework was needed. Moreover, the first scope change initiated by the client also caused unnecessary design changes. It has been stated that scope changes are not conceived as a type of waste, however in this case the scope change was not correct and adjusted later on in the project. This wrongly initiated scope change did provide the project team with valuable insights, but still a lot of rework resulted from this scope change.

The control measures that have been applied during the design process of the Zaanenstraat in order to mitigate the occurring types of waste are discussed below per type of waste.

Insufficient use of existing knowledge
Throughout the project, several changes of personnel have occurred, leading to loss of expertise and information. In order to prevent or mitigate this type of waste a few control measures have been mentioned. In case personnel are leaving the company, engage them to be available by telephone or provide back office work for a determined period of time, keep the appointed substitute up-to-date throughout the process and/or work in parallel during the transfer period of the new team member. With regard to the transfer of knowledge and information, make sure to document the essence explicitly, which is part of the SE mind set, use the back-to-back principle as an example and/or make use of decision and transfer lists.

Lack of alignment between disciplines
Since December 2016, when both teams started exploring a solution for the sewerage together, the teams started attending each other's design meetings. This way the two projects were more aligned and seen as one big project instead of two separate projects.

B.5 Validation session

This appendix provides insight into the discussion of the proposed recommendations during the validation session with three experts from the Innova58 project team.

B.5.1 Werken met de verkeerde, aannames, eisen en/of informatie

Het expert panel herkent de drang om alvast te beginnen met het ontwerpen ook al zijn de aannames nog niet duidelijk. Zij bevestigen dan ook de bevinding uit het onderzoek dat het werken met aannames nodig is om het ontwerpproces te starten en communicatie mogelijk te maken. Het A58 kernteam heeft vooraf ingeschat dat het werken met aannames tot enorme verspilling kan leiden, zowel op het gebied van energie- en tijdverspilling als het verspillen van talent en het verliezen van plezier in het werk. Om deze redenen wordt er binnen de A58 veel aandacht besteed aan het duidelijk krijgen van de aannames voordat er wordt begonnen met ontwerpen.

Binnen de A58 vormde het Plan van Aanpak de basis van waaruit uitgangspunten en onderzoek uitgangspunten zijn geformuleerd. Vervolgens zijn op de meest kritieke onderdelen werkhypotheses geformuleerd. De rijlijn van de hoofdrijbaan is voor een infrastructuur project bijvoorbeeld altijd heel belangrijk. Deze is daarom onderkend als belangrijkste aanname. Vervolgens heeft er een discussie plaatsgevonden over de impact die deze aanname kan hebben op zowel de planning als de kosten van het project als de aanname niet juist blijkt te zijn. De zekerheid van deze aanname is ook van belang, omdat er veel van deze aanname wordt afgeleid. Impliciet worden aannames dus langs de assen van de APN gelegd, maar dit wordt niet expliciet gedocumenteerd. Een ander voorbeeld is een bepaald kruispunt waarvan het project team weet dat de aanname onstabiel is. Op de zekerheid-as van Turbit (2005) zou deze aanname dus geschaald worden op *low confidence* met een score van 4. Doordat deze aanname zo onzeker is, is besloten om deze aanname vanuit risicomanagement aan te sturen.

Haalbaarheid

Het expert panel geeft aan dat de aanbevelingen zeker haalbaar zijn en zij zijn hiervan overtuigd omdat de aanbevelingen tot op een zekere hoogte impliciet al worden toegepast binnen de A58. De aannames worden impliciet beoordeeld op de drie parameters van het APN en wanneer aannames een lage zekerheid maar grote impact kunnen hebben op het proces worden deze aangestuurd vanuit risicomanagement. Het expliciet prioriteren wordt gezien als een waardevolle extra stap, die nu nog niet wordt genomen. Door de aannames expliciet te prioriteren kan er expliciet een inschatting gemaakt worden voor welke aannames het van belang is om deze snel om te zetten tot een vastgesteld uitgangspunt. Het koppelen van actiehouders wordt nu ook nog niet expliciet gedaan, maar dit wordt ook als waardevol gezien. Vooral omdat Rijkswaterstaat moeite lijkt te hebben om met aannames om te gaan, omdat zij bang zijn dat zij de rekening krijgen wanneer ze akkoord gaan met een aanname die achteraf niet juist blijkt te zijn. Door actiehouders verantwoordelijk te stellen voor specifieke aannames kunnen de aannames continu gemonitord en bijgesteld worden totdat het evalueert tot een vastgesteld uitgangspunt. Op deze manier is het ook voor iedereen duidelijk waar men mee bezig is en wie er verantwoordelijk is voor welke aanname. Dit zou in

Relatics vastgelegd kunnen worden of, wanneer Relatics hier nog niet geschikt voor is, in een simpel Excel bestand.

Het expert panel heeft daarnaast aangegeven dat er een aantal voorwaarden zijn om de aanbevelingen te kunnen implementeren. Allereerst, de samenstelling van het team. Het team moet niet conflict mijdend zijn, maar juist naar het conflict toe bewegen. Daarnaast moet het team voldoende senior consultants bevatten, die op het juiste niveau kunnen inschatten wat een onzekere aanname is. Voor deze inschatting is ervaring en expertise op het juiste niveau nodig, omdat men met weinig informatie de kern van het probleem moet kunnen doorgronden. Als laatste werd voldoende overtuigingskracht genoemd. De A58 is een Best Value Procurement (BVP) project, wat betekent dat Witteveen+Bos de regie heeft over het werkproces. Vanaf het begin heeft Witteveen+Bos aangegeven dat zij de stoorkosten willen minimaliseren door eerst de aannames scherp te krijgen en dit hebben zij gedurende het proces weten vast te houden. In niet-BVP projecten, maar ook in BVP projecten, is het wel van belang dat het project (management) team voldoende overtuigingskracht heeft om het belang van werken met aannames te kunnen onderbouwen en de opdrachtgever hier ook van te overtuigen.

Bereidheid

Het A58 project is een vrij uitzonderlijk project binnen Witteveen+Bos, omdat het qua proces vrij ver voorloopt op andere processen. Vanuit de visie van het project zijn er een aantal principes ontwikkeld en daar wordt in het project consequent op gestuurd, bijvoorbeeld het gebruik van Relatics en het expliciet werken. Toch is het expert panel van mening dat de bereidheid binnen Witteveen+Bos om de aanbevelingen met betrekking tot het toepassen van aanname management groot is. Zeker omdat de impliciete vorm van aanname management, zoals deze binnen het project van de A58 wordt toegepast, als positief wordt ervaren. Een leerervaring die wordt meegegeven vanuit het A58 proces, is dat het omgevingsproces op de een of andere manier al wel eerder in gang moet worden gezet, bijvoorbeeld door een hele grove schets te communiceren naar de omgeving. Een groot nadeel van het werken met aannames is namelijk dat de omgeving pas later betrokken kan worden bij het ontwerpproces, omdat zij veelal afhankelijk zijn van visuele vertalingen. Wanneer er wordt gewerkt met aannames komen de visualisaties pas later in het proces aan bod, omdat men dan eerst bezig is om alle aannames duidelijk te krijgen voordat er überhaupt wordt ontworpen. Hoe de omgeving precies beter of eerder bij het proces kan worden betrokken is iets waar nog verder over nagedacht moet worden en dat uitgezocht moet worden.

B.5.2 Onvoldoende gebruik van bestaande informatie (proces gericht)

Vanuit het expert panel wordt bevestigd dat er momenteel inderdaad te weinig uit de evaluaties wordt gehaald. Er wordt op meerdere manieren geëvalueerd, bijvoorbeeld door evaluatiesessies te organiseren, KPI metingen te verrichten, audits te doen, etc. en dit wordt allemaal in losse notities en verslagen gedocumenteerd. Deze documentaties worden vervolgens door de PMC leiders gelezen, maar verder wordt er niets concreets mee gedaan.

Vanuit het Centraal Kwaliteit Team (CKT) van Witteveen+Bos is er een actie opgezet om een kwaliteitsdatabase op te zetten. De opzet van deze database is gekomen vanuit de overtuiging dat er meer gehaald kan worden uit de evaluaties dan er momenteel wordt gedaan. Momenteel is het CKT bezig met de eerste stap, namelijk het opzetten van een database waarin alle bevindingen uit de verschillende vormen van evaluaties bij elkaar worden gebracht. Het CKT gaat al deze evaluaties bekijken en bepalen welke lessen eruit gehaald kunnen worden, dus wat hebben we geleerd, wat is ons advies en hoe zou deze les in het vervolg gebruikt kunnen worden? Deze lessons learned worden ook gedocumenteerd in de database. De volgende stap zou zijn om deze bevindingen en lessons learned inzichtelijk te maken voor alle medewerkers en uiteindelijk is het de bedoeling dat medewerkers de database direct zelf kunnen aanvullen na bijvoorbeeld een evaluatiesessie.

Haalbaarheid

In principe worden er momenteel dus al verschillende vormen van evalueren toegepast, maar het expliciet documenteren en vervolgens gebruiken van deze evaluaties in vervolg projecten blijft nog erg achter in de praktijk. Volgens het panel zal er door het opzetten van een database waarin al deze evaluaties een plek krijgen, een eerste stap gezet worden om het gebruik van de evaluaties in nieuwe projecten te stimuleren. Zeker wanneer er ook concrete lessons learned worden gekoppeld aan de evaluaties.

Het koppelen van de lessons learned aan de VPI's wordt door het panel als een waardevolle aanbeveling gezien, die ook in de praktijk haalbaar lijkt te zijn. Het panel is van mening dat een de koppeling van VPI's aan de database met daarin best practices en lessons learned kan helpen om scherpte te brengen in je afwegingen. Dus dat je bij elke overweging kan checken wat het in het verleden heeft opgeleverd, wat de voorwaarden voor een bepaalde aanpak zijn, etc. Bovendien wordt er naast de kwaliteitsdatabase binnen Witteveen+Bos ook gewerkt aan het opzetten van een VPI database. Door deze twee databases met elkaar te koppelen komt alle projectinformatie uiteindelijk terecht in één database. Dit is een extra kleine handeling die gedaan moet worden bij elke evaluatie en dus goed te combineren. Bovendien moet iedere stelling bij BVP projecten onderbouwd worden met VPI's, dus het gebruik van VPI's wordt al steeds meer toegepast. Hierdoor komen steeds meer werknemers al in aanraking met het werken met VPI's en deze ervaring draagt bij aan een grotere haalbaarheid van het evalueren van projecten op basis van VPI's of het koppelen van VPI's aan evaluaties.

Het panel geeft echter wel aan dat een database alleen niet de oplossing zal zijn voor het probleem. Zij geven namelijk aan dat de discussie gedurende een evaluatie ook een enorme toegevoegde waarde heeft en dus minstens zo belangrijk is als het hebben van een database. Deze evaluatie gesprekken zijn vrij intensief en door het samen formuleren van leerervaringen blijft het beter hangen dan dat iedereen individueel zijn/haar leerervaringen in een database documenteert. Daarnaast is het belangrijk dat degene die de database raadpleegt ook inzicht heeft in bij wie hij/zij terecht kan voor verdere vragen of toelichting bij een bepaalde lessons learned. Dus het koppelen van een eigenaar bij elke evaluatie of elke lessons learned is ook van belang.

Bereidheid

Het feit dat er binnen Witteveen+Bos al acties opgezet zijn om met databases te werken, laat zien dat er bereidheid is, in ieder geval onder bepaalde werknemers, om meer uit de huidige evaluaties te halen. Er wordt aangegeven dat er enorm veel uit evaluaties geleerd kan worden en dat degenen die de evaluatie doen er het meeste van leren. Zonder de databases is de kans klein dat de bevindingen bij de andere werknemers terecht komen, omdat de PMC leiders momenteel de enige zijn, op uitzonderingen na, die de evaluaties lezen. Het is nu aan de PMC leider of hij/zij bepaalde lessen uit de evaluaties haalt en in hoeverre deze worden doorgegeven aan de medewerkers.

De bereidheid om de evaluaties te koppelen aan VPI's wordt duidelijk uit deze validatiesessie wanneer er vanuit het expert panel wordt aangegeven dat het een goed idee is om eens te kijken in hoeverre dat nu al mogelijk is. Binnen Witteveen+Bos is men dus al bezig met het opzetten van een VPI database en daar zijn nu zes concrete en veel voorkomende project doelstellingen geformuleerd die gekoppeld zullen worden aan de VPI's. Binnen het CKT zal gekeken worden of het mogelijk is om elke lessons learned aan één of meerdere VPI's te koppelen. Dit is een extra kleine handeling die gedaan moet worden bij elke evaluatie en dus goed te combineren.

B.5.3 Gebrek aan afstemming tussen disciplines

Het expert panel bevestigd dat afstemming tussen verschillende disciplines één van de grootste uitdagingen is in alle grote projecten, maar zeker ook in de infrastructuur projecten. Daarbij geven zij aan dat hier (nog) geen ultieme oplossing is gevonden, maar dat er wel al allerlei tools en werkwijzen worden toegepast om de afstemming tussen disciplines te verbeteren.

Binnen het A58 project wordt er heel bewust gestuurd op de samenwerking en afstemming tussen de verschillende disciplines. Door gebruik te maken van voortdurend wisselende werkvormen komen de disciplines steeds op verschillende manieren met elkaar in gesprek. Er vind bijvoorbeeld elke twee weken een inpassingsoverleg plaats, waarin op verschillende niveaus met elkaar besproken wordt waar elke discipline mee bezig is. Daarnaast komt het hele projectteam 1 à 2 dagen per week samen op dezelfde locatie om samen te werken. Op deze manier kan het nog steeds voorkomen dat er gebrek aan afstemming is, maar het is wel een eerste stap waarbij de verschillende disciplines bij elkaar gezet worden om zo beter samen te kunnen werken. Bovendien is er een ontwerpweek gepland, waarin alle disciplines bij elkaar komen en een hele week intensief samenwerken aan het ontwerp. Bovendien wordt er ook een mix aan tools en instrumenten ingezet, zoals parametrisch ontwerpen en reviewmomenten, om verschillende type raakvlakken op verschillende niveaus te identificeren.

Haalbaarheid

Het expert panel geeft aan dat de aanbevelingen zeker goede voorbeelden zijn van maatregelen die een bijdrage kunnen bieden aan een betere afstemming tussen disciplines, maar dat dit maar een klein gedeelte is van de hoeveelheid maatregelen die nodig zijn om complete ontwerpintegraliteit tot stand te brengen.

Desalniettemin worden de aanbevelingen die gemaakt zijn wel bevestigd als waardevolle aanbevelingen, aangezien alle aanbevelingen in verschillende mate worden toegepast binnen het A58 project en allen een positief effect blijken te hebben.

Vooral de LPM wordt gezien als een hele goede en waardevolle planningsmethodiek. Binnen het A58 project is deze al een aantal keer toegepast, waarbij elke sessie weer leerervaringen bevat die worden meegenomen in de volgende sessie. Door het toepassen van de LPM kan er in een relatief korte doorlooptijd een planning opgezet worden, maar vooral het gesprek dat hierbij wordt gevoerd draagt bij aan het verbeteren van de afstemming tussen de disciplines. Het kernteam heeft vooraf een grove planning gemaakt, waarin bijvoorbeeld alle mijlpalen staan aangegeven, maar tijdens het gesprek komen er ook aspecten aan bod die het kernteam niet kon bedenken zonder input van de verschillende disciplines. Ondanks dat het A58 project team geen externe betrekt bij de planningssessies, zijn de sessies over het algemeen wel effectief gebleken. Het expert panel is daarom van mening dat de LPM ook kan worden toegepast zonder externe (bege)leiding.

Binnen het A58 project zijn de communicatie lijnen kort en daarom wordt er geen gebruik gemaakt van DSM's maar wel van weekly standup meetings (WSM's). Deze methode wordt ervaren als een goede methode om elkaar bij te praten en het feit dat het een staand overleg is draagt bij aan de effectiviteit en doelmatigheid van het overleg. De standup meetings blijken dus haalbaar te zijn binnen Witteveen+Bos en de frequentie van de meetings hangt af van de onderlinge communicatie binnen het team. Hoe korter de communicatie lijnen, des te lager de frequentie van de meetings. Er worden daarnaast ook tweewekelijkse standup meetings gehouden met opdrachtgever. Het doel is hier niet zozeer de afstemming tussen de disciplines, maar het gaat dan eerder om draagvlak, imago en betrokkenheid.

Het gebruik van CFT's zoals dit in de literatuur wordt gepresenteerd, waarbij disciplines bij wijze van spreken elkaars rol overnemen, is volgens het expert panel niet realistisch. Toch wordt er wel geprobeerd om zo veel mogelijk nauwe samenwerkingen te creëren, door bijvoorbeeld in koppels van verschillende disciplines te ontwerpen. Daarnaast bestaat het kernteam uit verschillende disciplines, maar om tot diepgang en productie te komen is er ook specialisatie nodig. Dus op een hoog niveau is er zeker sprake van een CFT, maar hoe lager je komt de projectorganisatie, hoe gespecialiseerder het wordt.

Bereidheid

Op basis van het feit dat de aanbevelingen reeds worden toegepast binnen het A58 project en de positieve ervaringen hiermee, kan gesteld worden dat er binnen Witteveen+Bos zeker bereidheid is om de aanbevelingen in verschillende mate ook in andere projecten te implementeren.

Zoals al aangegeven bij de haalbaarheid van de DSM's hangt het heel erg van de communicatie binnen het betreffende project af hoe vaak de stand up meetings plaats vinden. Daarnaast is het werken met CFT's niet volledig haalbaar door de specialismes die nodig zijn bij elk project, maar door het succesvol toepassen van verschillende werkvormen is de bereidheid om nauw met andere disciplines samen te werken wel aanwezig.

Het gebruik van de Percent Plan Complete wordt nog niet toegepast, maar werd wel gezien als een goede en efficiënte manier om bij te houden welke activiteiten uitgevoerd zijn en wat de mogelijke oorzaak is van het feit dat een geplande activiteit nog niet (helemaal) uitgevoerd is. Echter, moet hier wel een easy-to-use tool of werkwijze voor worden gevonden om te voorkomen dat werknemers dit als extra administratieve taak gaan zien.

C LITERATURE RESEARCH

This appendix provides additional information and findings on literature and is subdivided into three parts, being design views, TOE framework, recommendations.

C.1 Overview design views

First, an overview of the comparison of the three design views according to Ballard and Koskela (1998) and Tzorzopoulos & Formoso (1999) is provided.

Table C.1 I Comparison of conversion, flow, and value generation views (Ballard & Koskela, 1998)

Item	Conversion	Flow	Value generation
Conceptualisation of engineering	As a conversion of requirements into product design	As a flow of information, composed of conversion, inspection, moving and waiting	As a process where value for the customer is created through fulfilment of his/her requirements
Main principles	Hierarchical decomposition, control and optimisation of decomposed activities	Elimination of waste (non-conversion activities), time reduction	Elimination of value loss (achieved value in relation to best possible value)
Methods and practices	Work breakdown structure, critical path method, organisational and responsibility chart	Rapid reduction of uncertainty, team approach, tool integration, partnering	Rigorous requirement analysis, systemised management of flow down requirements, optimisation
Practical contribution	Take care of what has to be done	Taking care that what is unnecessary is done as little as possible	Taking care that customer requirements are met in the best possible manner
Suggested name for practical application	Task management	Flow management	Value management

C.2 TOE framework

Bosch-Rekveldt (2011) has developed a framework that consists of a total of 47 elements, the so-called TOE framework (see Table C.2), that indicates either technical, organisational or environmental complexity.

Table C.2 I Final TOE Framework (Bosch-Rekveldt, 2011)

Technical Complexity (17 elements)	Organizational Complexity (16 elements)	External Complexity (14 elements)
Number of project goals	High project schedule drive	Number of external stakeholders
Non–alignment of project goals	Lack of Resource & Skills availability	Variety of external stakeholders' perspectives
Unclarity of project goals	Lack of Experience with parties involved	Dependencies on external stakeholders
Uncertainties in scope	Lack of HSSE awareness	Political influence
Strict quality requirements	Interfaces between different disciplines	Lack of company internal support
Project duration	Number of financial sources	Required local content (forced co-operation with local parties)
Size in CAPEX	Number of contracts	Interference with existing site
Number of locations	Number of different nationalities	Weather conditions
Newness of technology (world–wide)	Number of different languages	Remoteness of location
Lack of experience with technology	Presence of JV partner	Lack of experience in the country
Number of tasks	Involvement of different time zones	Company internal strategic pressure
Variety of tasks	Size of project team	Instability of project environment (exchange rate, oil price, raw material price, etc.)
Dependencies between tasks	Incompatibility between different project management methods / tools	Level of competition
Uncertainty in methods	Lack of trust in project team	Risks from environment
Involvement of different technical disciplines	Lack of trust in contractor	
Conflicting norms and standards	Organizational risks	
Technical risks		

C.3 Recommendations

This appendix provides additional information on the tools and methods that are part of the proposed recommendations and is subdivided into APN rating explanation and LPM total planning.

C.3.1 APN rating explanation

According to Turbit (2005) the assumption parameters are:

- Confidence. How sure are we that the Assumption is true?
- Lead time. How long before we can prove or disprove the Assumption?
- Impact. If the Assumption proves incorrect, how much rework is involved

Confidence

Confidence is important because it is a measure of how certain we are of the Assumption. Confidence can vary during the period of the Assumption. For example, we may assume "Branch A" is the first in line for our rollout at the start of the program. As time progresses, we might become more attracted to "Branch C" before settling on "Branch B". Our level of confidence falls as the project progresses. Confidence is rated on a scale of 1 to 4 :

1. Almost Certain. Very little doubt about the Assumption.
2. Highly Confident. Some doubt but we all feel it will be true
3. Reasonably confident. Our best guess at the time, but we would not be surprised if it did change
4. Low confidence. We would prefer to not make a prediction, but if we have to this is our guess. There are many factors that could prove us incorrect.

Lead Time

Lead time has an impact in that the longer it is before the Assumption is proven true or false, the more work will be done based on the Assumption, or the more 'finished' will be the deliverables of the project. The other factor is the less time to undo any completed work that may be required. Lead Time is rated on a scale of 1 to 2:

1. The Assumption will be proven or disproven within the first half of the remaining project time.
2. The Assumption will be proven or disproven within the second half of the remaining project time

For example, if the project has 4 months to implementation, and the Assumption would not be able to be verified for 3 months it would rate a 2

Impact

Impact relates to the amount of rework that will need to be undertaken if the Assumption proves incorrect. Impact can be rate as follows:

1. Minimal Rework. Would have a minimal impact on the workload. Typically less than 3% of the total work
2. Some Rework. There would be a requirement for additional work however it could still be accommodated within the existing timeframes. Typically no more than 10% of the total project would need to be reviewed and possibly reworked, or additional work undertaken.
3. Medium Rework. There would be either additional resources required, or the finish date would need to be adjusted. Up to 30% of the project would need to be reviewed and potentially reworked or additional work undertaken.
4. Significant Rework. A major impact on the project with more than 30% of the project work needing to be reviewed and changed, or additional work undertaken.

Example: If the total project was 4 man months work, and if the Assumption was incorrect, the review and rework would account for an additional man month, it would rate a 3.

Assumption Priority Number

The three ratings should be added together to provide an Assumption Priority. Using the formula above, we can rate the priority of Assumptions as:

- 9-10 Critical
- 7-9 High
- 5-7 Medium
- 3-4 Low

The priority can be used to focus on potential failure points in a project.

C.3.2 LPM total planning

Figure C.1 provides an overview on the total planning of the Last Planner Method.

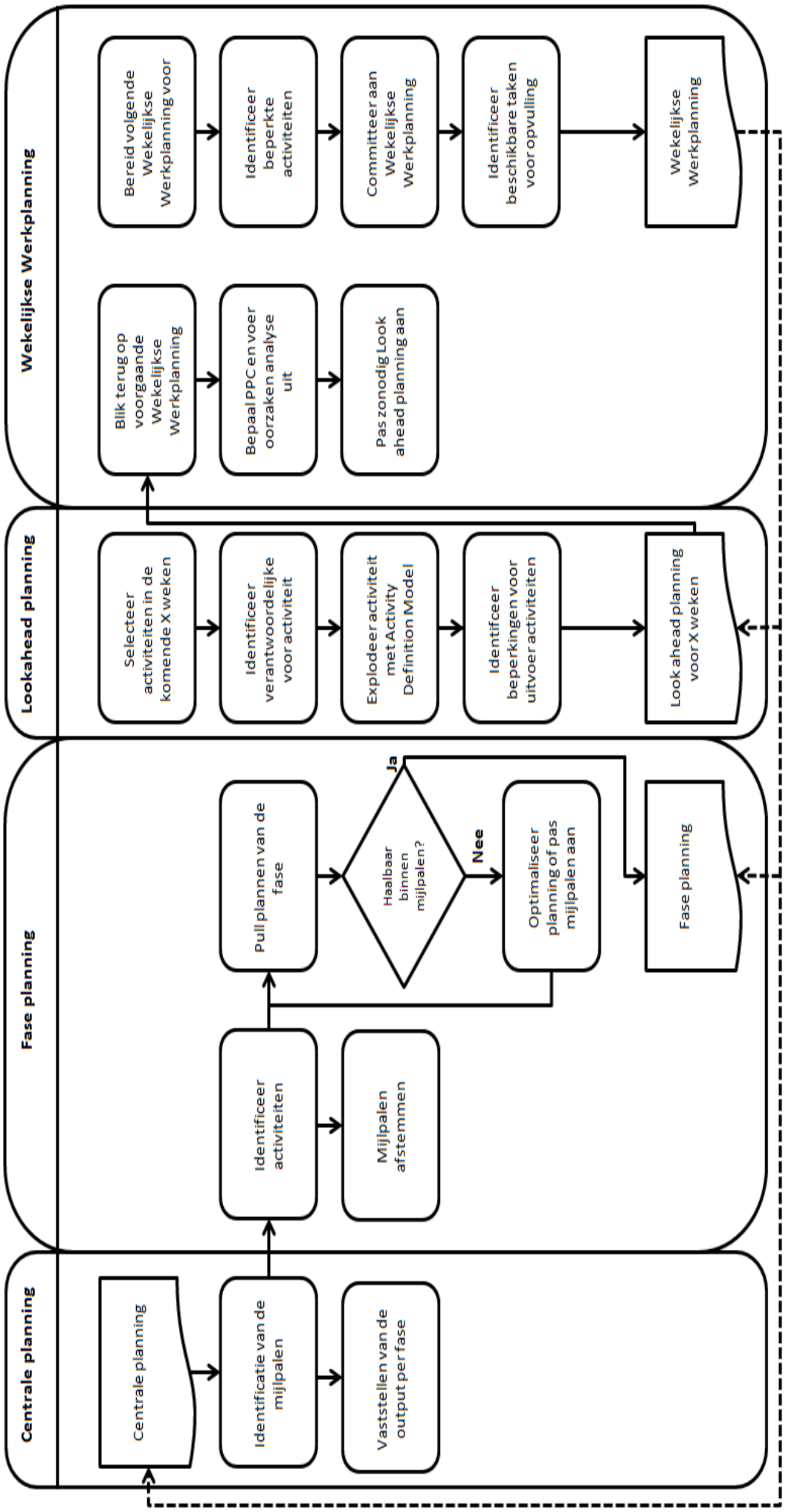

Figure C.1 | Last Planner processchema as cited in Schonk (2013)(Hamzeh et al., 2009)