WORKING TOWARDS INFRASTRUCTURAL STANDARDIZATION:

STANDARDIZING THE OVERPASS STRUCTURAL DESIGN PROCESS USING VSM-ANALYSIS, AND A FIRST STEP INTO TOOL CONCEPTUALIZATION.

D.M. Boterman - MSc Thesis
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PREFACE

During my studies, I have always been interested in change management. Improving things which in my eyes could be smarter or better organized, yielding better results. This is why, failure costs have always been something I have been interested in. And it would only seem fitting to somehow incorporate the subject into my master thesis by improving something to help reduce failure costs.

Heijmans offered me this chance as they have been playing with the idea of standardizing products and the corresponding design processes. This research is the first step into the process of standardizing end product and focuses on determining if and how civil engineering end products and their design processes, the chosen scope of the research was an overpass, should be standardized. Mainly by establishing potential benefits and challenges, analyzing the current overpass structural design process by using Value Stream Mapping, improving and standardizing this process, and determine how changing towards this improved state should be implemented. The second part of the research conceptualizes an overpass design tool which is used in the improved process. It describes how such a tool should operate and how data should be processed by using BPMN and exchange requirements.

This research concludes my graduation project for my master 'Construction Management and Engineering' at Eindhoven University of Technology. A study which, after first finishing my Civil Engineering bachelor at the Avans University of Applied Sciences and the pre-master program, marks the end of my full-time studying career, and simultaneously marks the beginning of my working career in the field. Even if I already have been working at Heijmans for over a year now, resulting in this research being finished later than intended.

I would very much like to thanks Heijmans and my colleagues at Heijmans for providing me with the opportunity to conduct my research at this great company and for having a splendid time whilst doing so. Also I would like to thank the specialists who have been involved in the research and who have generously donated their time to help me understand some of the more die-hard parts of their fields of expertise. In particular I would like to thank Jaap van Lier for his guidance during and even after my research period. Our talks, both on subject of my research and on business strategy, have been priceless.

I would also like to thank my TU/e tutors Bauke de Vries, Aant van der Zee, and Jakob Beetz, who have guided me through a less than fluent research process with a lot of changes in the direction of the thesis. You have provided me with valuable insights and supportive criticism which helped the quality of my research.

Finally I would like to thank my friends and family for the continuous support during my study and for motivating me through the rough patches of the research process. Even if it drove you guys crazy, you always listened and provided suggestions to improve. That leaves me with the most important thank you, to my incredible girlfriend Suzanne without whom I would not have reached the finish line. She has been my rock!

SUMMARY

The civil engineering branch has been plagued by the high amount of failure costs for a long time now, ~11% (USP-MC, 2013), resulting in very low margins across the market. A number of solutions have been tried, LEAN engineering is the latest and probably most successful technique used to decrease the failure costs. LEAN is already being used by a number of organizations in the civil engineering branch, but it has been used mainly to improve management processes and project schedules. As part of the LEAN philosophy, standardization has been used to create standard documents and standard approaches for relatively simple processes. This research offers an example how organizations can use LEAN and Value Stream Mapping to improve their more complex processes to try and reduce the high failure costs of the organization by working towards product standardization. The research focuses on the case study of an overpass but it is assumed that found benefits and challenges are also applicable to other end products.

End product standardization, in the form of module based designing and with a standardized design process, can offer a lot of improvements over the current structural design process. The literature study and the field research show that a standardized design process will allow for better interfaces between construction and design disciplines, it allows for increased productivity and effectiveness in creating the design, it allows for quality optimization and a increased certainty of completion date and costs. Product standardization allows for products to have a tried and tested track record, predictable quality and performance, it allows for increased productivity and effectiveness in building, and it allows a reduction of waste. There are, however, also some challenges for starting with process- and product standardization in the civil engineering branch. The civil engineering branch is generally slow to change and change is hard-fought. An implementation plan has been created to help with this issue. It is also important for civil engineering products, and in this case an overpass, to remain flexible enough so that a standard product can be used in multiple projects. To this end it has been conceptualized that a module-based design best fits the need for standardization whilst still being flexible enough.

Despite the challenges, the use of process- and product standardization might not be only an option. Even though it does not fit inside the scope of this research project, it is abundantly clear that standardization of components is very helpful in moving towards a circular economy, reducing material costs and waste by re-use, and overall being more durable in the entire construction process. The linear production model leads to unnecessary resource losses in several ways: waste in the production chain, end-of-life waste, energy consumption, and erosion of ecosystem services. A linear model is heavily depending on the global commodity stock (Verberne, 2016). Standardization offers a chance to optimize design and construction of components, increasing the quality, decreasing waste, and thus moving towards more durable and sustainable buildings and infrastructure.

By using the LEAN manufacturing technique Value Stream Mapping and translating the technique to the civil engineering branch, the design process of the contractor has been analyzed. This analysis showed a lot of room for improvement, mainly in the large amount of activities that have been classified as necessary waste and the amount of waste hidden in the process. To try and solve the problems of the current design process of an overpass, an improved state design process has been proposed which includes an automated overpass design tool. This improved design process is projected to reduce the overall total lead time of the design process by **18.2%.** The ratio value adding – necessary waste activities swings **23,3%** and **16,42%** (respectively for the client and the construction team) towards more time spent on value adding activities.

To implement the improved state design process, an implementation plan has been developed which can be found in Appendix 4. In it, a series of steps based on the Golden Circle Model of Simon Sinek has been proposed. This implementation process also utilizes Whole Scale Change theory opposed to more common change management theories. Whole Scale Change theory is deemed more suitable because it offers a wide approach to engage all stakeholders in the process of change. If the contractor wants this initiative to succeed, it is imperative that there is a sufficient base among employees, even more so if the contractor wants to expand the modular approach from only the design phase to the procurement and realization phases as well (which they should because it will only increase the amount of advantages the approach brings to the table). Whole Scale Change will aid to create a sufficient base by involving stakeholders in an early stage.

End product standardization should be able to fit in the current market and contracts as long as the contracts allow sufficient design freedom and the clients are willing to void or change a few requirements to allow for the standardized end product. Talks with Rijkswaterstaat indicate that it is prepared to meet these conditions as long as contractors can prove the extra value standardized end products bring. It is up to the contractor to ensure enough variation range in the modules to make sure that the standard product is no 1-trick pony. It is also advisable for contractors to work together with an architect to design esthetic modules (for instance for the edge elements of a overpass) so that the tender meets the esthetic requirements of the client.

The improved design process introduces an overpass design tool which is conceptualized to provide a first step into the tools development. The tool offers a second level of standardization; standardizing the structural design process is the first level of standardization, standardizing certain variables within those calculations via the use of modules is the second level. The purpose of the automated overpass design tool will be to benefit from both levels of standardization; By using the tool, the overpass structural design process can be completed more efficiently meaning that more valuable time can be spend on "specials", and it allows for the use of modules which offers the possibility to benefit from the use of standard products. The system breakdown structure of the overpass is used to explain the composition of the overpass and to choose a section to go into more detail with. For the chosen scope, a BPMN diagram (business process model and notation) will be used to map the transfer of data and to create the needed exchange requirement which will help setting up a data structure for the structural design tool. The BPMN and the derivative data structure will help the contractor in ensuring that all the needed variables for the tool have the required data to execute the calculations.

SAMENVATTING

De civieltechnische branche wordt al lange tijd geplaagd door de hoge hoeveelheid faalkosten, ~ 11% (USP-MC, 2013), wat resulteert in zeer lage marges op de markt. Een aantal oplossingen zijn reeds geprobeerd, LEAN-engineering is hiervan de nieuwste en waarschijnlijk meest succesvolle techniek die wordt gebruikt om de faalkosten te verlagen. LEAN wordt al gebruikt door een aantal organisaties in de civieltechnische branche, maar het wordt voornamelijk gebruikt om managementprocessen en projectplanningen te verbeteren. Als onderdeel van de LEAN filosofie wordt standaardisatie reeds gebruikt om standaarddocumenten en standaardbenaderingen voor relatief eenvoudige processen te maken. Dit onderzoek geeft een voorbeeld van hoe organisaties LEAN en Value Stream Mapping kunnen gebruiken om hun complexere processen te verbeteren en de hoge faalkosten van de organisatie te verminderen door te werken aan productstandaardisatie. Het onderzoek richt zich op de case study van een viaduct, maar er wordt verondersteld dat gevonden voordelen en uitdagingen ook van toepassing zijn op andere eindproducten.

Standaardisatie van eindproducten, met behulp van modulair ontwerpen en met een gestandaardiseerd ontwerpproces, kan veel verbeteringen bieden ten opzichte van het huidige constructieve ontwerpproces. De literatuurstudie en het veldonderzoek tonen aan dat een gestandaardiseerd ontwerpproces betere interfaces tussen constructie- en ontwerpdisciplines mogelijk maakt, zorgt voor verhoogde productiviteit en effectiviteit bij het maken van het ontwerp, zorgt voor kwaliteitsoptimalisatie, en zorgt voor een verhoogde zekerheid van de opleverdatum en kosten. Productstandaardisatie zorgt er op zijn beurt voor dat producten een beproefd en bewezen staat van dienst hebben, voorspelbaar zijn in geleverde kwaliteit en prestaties, zorgen voor een hogere productiviteit en effectiviteit bij het bouwen, en productstandaardisatie zorgt voor een vermindering van het vrijkomende afval. Er zijn echter ook enkele uitdagingen m.b.t. het opstarten van proces- en productstandaardisatie in de civieltechnische branche. De civieltechnische branche is over het algemeen traag en log in veranderen, en het kost vaak veel moeite om veranderingen door te voeren. Hiertoe is er een implementatieplan gemaakt om de verandering soepeler te laten verlopen. Het is ook belangrijk voor civieltechnische producten, en in dit geval een viaduct, om flexibel genoeg te blijven zodat een standaardproduct in meerdere projecten kan worden gebruikt. Hiertoe is vastgesteld dat een modulair ontwerp het beste aansluit bij de behoefte om te standaardiseren, terwijl het nog steeds flexibel genoeg is om op meerdere projecten toegepast te worden.

Ook al zijn er uitdagingen, het gebruik van proces- en productstandaardisatie is van groot belang. Hoewel het niet binnen de scope van dit onderzoeksproject past, is het overduidelijk dat standaardisatie van componenten/modules zeer nuttig is om toe te werken naar een circulaire economie en daarmee materiaalkosten en afval te verminderen door hergebruik en het gehele bouwproces duurzamer te maken. Het lineaire productiemodel leidt op verschillende manieren tot onnodige bronnenverliezen: afval in de productieketen, end-of-life afval, energieverbruik en erosie van ecosysteemdiensten. Een lineair model is sterk afhankelijk van de wereldwijde grondstofvoorraad welke niet oneindig meegaat (Verberne, 2016). Standaardisatie biedt een kans om het ontwerp en de constructie van componenten te optimaliseren, de kwaliteit te verhogen, afval te verminderen en zo te groeien naar meer duurzame gebouwen en infrastructuur.

Door de LEAN-productietechniek Value Stream Mapping te gebruiken en de techniek te vertalen naar de civieltechnische branche, is het mogelijk gemaakt het constructieve ontwerpproces van de aannemer te analyseren. Deze analyse toonde veel ruimte voor verbetering, voornamelijk in de grote hoeveelheid activiteiten die werden geclassificeerd als necessary waste, en de hoeveelheid waste die in het proces verborgen is. Om de problemen van het huidige ontwerpproces van een

viaduct op te lossen, is een verbeterd ontwerpproces voorgesteld welke gebruik maakt van een geautomatiseerde ontwerp tool. Er wordt verwacht dat dit verbeterde ontwerpproces de algehele totale doorlooptijd van het constructieve ontwerpproces met 18,2% zal verminderen. De ratio value adding - necessary waste verschuift met 23,3% en 16,42% (respectievelijk voor de klant en het bouwteam) in de richting van meer tijd besteed aan value adding activiteiten.

Om de implementatie van het verbeterde ontwerpproces goed te laten verlopen, is een implementatieplan ontwikkeld dat te vinden is in Bijlage 4. Hierin is een reeks stappen voorgesteld die gebaseerd zijn op het Golden Circle Model van Simon Sinek. Dit implementatieproces maakt ook gebruik van de Whole Scale Change-theorie, in tegenstelling tot de meer gangbare theorieën voor verandermanagement. Whole Scale Change-theorie wordt meer geschikt geacht omdat het een brede benadering biedt om alle belanghebbenden bij het veranderingsproces te betrekken. Als de aannemer wil dat dit initiatief slaagt, is het absoluut noodzakelijk dat er voldoende basis is onder de werknemers, vooral als de aannemer de modulaire aanpak van de ontwerpfase ook naar de inkoop- en realisatiefase wil uitbreiden (iets dat zeker aan te raden is omdat het het aantal voordelen dat de aanpak met zich meebrengt zal vergroten). Whole Scale Change zal helpen om een solide basis te creëren door belanghebbenden in een vroeg stadium te betrekken.

Standaardisatie van eindproducten moet in de huidige markt en contracten kunnen passen zolang de contracten voldoende ontwerpvrijheid bieden en de klanten bereid zijn om een paar vereisten in te trekken of te wijzigen, om rekening te houden met het gestandaardiseerde eindproducten. Uit gesprekken met Rijkswaterstaat blijkt dat zij bereid is om aan deze voorwaarden te voldoen zolang aannemers de extra waarde die gestandaardiseerde eindproducten opleveren kunnen aantonen. Het is aan de aannemer om voldoende variatie in de modules te garanderen om ervoor te zorgen dat het standaardproduct geen 1-trick pony is. Het is ook aan te raden dat aannemers samen met een architect esthetische modules ontwerpen (bijvoorbeeld voor de randelementen van een viaduct), zodat de inschrijving voldoet aan de esthetische eisen van de klant.

Het verbeterde ontwerpproces introduceert een ontwerptool welke in dit onderzoek geconceptualiseerd wordt om alvast een eerste stap te bieden in de ontwikkeling van de tool. De tool biedt een tweede niveau van standaardisatie; standaardisatie van het constructieve ontwerpproces is het eerste niveau van standaardisatie, het standaardiseren van bepaalde variabelen die gebruikt worden in berekeningen door standaardmodules te ontwikkelen is het tweede niveau. Het doel van de geautomatiseerde ontwerp tool is het profiteren van beide niveaus van standaardisatie; Door het gebruik van de tool kan het constructieve ontwerpproces van het viaduct efficiënter worden voltooid, wat betekent dat er meer waardevolle tijd kan worden besteed aan "specials", en het maakt het mogelijk modules te gebruiken die de mogelijkheid bieden om te profiteren van het gebruik van standaardproducten. De system breakdown structure van het viaduct wordt gebruikt om de samenstelling van een viaduct uit te leggen en een sectie te kiezen waarmee verder de diepte wordt ingegaan. Voor de gekozen scope zal een BPMN-diagram (business process model and notation) worden gebruikt om de overdracht van gegevens in kaart te brengen en om de benodigde uitwisselingsvereisten te creëren die helpen bij het opzetten van een gegevensstructuur voor de constructieve ontwerptool. De BPMN en de afgeleide gegevensstructuur helpen de aannemer ervoor te zorgen dat alle benodigde variabelen voor de tool over de vereiste gegevens beschikken om de berekeningen uit te voeren.

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1. INTRODUCTION

"Each project is unique"

Everyone that works within the civil engineering sector has used or at least heard this statement in their professional career. Each project is different from the last and therefore the 2 cannot be compared. This notion, while in essence true, is flawed. The copy-pasting of (parts of) contracts, designs, calculations and other documents is a daily reality which contributes to the large failure costs of contractors of ~11% (USP-MC, 2013) of their revenue.

While other sectors modernized through the introduction of interchangeable parts, then assembly lines, and then automation, construction retained its craft method of operation. As a result of that it fell further and further behind the rest of the manufacturing industry in term of productivity, quality, and therefore value for money (Winch, 2003).

Construction has been blamed for its low performance and productivity, and high amount of waste, for years, especially when compared with the manufacturing industry, which is mainly based on well-managed and standardized processes. This ongoing discussion about problems, such as low profitability and high construction costs, results in demands for higher value, cost savings, better quality, and longer guarantees in construction. However, construction is not manufacturing, but it does provide elements that can be exploited to improve processes and reduce waste. Moving towards better quality and more homogenous construction can be achieved by standardized processes and by using standardized products in those processes (Aapaoja & Haapasalo, 2014).

Luckily, process standardization has been adopted by the branch to increase efficiency and quality and move away from the sole focus of saving material. The branch has been shifting its focus towards quality, lead-time, stakeholder management and durability, generally the EMVI-criteria. The next step towards product and quality optimization will be product standardization.

The concept of product standardization is not new, it is widely used in a lot of different fields. The building sector has implemented standardization in prefab building elements, but larger end products such as overpasses or complete buildings have always been deemed to complex. Another barrier in the discussion has been the subject of esthetics; generally people do not want similar buildings everywhere. The last couple of years, the discussion of end product standardization has been sparked again by the introduction of innovations like additive manufacturing and automated building, and research into the subject such as the "LEGOlisering" concept of prof. dr. ir. Hennes de Ridder from TU Delft. Building contractors have started to implement modular building where parts of a building are prefabricated "modules" which only have to be assembled at the construction site.

The purpose of this research will be to examine the viability of end product standardization within the civil engineering sector. End products within this sector are highly focused on function and much less on esthetics, therefore voiding that barrier. The main focus will be a overpass but the principles of the created processes and models should be applicable to other end products in the civil engineering sector as well. The research will be of explorative nature since there is (close to) no data on product standardization in this branch and on this level.

1.1. PROBLEM DEFINITION

Product standardization is widely used and its benefits are known. Within the organization of the contractor that facilitated this research, the interest to research the possibilities and the implementation of standardized end products has been expressed. The contractor suspects end product standardization does not only result in quantifiable improvements such as improved cost efficiency, but also in qualitative improvements such as better chain relations and calmness in project teams.

Whilst the contractor has a good idea of the potential benefits, it remains unclear how the process of creating standardized end products should be organized and how standardized end products should be implemented.

To narrow down the scope, it was decided to focus the application part of the research on the design process of an overpass and assume the findings can be applied to other end products such as bridges and tunnels.

1.2. RESEARCH QUESTIONS

To try and resolve these uncertainties, research has to be conducted into the standardization of end products, resulting in the following research problem:

"How can end product standardization improve civil building development and how can the design process be standardized in order to develop and implement end product standardization at a contractor?"

To decompose the research problem, the following research questions are formulated;

<u>Part I: Literature study on product standardization</u>

1. What are the benefits of standardizing end products?
2. What are the challenges in standardizing end products?
3. How can be ensured that the benefits from standardized end products are being optimized?
4. Can standardization be applied to the civil engineering branch?
   a. Are there examples available and what do they teach us?
   b. How should standardization be applied to a contractors standard overpass?

<u>Part II: The process of creating standardized end products</u>

1. How is the current design process organized and how can it be improved by standardization?
2. How should the process of creating standardized end products be organized and how should said process be implemented in the business process?
3. How do we ensure standardized end products within the contractor are being continuously further developed?
4. Are there external changes required to facilitate the use of standardized end products?

<u>Part III: Conceptualization of the overpass design tool</u>

1. How should the overpass structural design tool work and how should it be operated?
2. How should the data structure of the overpass structural design tool be organized and how does it benefit the structural design tool?

1.3. Research design

The research problem; "How can end product standardization improve civil building development and how should end product standardization be implemented at a contractor?" is split into three parts and 11 research questions. The following table depicts methodological justification per research question (RQ). Appendix 1 visualizes the research design.

RQ	Method(s)	Justification
1.1 + 1.2	Literature study	Literature on product standardization is widely available, information specific about standardization in the civil engineering sector is more sparse but still available. Literature will help to form a solid base of knowledge which will help in acquiring the sought after information from interviews.
	Interviews	There are a number of companies that have sparked the interest in this research subject for both the researcher and the mentors, these companies know what product standardization has to offer and how bottlenecks can be avoided.
1.3 + 1.4	Literature study	Literature on product standardization is widely available, information specific about standardization in the civil engineering sector is more sparse but still available. Literature will help to form a solid base of knowledge which will help in acquiring the sought after information from interviews.
	Interviews	There are a number innovators who have been proclaiming the concept of standardization in the civil engineering sector. These innovators will have valuable experience in standardization.
2.1	VSM-analysis	VSM-analysis will help analyzing the current design process and determining the weak spots of the process that can be improved.
	Interviews	Interviews will be used to gather data on the current design process.
2.2	Interviews	In order to achieve optimal implementation of the standardization process in the business structure of the contractor, internal interviews are essential.
2.3	Interviews	External interviews will be used to gather best practices and these combined with internal interview will be used ensure continuous development.
2.4	Interviews	Both internal and external interviews will provide valuable insights with which the research question can be answered.
3.1	Interviews	Internal interviews will be used to determine the conceptualization of the structural design tool.
3.2	Interviews	Internal interviews will be used to determine how data structuring has been handled in past projects.
	BPMN	BPMN will be used to develop a process map, exchange requirements and the corresponding data structure for the structural design tool.

Table 1 Methodological justification

1.4. EXPECTED RESULTS

Figure 1 below shows the expected benefits of standardizing end products such as overpasses. It is expected that end product standardization does not only result in quantifiable improvements such as improved cost efficiency, but also in qualitative improvements such as better chain relations and calmness in project teams. The development of the standardization process in consultation with experts will make sure that the process is assimilated into the contractors' business structure and that the potential benefits will be optimized. This thesis will, with a limited scope, explore the first steps into end product standardization. This thesis will test the developed design process, discover possible faults/waste, and further sharpen the process. The thesis will try to determine the properties of a standardized overpass and it should give an insight into the type of elements that should remain variable in order to meet the clients' wishes. Based on the literature study into standardization and the analysis of the current structural design process, a first concept of the structural design tool will be created. To aid further development of the tool, a BPMN will be created which will cover input- and output data, and the required data structure in detail.

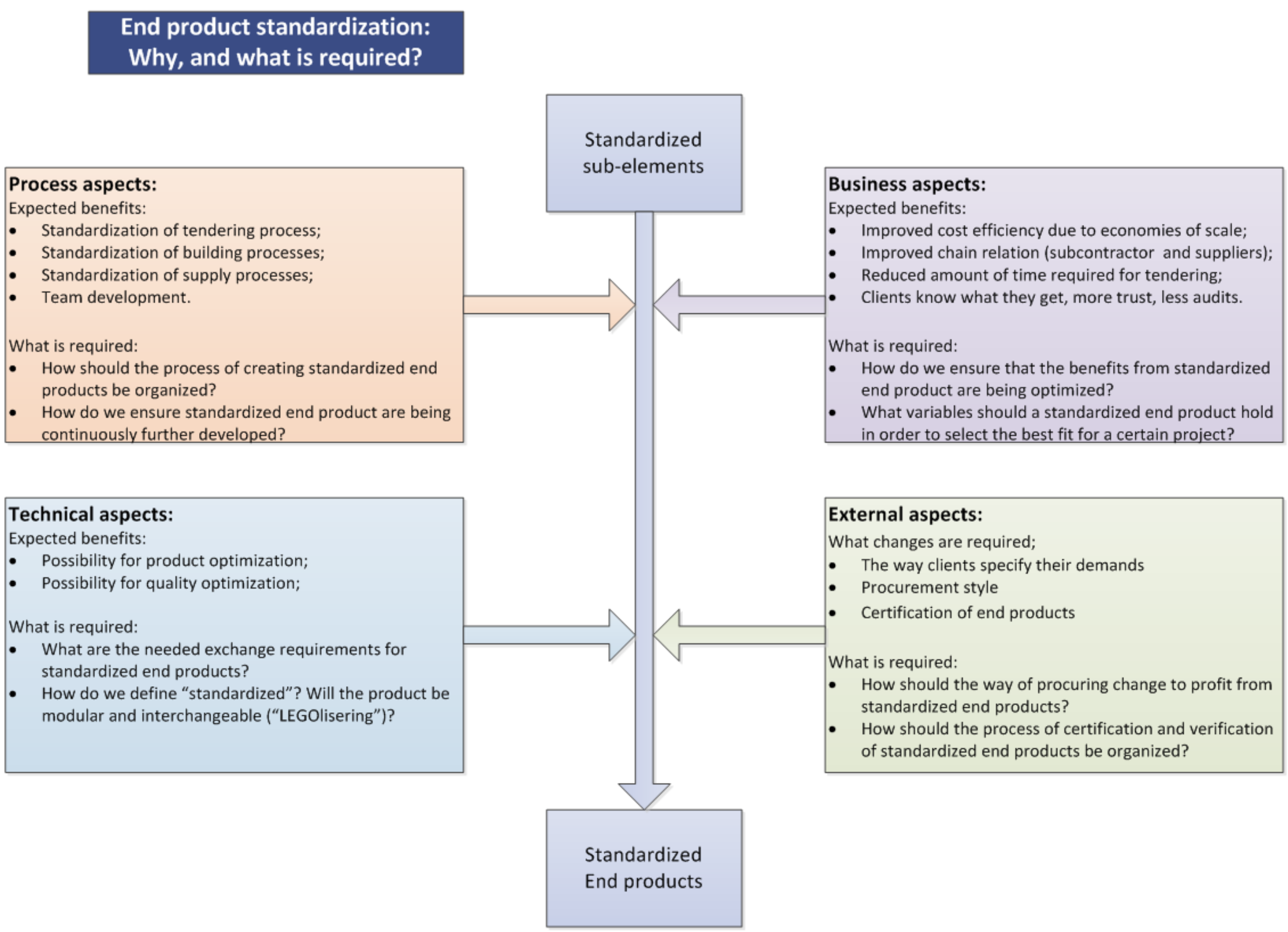


Figure 1 Benefit hypothesis

2. Literature review: Understanding standardization and the use of LEAN

Standardization is the extensive use of processes or procedures, products or components, in which there is regularity, repetition and a record of successful practice (Gibb & Isack, 2001). Standardization is not new but the application of standardization to larger construction projects (both utility and civil) is trending in the Netherlands. It seems amazing that standardization is so poorly understood by many involved in the construction process, especially those involved in procuring construction projects (CIRIA, Standardisation, Pre-assembly and Modularisation – A Client's Guide, 2000). This chapter focuses on the benefits of standardization, the way standardization can be projected onto the construction sector, what improvements standardization can provide for the structural design process of a overpass, and how a "standard overpass" will be defined for this research project.

2.1. Initial hypothesis

Within the organization of the contractor, the interest to research the possibilities and the implementation of standardized end products has been expressed. The contractor suspects end product standardization does not only result in quantifiable improvements such as improved cost efficiency, but also in qualitative improvements such as better chain relations and tranquility in project teams. More of the expected benefits of standardized end products are described on the previous page, in figure 1.

2.2. The influences of LEAN Engineering on Standardization

When speaking of standardization, LEAN engineering or LEAN construction is the next thing that comes to mind. Lean thinking has made its introduction into the Dutch construction sector for a couple of years now and almost all the major players have started with implementing its principles into the their organizations. The implementation of LEAN in the construction sector mainly focusses on processes and not on products, which is remarkable because the LEAN philosophy originates as product chain improvement. The focus on processes could be attributed to the general assumption that each project is unique. Creating standardized end products and implementing LEAN are strongly connected, therefore a paragraph on LEAN engineering will be included in this literature study. LEAN is a management philosophy that focuses on maximizing customer value while minimizing waste. Waste can be all kinds of resources such as waiting-hours, transport movements, excess products, etc.

2.2.1. LEAN Thinking

A lean organization understands customer value and focuses its key processes to continuously increase it. The ultimate goal is to provide value to the customer through a value creation process that has zero waste. To accomplish this, lean thinking changes the focus of management from optimizing separate technologies, assets, and vertical departments to optimizing the flow of products and services through entire value streams that flow horizontally across technologies, assets, and departments to customers. Eliminating waste along entire value streams, instead of at isolated points, creates processes that need less human effort, less space, less capital, and less time to make products and services at far less costs and with much fewer defects, compared with traditional business systems. Companies are able to respond to changing customer desires with high variety, high quality, low cost, and with very fast throughput times. Also, information management becomes much simpler and more accurate (What is Lean?, 2016).

According to (Womack & Jones, 2003), Lean thinking can be summarized in the following principles:

- Identify specified value for customer;
- Identify value stream for each product;
- Create value flow without interruptions;
- Pull production;
- Aim for perfection.

Figure 2 Lean principles (from lean.org)

These Lean principles focus on creating maximum value for the customer while minimizing waste. Using these principles, a production process can be analyzed and improved where the end goal will be to eliminate all waste so all the activities in the process will create value for the customer by continuously improving the process and product.

Value in construction is like value in any business: it is a return on your investment. Adopting lean principles is an investment in the future of the project, which will reap benefits and give a solid return on investment (Intergraph, 2012):

- Improve communication planning with owner, work force, contractors, and suppliers with visualization and open display of schedule, design, and workflow;
- Eliminate waste of materials, poor communication, duplication of efforts, and design errors;
- Improve work planning by early planning, with a focus on improved workflow, achievable tasks, distribution of workload, and a clearly defined work scope;
- Look-ahead scheduling with just-in-time deliveries, engagement of all parties, availability of resources, access to site, and coordination of other dependencies;
- Plan and coordinate off-site fabrication and modular construction activities to reduce site congestion, distribute workload, minimize field work force, and improve just-in-time delivery;
- Create a clean, safe, and efficient working environment, and communicate safety.

These suggestions translate the abstract lean principles displayed in figure 2, to a more construction focused concept.

Applicability of lean principles to construction might seem to require that construction’s differentiating characteristics be softened or explained away. This is the strategy employed by those who advocate making construction more like the manufacturing from which lean thinking originated. Following that line of thought, successive waves of implementation would leave ever smaller remainders that are not yet reduced to manufacturing, and consequently not yet capable of being made lean. This approach offers tremendous opportunity for reducing the time and cost of constructed facilities (Ballard & Howell, 1998). Where some parts or elements of a construction project can certainly fit this description, there are a lot of elements of a construction project that do not fit this description.

What we call "construction" covers a spectrum ranging from slow, certain, and simple (stodgy) projects on one end to quick, uncertain, and complex (dynamic) projects on the other. For the former, a manufacturing strategy is appropriate; i.e., making construction more like manufacturing through such initiatives as standardization. For dynamic projects, however, a manufacturing strategy is insufficient. We must learn how to manage uncertainty and complexity and quickness within the characteristic construction conditions of site production, unique product, and temporary organization (Ballard & Howell, 1998).

Höök (2008) found that standardized and predictable processes are the most essential to obtain if a Lean culture is aimed for. Moreover, "unique" projects should be managed as a repetitive process, because "standardization is dependent on specific projects being managed within a recurrent (and standardized) production process, with a smooth and standardized production pace" (Höök, 2008).

In conclusion, it can be stated that one cannot only consider product standardization. Process and product standardization are intertwined and cannot be viewed separately. In order to achieve the optimum product and maximum customer value, the entire process should be analyzed and adapted to lean principles. Even if construction projects do not lend themselves to the standard manufacturing strategy, this does not mean Lean cannot be applied to construction projects altogether. It is important that construction projects are molded into standardized and recurrent production processes that can be optimized by the use of Lean principles. An example of a standardized production process could be modularization.

2.2.2. Value stream mapping

An important implication of applying the lean philosophy to construction is the understanding of waste and value. This information will be used to analyze the current design process of a overpass, to identify waste and value in the design process, and to adapt the design process to the use of standard products. The theory of LEAN production states that every process and operation consists out of three types of activity (Jørgensen & Emmitt, 2008):

1. Value adding activities
2. Necessary non-value adding activities (necessary waste)
3. Unnecessary non-value adding activities (pure waste)

In the lean terminology value is understood very narrowly as consisting only of what the end customer perceives as representing value to him/her. Anything that does not directly add to this value is regarded waste. Consequently any process is wasteful, so it is appropriate to distinguish between waste that cannot be avoided but should be reduced as much as possible (type 1), and waste that in principle is not required for delivering the value requested (type 2) which should be eliminated. In the lean construction literature value is either unaddressed, or it is largely discussed in the context of the construction project (the process), not the resultant building (the product) (Jørgensen & Emmitt, 2008). Figure 3 depicts the three types of activities in a process.

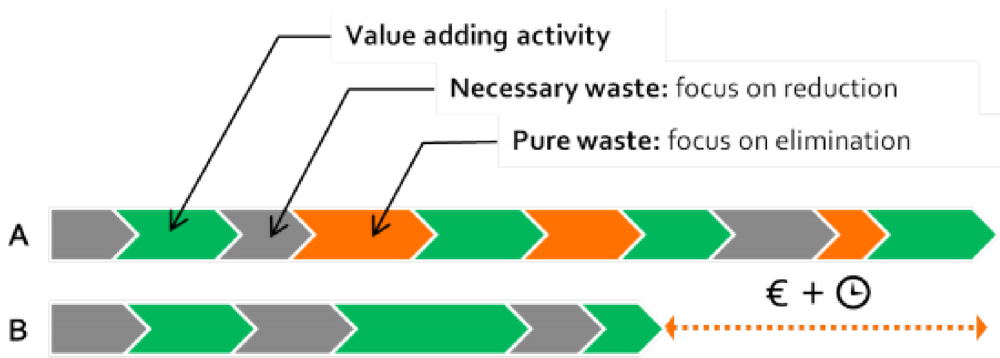


Figure 3 Value stream mapping (Boschker, 2013)

Boschker (2013) states that many organizations aim to optimize the value adding work to increase their profit, while organizations implementing Lean thinking are focusing on the elimination of wasteful work (the type 2 waste from Jørgensen & Emmitt). In the civil engineering sector, almost all contracts have a set of requirements regarding the quality of the product(s) (and processes) that have been established in advance. These requirements need to be met in order to finish a project and achieve financial close. Because the level of quality required is stated, focussing on value adding activities only results in a limited improvement. Focussing on waste reduction and elimination will presumably yield greater results, especially with the large amount of failure costs currently present in the civil engineering sector. In the experience of the researcher, the value adding activities are often allready addressed, for example with standard workplans. The waste is partially known by employees and is cause for irritation ("why do I have to wait for that information? If I do this now, there is a chance I have to do it again"), but the solution is thought to be in the hands of the management so not really much happens to reduce the waste.

In literature on lean production, waste is commonly divided into eight subtypes, see figure 4 (Gerth et al, 2013). Waste types 1–5 are mainly addressed at the production management level, which in the case of construction includes project manager, design engineer and site manager. Types 6 and 7 are mostly addressed at the operational level, e.g. by craftsmen, but controlled by supervisors such as foremen. Waste type 8 is addressed at both levels.

	Type	Examples in manufacturing	Examples in construction
	1. Overproduction	Making more than is immediately required.	Completing operations earlier than necessary, e.g. painting of walls in rooms that are not completed
	2. Waiting	Waiting for parts, information, instructions and equipment.	Blueprints are not finished when on-site operations need them
	3. Transport	Moving people, products and information.	Inappropriate distances between storage, workplace offices on site owing to little logistic planning
	4. Over-processing	Tighter tolerances or use of higher quality in materials than necessary.	Including more functions within the product than the customer wants
	5. Inventory	Storing parts, pieces, and documentation ahead of requirements	Unnecessary large storage of materials and components on site
	6. Motion	Bending, turning, reaching and lifting	Inappropriate work conditions, e.g. unnecessarily heavy and high lifts
	7. Defects	scrap and incorrect documentation	Rework of operations and construction material affected by climate
	8. Unused employee creativity	Under utilizing capabilities	Not considering on-site experiences from earlier projects in new projects

Figure 4 Examples of the different types of waste according the Lean philosophy (Boschker, 2013)

2.2.3. LEAN AND STANDARDIZATION

Reducing and eliminating the waste can be achieved through the use of standardization, where type reduction is the first step. By reducing the number of different types of products and/or solutions for certain elements (for example abutments), both the design processes and production processes can be started to be standardized. By standardizing these processes, everyone will know how the standard process should be and what the workflow is. This will reduce necessary waste and eliminate unnecessary waste, for example with just-in-time supply of calculations to reduce waiting time and the implementation of more decision points to decrease “do-over”. The standardized design and production processes can be iteratively improved to further reduce waste (this is called Kaizen in the Toyota LEAN philosophy). This continuous improvement of the entire construction process will increase the efficiency and decrease failure costs over time.

By standardizing products, one can start to implement Design for construction (DFC). Design for construction (DFC) is based on the same principles as DFMA (Design for manufacturing and assembly) i.e. the improvement of a product design’s constructability should to a great extent be based on minimizing the number of components, parts and materials that need to be processed, assembled and handled on site. By following these principles, as well as by coordinating with nonproduction disciplines and dealing with quality defects, customer value can be increased and the complexity in production management reduced. By reducing the number of parts, the number of onsite activities is decreased and the total production time can be reduced (Ulrich & Eppinger, 2008). A detailed description of DFC is outside the scope of this research as only the design process will be analyzed and improved via value stream mapping.

2.2.4. Workflow improvement

In comparison with the smooth (serial) workflows in manufacturing environments, for example the use of assembly lines in the automobile industry, it is more difficult for the construction industry to define value-adding production steps. This is perhaps more evident in civil construction projects as value is often viewed differently by different stakeholders. Root cause is the unique nature of most on-site construction projects (more information about the differentiating features of the construction sector can be found in section 2.3). A random construction process is not standardized and needs to be developed from scratch most of the time, this means that the contractor is not using his available time to optimize said process. It is a 'low volume, high variety' environment in which workforce, equipment and materials must be taken to the site where the end product will be assembled/constructed (Errasti et al., 2009).

To improve productivity in the construction sector, one of the most important aspects is reducing on-site material handling and lead times proper workflow management (Simonsson et al., 2012). For improving workflow in construction there seems to be two different strategies (Peter Simonsson et al., 2012 Sven Bartelsen, 2004; Höök and Stehn, 2005): to reduce the complexity to a level where the principles from the ordered world of manufacturing can be used, or to develop new methods for the management and control of the construction process as a complex system. In other words, to develop either the product or the process. In practice the product strategy, means to transfer more and more parts of the construction work into off-site fabrication, and thereby make the site work an assembly only. The process strategy aims to develop the on-site construction process in its own right. Consequently, it is possible to work with workflow at both the early stages of a construction project using so called proactive workflow methods and during the project execution at the construction site using so called reactive workflow methods (Simonsson et al., 2012):

- **Proactive workflow management (Product strategy)**.
  Aims at removing hindrances to production workflow in the design phase. Common methods are e.g. improved buildability and proper production planning. Another useful method for proactive workflow management is simulation using for example 4D planning (Björnfot and Jongeling, 2007).
- **Reactive workflow management (Process strategy)**.
  Aims at removing hindrances in the production phase so that even workflow is achieved at the construction site. Common methods are e.g. planning for pull production and standardizing work tasks. Another useful method for reactive workflow management is to highlight workflow by mapping the value stream (Yu et al., 2009).

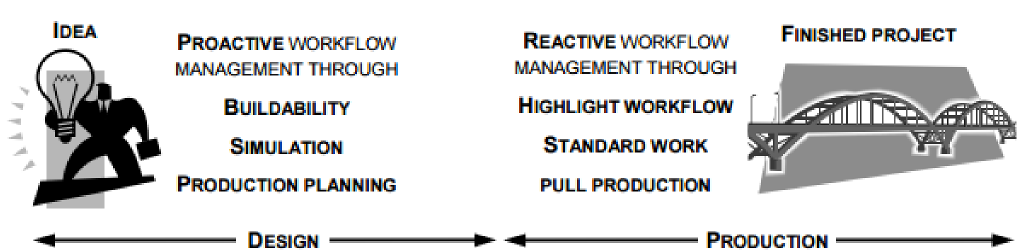


Figure 5 Applicability of proactive and reactive methods to improve workflow (Simonsson et al., 2012)

When considering both strategies, the **product strategy** aims for modularization of construction projects where elements of the end product are manufactured off-site, transported to the construction site and then assembled there. This strategy aims to reduce lead time of the project, to reduce the amount of inventory lying around the construction site, and to reduce the manufacturing costs of the project. Moving the manufacturing of elements off-site also means that the quality of the elements is better ensured and the construction is less viable to hindrance because of weather conditions. The **process strategy** aims towards optimizing the process of constructing the actual end product, assembling the different elements to create the end product. The strategy uses the last planner system (LPS) and standardized work tasks in order to improve operational performance and strives for continuous improvement because the construction process becomes more standardized (and thus less mistakes). With the construction process becoming more standardized, value stream mapping can be used to eliminate non-value adding activities.

Combining both strategies and translating them to this research project signals that modularization of the overpass elements and standardizing the construction process are needed to improve the workflow and eliminate waste. Eliminating waste could be translated to;

- Shorter lead times;
- Less inventory through LPS;
- Less inventory means less capital costs;
- Less inventory means smaller storage areas, good for safety and EMVI;
- Less handling and transportation of materials;
- Smaller operational costs through less staff needed.

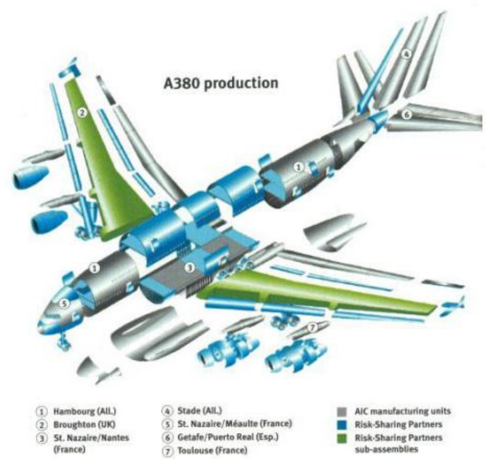


Figure 6 Example of modularization (http://fundunet-technology.blogspot.nl/2011/05/airbus-380.html)

An important factor in both strategies seems to be the subcontractors and suppliers because they account for a large portion of the project. When opting for standardization and prefabrication off-site means that this portion becomes even greater and thus the influence of the subcontractors and suppliers on the overall performance of the project becomes greater. Missing from the literature seems the option to standardize the design product and the design processes: When aiming for modularization and moving element production off-site, standardizing said elements is only the next logical step. The amount of standardization can be discussed (and is discussed in the rest of chapter 2) but standardizing the elements and standardizing the construction/assembly process only complement each other. And with standardizing the design product comes the possibility of standardizing of the design process.

This research focuses on the conceptualization of standardizing (certain) elements of a overpass for them to be constructed either off-site or via standardized work process on the construction site. By standardizing the elements, the design process can be standardized as well because the amount of variants is strongly reduced. In a later stage, building upon this research project, modeling tools, standard calculations and drawings that match the standard elements can be created to efficiently pick and mix the most optimal overpass for tender. Standardization seems to be a necessity in order to make the construction sector LEAN. Eliminating the huge failure costs, and thus waste, of the sector can only be achieved by making the construction more like manufacturing so that the LEAN manufacturing principles can be applied to them. Standardization offers this possibility.

2.3. Standardization in the construction sector

Prefabrication (including preassembly, and modularization) has been viewed as one potential way to assist the development of construction (Koskela, 2000) and increase value for money (Pasquire & Gibb, 2002).

As long as key players claim that they do not use standardization (even though it is apparent in all construction projects) and as a result fail to manage its application effectively, the potential benefits will not be realized (Gibb, 2011). Research conducted into this topic shows that deliberate, systematic use of standardization, started early in the process, will add value to projects by increasing predictability and efficiency (CIRIA, 1999). The construction sector has had other sectors as an example for a long time and research how to implement standardization into the construction sector has been conducted, so why is there still so little standardization present in the current day civil engineering sector?

Manufacturing plants and construction sites are different entities, this is why LEAN production has not yet been implemented into the construction sector, LEAN needs to be adapted. The construction industry has three features that distinguishes it from manufacturing (Koskela 2002 in Salem et al., 2006):

On-site production
Construction is site-position manufacturing, as opposed to fixed-position manufacturing, which applies to ship and airplane manufacturing and in which the product can be moved after assembly. In construction, installation and erection are the activities that most increase the value of the product. The contractor must ensure that all components assembled on site meet high-quality standards that are greatly influenced by specific site conditions.

One-of-a-kind projects
Normally manufacturing takes advantage of specialized equipment to make standardized units, allowing only a limited level of customization by retailers. In construction, customers play a key role throughout the project cycle. Under guidance from the designer, customers define their product explicitly through the bid package or contract. The owner or the owner's representative can modify the requirements and details of the contract by addenda (before bids are opened) or change orders (once the bid is closed).

Complexity (temporary multi-organization and regulatory intervention)
In manufacturing, many components from different subassemblies can be easily managed because suppliers are selected early in the design phase. Specialized facilities with suitable technology and layout ensure the reliable flow of the product. With repetition, this supply network eventually becomes manageable and optimized. In contrast, in construction, the completion of activities is highly interrelated and complicated. Construction projects are characteristically complex, unique, dynamic systems that must rely on an initial design that involves a number of subassemblies with variable specifications. Being an on-site production, the installation of those subassemblies is constrained by the interacting and overlapping activities of different contractors, making it more difficult to meet a fixed schedule.

The combined effect of on-site, one-of-a-kind, and complex production is uncertainty. The manufacturing process makes it possible to reduce uncertainty by increasing control over the process itself. A steady state is desirable in order to increase efficiency through repetition. In construction projects, significant uncertainty exists throughout the project. Weather conditions, soil conditions, owner changes, and the interaction between multiple operations can produce unique circumstances, which could be as critical as the planned activities and have a significant impact on project cost (Salem et al., 2006).

The uncertainty Salem et al. talks about can be reduced by introducing standardization into the construction sector. The question will be the amount of standardization, can a construction project be made 100% standard? Soil conditions impact the design decisions a lot and it is a factor that cannot be standardized so 100% standard will not be achieved. A possible solution can be modularization as it offers type reduction whilst keeping flexibility.

2.3.1. Struggle between standardization and flexibility

Historically, those taking standardization seriously (e.g. Gropius in Russell 1959 p.48) have always struggled to resolve the conflict between uniformity and variation, between maximum standardization and flexibility. This conflict has still not been resolved – it remains as a tension that sometimes leads to design impotence, but should be used to ensure optimal implementation (Gibb, 2011). Hence, the focus of standardization in construction is the interfaces between the components, rather than the single components themselves. However, the standardized processes are the most crucial things in construction, because there is no use for standardized products or components if those processes are not used properly and effectively. (Gibb 2001, CIRIA 2001.) Therefore it can be argued that in construction, standardization is not about the standard systems or products, but the systematic approaches to perform things. Only by that can the benefits of standard products or components be exploited effectively. (Aapaoja & Haapasalo, 2014)

The Dutch civil engineering sector has a culture where every project is perceived unique, so design has to maintain flexibility. Clients often have a large amount of requirements which lead to a constraint on the possibility to use a standard design. Finding the correct balance between uniformity and variation, a standard and flexible design, will be key in determining the success of standardization in the civil engineering sector.

2.3.2. Clients and contracts

It is highly unlikely that clients will change their method of procurement towards a "standard friendly" procurement environment when standard products are not yet available. In turn, completely standard designs are useless in the current procurement environment and thus progress will very slow or non-excitant at all.

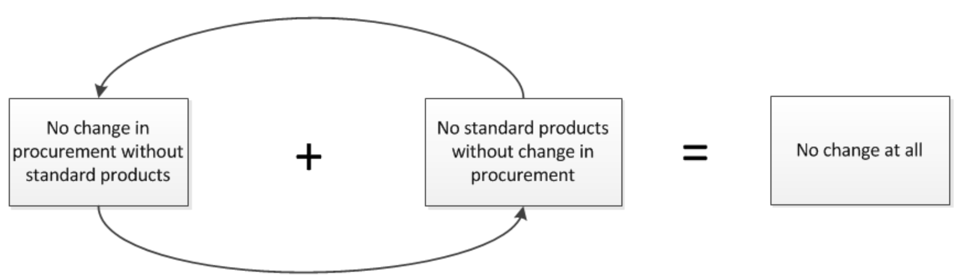


Figure 7 Chicken or the egg?

With government being the largest portion of clientele, change will be very slow and cautious. The change towards standardization will require joint effort to maximize commitment from both client and contractor.

Furthermore, the ongoing transformation of clients towards more of a managing role instead of an expert role means that there are a lot of outside consultants involved in the decision making phase. If there are benefits to be realized from standardization, then all of these groups must be aware of how to facilitate effective implementation (Gibb & Isack, 2001).

The research of Gibb and Isack among clients shows that more than 70% of their respondents felt that there should be an increase in future component standardization (More: 71%, less: 2%, the same: 24%, no opinion 2%). It is expected that the numbers for Dutch civil clients are somewhat lower and depend on the type of project discussed; projects that are more regular such as overpasses and underpasses are expected to be perceived more favorable for standardization. More complex and unique projects such as tunnels and bridges are expected to be perceived less favorable for standardization.

Pasquire and Gibb interviewed a number of clients and found that contractual arrangements were thought to have a substantial effect upon the degree to which standardization and pre-assembly were feasible. Typical arrangements found by the survey were two-phase tendering combined with value management (Dutch variant: Design & Build), term contracts (contract for a certain period, for example for consultants), and partnering in one form or another. In such arrangements, early consideration can be given to standardization and pre-assembly and their impact on all aspects of total project design. It was claimed that this close working of the whole team at an early stage reduced error and the resulting conflict, improved efficiency (which includes reducing cost and/or increasing quality), and that such is not usual in a traditional setting (Pasquire & Gibb, 2002).

Since the research of Pasquire and Gibb, the design& build contract has been evolved to include the finance of the project, the maintenance of the construction after the project has finished, and even the operation of the construction although that is not applicable to overpasses because it is highly unlikely that The Netherlands will implement toll roads to anything other than large tunnels. DB(F)M contracts are very well suited to facilitate standard overpasses since it gives more design-freedom. Another suited type of contract is the Alliance-model where client and contractor join forces and integrate their organizations to work together. This type of procurement is more expensive than normal tenders so the Alliance-model is only competitive when the project houses a larger amount of overpasses. In general; in order to facilitate standardization in the current contracts, the contract has to offer sufficient design-freedom.

2.3.3. Benefits of standardization

Clients commission construction projects for various reasons. They all want value for money, which to them means: lowest whole-life cost, lowest cost for a given quality, satisfied end users, highest quality for a given cost and consistent quality (Gibb & Isack, 2001). This need for value is demonstrated by the drift towards EMVI-criteria in Dutch procurement, so much even that it is required to procure by EMVI (economically most advantageous tender). Tenders are no longer being judged solely on costs but on best value offered for a certain amount of money.

In the research of Gibb & Isack, they researchers interviewed a large number of clients on the potential benefits of standardization in construction sector. Figure 8 displays the findings of the research of Gibb & Isack.

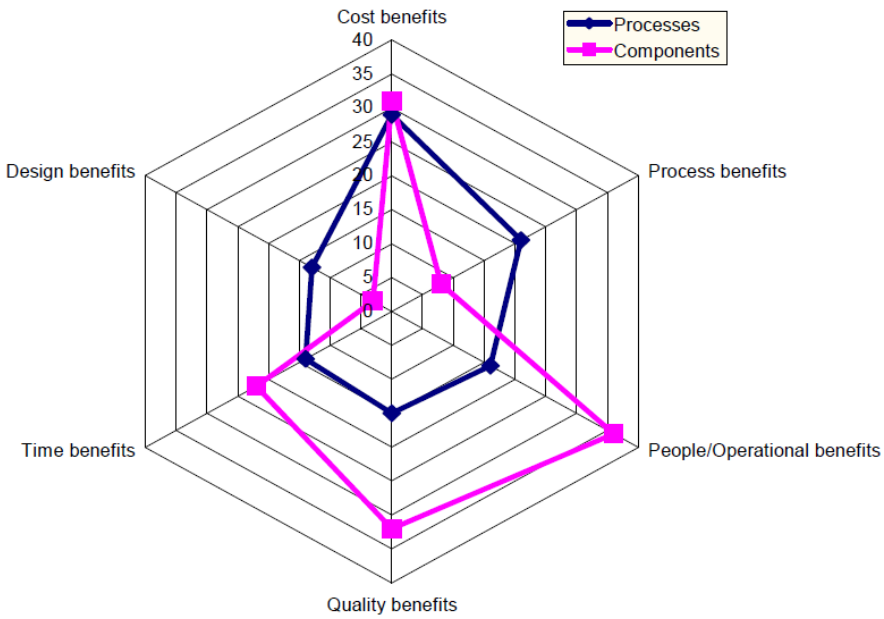


Figure 8 How standard processes and components help meet clients's business needs (# of responses - 109 processes - 132 components) (Gibb & Isack, 2001)

The figure shows major potential for cost, time, quality and operational benefits by standardizing components and hardly any design and process benefits. This is might look strange but is understandable as standardizing components does certainly result in design benefits, but just for the contractor. The contractor is able to create a standard component and a standard design process, which in return results in costs-, time, quality-, and operational benefits for the client.

In the research, an important issue was the fact that having standard components meant the construction users and the end-user understood what they were getting and how to use the product (Gibb & Isack, 2001). For clients in the civil engineering sector particularly, knowing what they get is very important. Almost each month there is a newsarticle about large construction projects that are delayed, that suffer an increase in overall cost, or both. This often results in a lot of media coverage, nation-wide criticism and a very affected relation between client and contractor. The remainder of the project will be under heavy pressure from management, resulting in a lot of conflicts because costs and time have to be rigorously managed, in turn resulting in more costs and more time lost. Standardization improves the certainty of the completion date and costs of a construction project because the client knows what he gets, the contractor knows what he supplies/creates and the product is tried, tested and optimized.

The most advanced form of product standardization in the civil engineering sector is the prefabrication of certain concrete components. Prime example are the prefabricated beams used in overpasses. These beams are catalogued by their manufacturer and contractors can buy them to use in the construction of their overpass. The greatest benefit of prefabrication is in changing the mindset of the construction industry from a project focus with unique and one-of-a-kind projects towards a standard repetitive process focus, which prevails in the manufacturing industry. Hence using the standardization of products and processes can be considered as an essential, and even the most important, factor when it comes to the prefabrication (Aapaoja & Haapasalo, 2014).

Standards are created by bringing together all of the interested parties, such as the manufacturers, consumers, and regulators, of a particular material, product, process, or service. All parties benefit from standardization through increased product safety and quality as well as lower transaction costs and prices (European Committee for Standards 2009.). By using standardized products or components, customers believe that saving costs is the most important thing, but there are also shorter lead-in times, higher quality, and operational benefits (Gibb & Isack 2001, Li et al. 2008, Pasquire & Gibb 2002).

In other words, high quality, reasonable costs, and effective product delivery are the results of repeatable, predictable, and measurable processes (Gibb & Isack 2001, Li et al. 2008, Pasquire & Gibb 2002). In addition, having standardized components and products means the construction users and the end-user understand what they are getting and how it should be used (Gibb & Isack 2001). Tables 2 and 3 summarize the benefits of standardization for processes and products (e.g., Gibb & Isack 2001, Pasquire & Gibb 2002). The benefits are mirrored to the Dutch GOTIK project management method to reflect where potential improvements are located.

Benefits of standardized processes					
Benefit	**Money (G)**	**Organization (O)**	**Time (T)**	**Information (I)**	**Quality (K)**
Rationalized interfaces			**X**	**X**	**X**
Minimized disruption	**X**		**X**		
Improved quality control				**X**	**X**
More predictable on-site activities		**X**			**X**
Better able to cope with congested construction sites		**X**	**X**		**X**
Improved certainty of completion date and costs	**X**		**X**	**X**	
Increased productivity through familiarization	**X**	**X**	**X**	**X**	
Statistical reduction in Health & Safety and environmental hazards		**X**	**X**		**X**
Fewer on-site operations, personnel & duration	**X**	**X**	**X**		
Less waste, noise, dust, etc.	**X**				**X**

Table 2 Benefits of standardized processes (adapted from Pasquire & Gibb, 2002)

The benefits that are described in table 2 are applicable to on-site construction processes, but also to the design processes and the planning processes. Given the focus of this research project on the design process, some of the benefits stated in table 2 are easier achieved then others. Reduction in health & safety and environmental hazards for instance is not directly achieved by standardizing the design process, but rather by standardizing the construction or assembly process and the use of the standard components. Chapter 2.4 will translate the benefits of standardization from the literature to more specific benefits for the design department of the contractor, using benchmark research conducted among several companies in the construction sector, and by reflecting the initial hypothesis to come up with a list of expected benefits for standardizing design processes and products.

Benefits of standardized components					
Benefit	**Money (G)**	**Organization (O)**	**Time (T)**	**Information (I)**	**Quality (K)**
Tried and tested track record				X	X
Available replacement parts	X		X		
More predictable lead-in times			X	X	
Increased productivity through familiarization both in design and on-site	X	X	X	X	
Greater certainty of completion date			X	X	
Predictable quality & performance		X			X
Reduction of waste	X	X			
Minimized overall project time			X	X	
Off-site inspection				X	X
Use of same components on follow-on projects	X	X	X	X	

Table 3 Benefits of standardized products (adapted from Pasquire & Gibb, 2002)

As with table 2, table 3 shows a number of benefits of which some are more applicable to the design department than others. The use of same components on follow-on projects is more of a benefit of standardizing components for the design department than available replacement parts which is a benefit for the construction phase.

An important potential benefit for clients, and thus for contractors, that is hardly mentioned in the literature, is the peace and trust that result from standardized processes and components. Clients want to be relieved of worries, they are shifting more and more to a managing role with less technical knowledge and thus expect expertise from contractors. Clients want projects to accomplish time, cost and quality targets and expect contractors to reach those targets. Failure to achieve those targets leads to a lot of unwanted administrative hassle and the need to answer for the failure.

By using standardized processes and products, contractors offer their clients a solution that has been tried and tested before, has been optimized and thus is more predictable in both project time and project costs. This results in less uncertainty for the client as the client knows what they can expect. Standardization also leads to more peace in project teams; designs have been optimized and are used over and over, Project members working on a project that uses standard processes and components know what they may expect from their follow project members, and what their follow project members may expect from them. Getting familiar with the processes and components leads to a more structured project approach and less "brandjes blussen", less solving ad hoc problems that arise. These ad hoc problems will still occur the first time the standard processes and components are used, but are then detected and solved and because the processes and components are used again, it is justifiable to spend time and money to eliminate these problems from the standardized processes and components. This way the processes and components are optimized and provide a predictable quality for next projects whereas the current way of copying a similar enough project and adapt it is very susceptible to mistakes. Another benefit for project teams is that teams can get attuned to each other, increasing efficiency and motivation/satisfaction by reducing coordination problems between team members.

2.3.4. Necessity of standardization for the construction sector

A lot has been said about why standardization would be good for both client and contractor, what benefits it brings and the next paragraph will be about the barriers and challenges that need to be overcome. But standardization should not only be viewed as an alternative to traditional building that might prove to be more costs-effective, standardization is a necessity for the construction sector.

Circular economy

During the last century, industrial and technological development in combination with global trade has resulted in an enormous economic growth, which has propelled human welfare (Circle Economy & IMSA, 2013). Throughout its evolution and diversification, our industrial economy has never moved beyond one fundamental characteristic, established in the early days of industrialization: a linear model of resources consumption that follows a 'take-make-dispose' pattern (Ellen MacArthur Foundation, 2013). The linear production model leads to unnecessary resource losses in several ways: waste in the production chain, end-of-life waste, energy consumption, and erosion of ecosystem services. A linear model is heavily depending on the global commodity stock (Verberne, 2016). The linear economic model has prevailed until now, because resources were cheap and abundantly available. In the last decade, however, prices for natural resources increased or became more volatile (Ellen MacArthur Foundation, 2013a). TNO (2013) estimates that the effects of an expanding circular economy for the entire Netherlands: a total an annual saving of 7.3 billion euros resulting in around 54.000 jobs.

Even though it does not fit inside the scope of this research project, it is abundantly clear that standardization of components is very helpful in moving towards a circular economy, reducing material costs and waste by re-use, and overall being more durable in the entire construction process.

Durability & Sustainability

Durability is a much hyped word in the construction sector where it is part of every EMVI-criteria and where everyone has a different definition. Luckily the focus of construction projects is shifting towards sustainable buildings and infrastructure, and not anymore on short-term cheap choices. The longer the structure lasts, the less resources are needed to build replacements. Additionally the more resistant buildings and structures are to wear and tear, the less maintenance is needed, thus further reducing the cost of ownership. Increasing construction quality and durability also means stronger building structures, which ensures life safety in case of severe weather or natural disasters (BASF, 2016). Standardization offers a chance to optimize design and construction of components, increasing the quality, decreasing waste, and thus moving towards more durable and sustainable buildings and infrastructure.

Reduction failure costs

Failure costs are an enigma for the construction sector, there is no other sector where companies have more than 3% failure costs and less than 8-15% profit. Yet the construction sector is still going strong with spilling more than 10% (some experts estimate the failure costs up to 40%) of their revenue. Reducing failure costs via the use of standardization (for example via increased efficiency and productivity through familiarization) will result in more net profit, solid and safe companies, and an improvement for the Dutch economy. The extra profit can be used for research into new developments and innovations such as moving towards a circular construction process, resulting in more jobs for the construction sector.

2.3.5. Barriers & Challenges

Research shows that standardization offers significant benefits over traditional design and construction methods. Seeing that standardization is only starting to get implemented in small scale and on detail-level leads to the conclusion that there are a number of barriers and challenges in place that need to be overcome.

One challenge identified by the research of Gibb & Isack (2001) is that few clients have any meaningful way of measuring success of their projects. Therefore, decisions on future strategy, including standardization, are most likely to be strongly influenced by the preconceptions of the clients and their advisors. Due to the inherent inertia in construction, unless effective measurement is implemented soon it is unlikely that much change will be effected. (Gibb & Isack, 2001).

The research results of Aapaoja & Haapasalo (2014) indicate that the challenges of standardizing the processes are that the importance of accurate planning and front-end activities are not completely understood and the projects are still considered as unique entities. Additionally, the standardization of products has the following challenges: construction projects and solutions are still perceived as unique handwork, designers do not understand the benefits of standardized products, and planning processes do not support using standardized products (Aapaoja & Haapasalo, 2014). If there is no agreed upon standard, a new way of doing is simply one more version by some individual, and it is only practicing (Lander & Liker, 2007). The research project, "LCIFIN2 – exploiting Lean in construction," funded by the Finnish Technology Agency, analyzed the differences between using standardized processed and/or products and the current practices in the Finnish construction sector. Aapaoja & Haapsalo summarized the findings of the research in tables 4 and 5 below:

Characteristics	Standardized processes	In construction	Challenges (in Finland)
Organizational interfaces and responsibilities	Defined and straightforward	Vague	Fragmented supply chain (i.e., lack of collaboration).
On-site activities	Predictable	Non-predictable	Hard to plan for and unlevelled schedule.
Productivity and effectiveness	High	Low	High variability. No standard methods (tacit work knowledge). No feedback loops in production.
Amount of waste	Low	High	Low process discipline, no standard methods.
Disruption	Low	High	Hard to plan, balance and standardize work.
Quality	High	Low/Medium	Low process discipline.
Value for money (e.g., cost-benefit ratio)	High	Low/Medium	The importance of front-end design is not understood properly.
People/operational benefits	Yes (standard tasks, activities)	No	Hard to standardize the jobs of operators and work knowledge.
On time/schedule	Yes	No	Variable takt time and unlevelled schedule.
Number of change orders	Minimal	High	The importance of front-end design is not understood properly.

Table 4 Differences between standardized and current processes (used from (Aapaoja & Haapasalo, 2014))

Characteristics	Standardized products	In construction	Challenges (in Finland)
Track record	Accurate	No	"Unique" products (inability to see parts to be standardized).
Using standard products in follow-on projects	Yes	No	The value of standard products/components (modularity) is not understood. Hard to learn from past actions.
Amount of waste	Low	High	High product variety.
Lead-in times (e.g., production runs)	Short	Long and unpredictable	Many custom items. The value of standardization is not understood properly.
Predictable and measurable quality	Yes	No	No standard methods (tacit work knowledge). No feedback loops in production.
Inspection	Accurate and off-site	Ad-hoc and on-site	No standard methods and routines.
Available replacement parts	Yes	No	"Unique and customized" solutions.
People/operational benefits	Yes	No	The current design processes do not support using the standard products and components. The inability to order (and offer) standardized products and solutions.

Table 5 Differences between standardized and current products (used from (Aapaoja & Haapasalo, 2014))

Even though this research was focused on the Finish construction sector, the analysis can be largely applied to the Dutch construction sector. Granted, some of the remarks made are being improved by the Dutch construction sector such as the creation and implementation of standard methods and the integration of the supply chain in these standardization efforts. These improvements are mainly started in the residential sector, whereas the civil engineering sector trails behind.

Höök (2008) emphasized that moving forward should be slow to ensure that all employees get time to adjust and become loyal to the development and settled mutual objectives and strategy, because an understanding and acceptance of Lean philosophy is important to consider.

The research of Aapaoja & Haapsala (2014) shows that a lack of collaboration between the project participants consequently upon the fragmented supply chain (and the culture and habits in general) may be one of the root causes that prevents process standardization. Aforementioned problem reflects in the design phase which essential role and the impact on project value creation is not assimilated, and especially, the importance of front-end activities and thorough planning should be emphasized in order to increase the buildability of the end products. Similar kinds of results have also been found in previous studies (Lessing et al., 2005 & Björnfot & Stehn, 2004)

Due to their interconnected nature, the challenges of using standardized products and components are partly consistent with the challenges in process standardization. Hence, it can be argued that process standardization demands the use of standardized products. At least, if we want to exploit all of the benefits of standardized processes. However, construction, and especially its solutions, are seen as unique, with an inability to see which parts and products could be standardized, and therefore the value of standardized products is not understood either. When the variety of the products gets high, most likely the amount of waste gets higher as well. At the same time, when there are no standardized processes and products, quality cannot be measured and is not predictable, which ultimately leads to the fact that continuous improvement is basically impossible. However, the results indicate that these aforementioned challenges are not the root causes of this lack of standardization, but more or less consequences. According to the company representatives, the most serious problem is that the current design processes do not support and enable the use of standardized products and components, because their value is not understood and therefore they are not offered. (Aapaoja & Haapasalo, 2014)

Process standardization and product standardization need to go hand in hand in order to achieve progress and results. Just focusing on either product or process standardization will yield subpar results and only partial benefits. This causes users to wrongly underestimate the value of standardization, and probably stop the development altogether.

The research of Schepers (2012) shows another important barrier; in his case-study, Schepers analyses a number of lists of requirements (vraagspecificaties) for railway underpasses and concluded that there was not enough design freedom in these requirements. The required solution was specified in great detail leaving almost no room for standardization initiatives.

The barriers and challenges mentioned in this paragraph will be translated to the scope of this research (focus on design department) in the next chapter.

2.4. Translation to Civil Engineering and Contractor´s Civil design department

This paragraph will be used to translate all the information found in literature to the scope of this research project; a start with standardizing the design process and products of overpasses. Together with the results from the benchmark research conducted on a number of Dutch construction companies, the translation of the literature will lead to a conclusion on the expected benefits that result from standardizing the design process and products, and the challenges that need to be overcome.

2.4.1. Field research

In order to get more feeling with the subject of standardization and to learn from companies already experimenting with standardization, a number of interviews has been conducted. These companies are all from the civil engineering sector or close by sectors. All interviews were structured around the same questions;

- Why did the organization decide to start with standardization, what where the expected benefits?
- What was the process of implementing/starting with standardization?
- Did you experience or do you expect to experience barriers and how are they overcome?
- If applicable; what are the benefits resulting from the standardization?
- What is the role of supply chain integration in the standardization process?
- What should be the focus when starting with standardization?

Down below, a short summary will be given for each of the interviewees with the most important statements that can benefit this research.

“Woonconcept Da Vinci Huis” - Hurks

Hurks has implemented standardization in their housing solution. Clients can use a configurator from Hurks to compose their perceived layout which is made out of standard elements. Hurks uses a standard “core” of the house which clients cannot alter in order to benefit from process optimization, reducing failure costs and completion time. Hurks still gives the clients a number of choices to make in order to keep flexibility and make custom fit possible. The most important challenge the project team of Hurks faced was changing the views and conventional ways within the company; the people needed to be convinced of the innovation, which is why the lead developer created a project team consisting out of young people with innovative mindsets as the driving force of the standardization project. Whilst Hurks is not operating in the civil engineering branch, the lessons learned can be applied to the contractor as well.

Standardization Tennet foundations Heijmans

Within Heijmans, the Tennet project has been originally started to standardize the foundations for power pylons. In a later stage of the project the change was made to move from standardization to parameterization. Whilst these constructions are less complex than a overpass, they can pave the way for the standardization project of overpasses because it can display the benefits of standardization to the Heijmans employees which was a problem when they first started with the project (as it was at Hurks). The reason for the standardization lies in the amount of waste in the design process; there were too many useless interaction between structural and geotechnical engineers. A tool is being developed where parameters can be set and where the construction is automatically calculated and only needs to be checked by the engineers. A big challenge is data management, how is the data to be structured and how can be made sure every stakeholder works with the same dataset?

Standardized overpass VolkerInfra
VolkerInfra is the best example for this research project as they have already created some sort of standard overpass. They standardized the elements of the overpass and use them when they need to design a new overpass. It has to be noted that these elements may be adapted if they do not yet meet the requirements of the client. For VolkerInfra it was important to have a strong driving force and to involve not only the designers, but also the planners, calculators and construction workers, in order to achieve maximum commitment. VolkerInfra used short design sessions where a team designed a single element and optimized it before they moved on to another element. The goal of the standardization project is to reduce failure costs and to reduce uncertainty of project costs and completion times.

Design standardization & optimization ABT
ABT is the most advanced company interviewed, because they have already moved past standardizing design and are working on design optimization via programming and modelling a parameterized optimal design. Their programs and scripts use standard design processes to calculate an optimal design, this results in more design freedom and ultimate waste reduction. ABT managed to reduce time needed to create a design from 3days to only 1,5hours, a reduction of almost 94%. Their biggest challenges are to determine the variables of their parameterized elements so that the scripts stay workable, and to have good mapping (the identification of variables between programs).

2.5. Conclusion benefits and challenges

When all the information from the previous paragraphs and the field research is analyzed, a translation can be made towards the scope of this research project; a start with standardizing the design process and products of overpasses. Down below, the benefits and challenges for standardizing the design process and design products of a overpass will be concluded.

Standard process benefits

Better interfaces between disciplines – Every stakeholder knows the standard process and what someone needs to supply, this reduces needed communication and attunement between disciplines, resulting in an improved process chain.

Increased productivity and effectiveness – Stakeholders become familiar with the standard process thus increasing productivity and effectiveness whilst reducing errors and needed changes, resulting in higher profit margins.

Allowing quality optimization – Standard design processes can be developed further and further, optimizing the process and reducing waste. This increases value for money and can show the high level quality process to the clients via audits.

Increased certainty of completion date and costs – Standard design processes also means standard lead times and standard costs for a certain task. This results in more predictable calculations and the ability to tender with more certainty.

Standard product benefits

Tried and tested track record – Standard designs are to be used in multiple projects, being tested and verified over and over, resulting in less time needed to verify the designs and the clients becoming assured of the quality of said designs. Any flaws that are noticed in the design can be eliminated for future projects.

Predictable quality & performance – In addition on the aforementioned; not only the clients experience the increased quality of standard designs, the design department increases its own predictability on delivering quality and performance to the other departments that are going to work with its designs.

Increased productivity and effectiveness – Standard design form a solid starting point where, in an ideal situation, nothing has to be changed. This eliminates the need to copy and adapt a previous "kind of similar" project and thus reduces overlooked details and errors. Working with standard designs increases productivity and effectiveness and frees up specialists to work on complex projects where their knowledge is an asset.

Reduction of waste – Optimizing standard designs, in cooperation with standard design processes, will result in a reduction of operational waste (waiting, rework, etc) and construction waste (economies of scale, possibility of prefabrication and pre-assembly, getting designs "sharper", etc).

The challenges for standardization

Changing the traditional culture – Convincing people of new method and getting people on board will be the biggest challenge. As with all big changes in working methods, people will be critical and resilient to the "new standard", respected initiators will have to be the driving force to spread standardization throughout the organization. The next step will be improving the discipline of follow standard processes which will need some getting used to.

Standard vs flexibility – In order to stay competitive, the standard designs have to maintain a certain flexibility and cannot be complexly standard. Clients are not (yet) at the point of facilitating 100% standard designs and realistically will never be because construction projects have too much uncertainty in outside factors. They might however facilitate 80% standard designs, or modular designs that use standard elements if they understand front-end design and the benefits standardization brings.

The process of creating standard designs – When starting the standardization process, it is important to take small steps to keep the process structured and clear. This also gives the opportunity to agree on rules to structurize and manage standardization data, preventing future uncertainties and conflict and thus waste. It is also necessary to involve stakeholder beyond the design department, on the one hand to increase commitment and to spread standardization throughout the organization, and on the other hand to use hands-on knowledge which may prove to result in different design choices.

Improving supply-chain – A future step will be improving the supply chain. By attuning the processes beyond the design department, a lot of waste can be reduced or eliminated from the total construction process. Utilizing suppliers and sub-contractors will not only lead to more efficient design processes, but also to reduced lead-in times, lower costs (economies of scale) and higher predictable quality for the entire construction project.

2.6. CASE STUDY ON STANDARD OVERPASS

In previous paragraphs, a lot has been said about how standard, standard should be. A number of options have been mentioned, and certain conditions have been established. This paragraph will be used to decide on a definition of standardization that is going to be used for the contractors design department and in the rest of this research.

2.6.1. DECISION ON DEFINITION STANDARDIZED END PRODUCT FOR THE CONTRACTOR.

In the table below, a number of standardization options is weight against a number of criteria. The difference between a modular design and a design with standard details is that a modular design assumes that the design is made up of a number of modules where each module has a number of presets, thus limiting the variety. A design using standard details still has an, in theory, unlimited number of possible variations on core elements.

Table 6 has been created in cooperation with the contractors departmental management in a designated meeting. The researcher had prepared the standardization options and the different criteria and during the meeting, together with the departmental management, the weights were appointed. During the meeting it was established that even though a 100% standard concept would give the most benefits, it would not work in the current market as it stands. The concept would hardly be applicable and thus there would be no business case. In agreement it was decided that the modular concept would fit the contractors goals the best as the modular concept would still offer standardization benefits whilst also being applicable to multiple projects.

Criteria	100% standard	Modular	Standard details	Traditional
Complexity	++	+	0	--
Flexibility	--	+	+	++
Waste reduction	++	+	0	--
Applicability	--	+	+	++
Type reduction	++	+	-	--

Table 6 Decision on amount of standardization

This means that a standardized overpass will consist out of a number of modules put together to form the overpass. Each module has a number of presets, which can be chosen in the design stage, to reduce possible variations. Presets that can interface (A land abutment of 15m wide should not be able to interface with a 20m wide support beam) need to be able to interface with each other to improve workability.

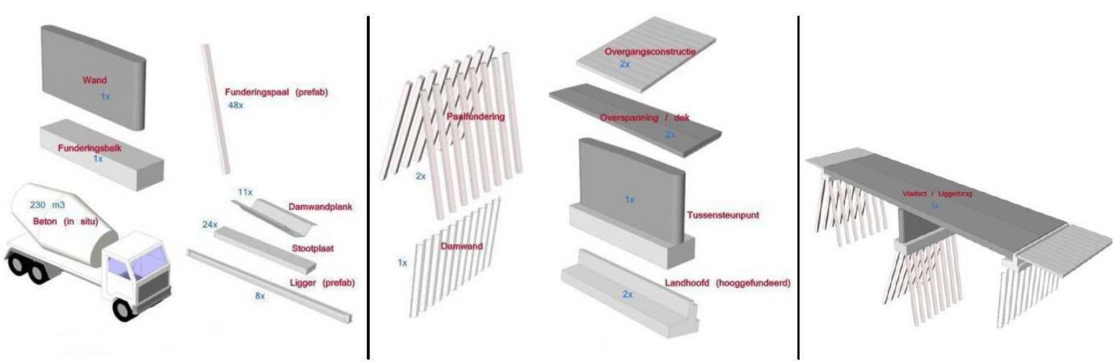


Figure 9 Example of modular viaduct (Schepers, 2012)

2.6.2. NEXT STEPS IN THE PROCESS

The standardization project (of which this research project is a part of) aims to go from current state to improved state to perfect state. The first step will be to choose to modules of the overpass that are going to be used for creating and testing the interfaces between modules via the use of scripting and programming. When this interface is established and tested with relatively simple representations of modules, more information and variables can be added to the modules (parametrization) and presets can start to be created, eventually working towards a realistic representation of a overpass and a workable design with calculations and drawings that optimize the benefits of standardization and reduce waste throughout the entire construction project.

Simultaneously, the current design process will be analyzed and visualized, what stakeholders are involved and at which phase of the process. Then the bottlenecks in the current design process will be identified via value stream mapping before possible reductions or eliminations of waste can be achieved. The lessons learned from analyzing the current state will be used to create an improved state based on standardized design processes and designs to connect to the modular overpass and amplify the perceived benefits.

3. PROCESS MANAGEMENT: ADAPTING THE OVERPASS STRUCTURAL DESIGN PROCESS TOWARDS STANDARDIZATION

3.1. INTRODUCTION

The contractor´s civil design department has stated that "working towards more standardization" is an objective for the (near) future. This is a result from striving to limit failure costs and increase effectivity, strengthened by the expected benefits of standardization described in paragraph 2.1. By standardizing easier design tasks, knowledge can be used for "specials"; projects that differ from day to day tasks and require specialist knowledge and expertise.

This chapter will use the research done in chapter 2 and build upon the decisions and conclusions from it. The current design process will be analyzed using value stream mapping to determine improvement potential, after which an improved state of the design process can be proposed. Appendix 2 shows the general design process of the contractor, encircled in red is the scope of analysis done for this research project. The scope of the design process will be the **structural design** from the conceptual design phase (CO) towards the final design phase (DO). The spatial design (ruimtelijk ontwerp) will not be included in the analysis because it has lots of interfaces with other disciplines such as road design and underground infrastructure and will be too complex and time consuming for this research project.

When the improved state has been proposed, a plan for implementing the improved state will be drafted to ensure the standardization process within the contractor will continue. The plan will also deal with ways to maximize commitment throughout the department to not only develop the modules for the modular overpass, but also to keep improving and expanding modules. This way the continuity of the modular overpass will be improved. This implementation plan can be found in Appendix 4 as it covers organization- and change management, topics which do not fit the general theme of this thesis. Readers interested in these topics can find the implementation plan in Appendix 4. An important section will be the market adaption which will cover the best way to roll out the concept and how the contractor can make profit from the concept. The final parts of this chapter will look into the future where will be tried to determine the steps that follow modularization.

3.1.1. VALUE STREAM MAPPING

To analyze the current state structural design process, Value stream mapping (VSM) will be used. Paragraph 2.2.2. covers VSM in detail, this paragraph will give a quick recap. A value stream is all the actions (both value added and non-value added) currently required to bring a product through the main flows essential to every product: (1) the production flow from raw material into the arms of the customer, and (2) the design flow from concept to launch (Rother & Shook, 2003). Value Stream Mapping is a LEAN management tool developed by Toyota to analyze and optimize the value stream by identifying what actions add value to the product for the customer, and what action are waste. By eliminating waste and focusing on value adding activities in the process, the value stream can be optimized to be more efficient and effective.

For this research, VSM will be used to analyzed the design flow of the structural design and aims to eliminate waste and optimize value adding activities. To facilitate the VSM-analysis, the next section will determine the definition of the product, the customer and the value for customer.

3.2. ANALYZING THE CURRENT STATE DESIGN PROCESS

3.2.1. PRODUCT AND VALUE DEFINITION

As said, the current design process will be analyzed by using value stream mapping, a technique derivative of LEAN management. But before the analysis can be started, a few things have to be clarified;

- What is the product?
- Who will be defined as customer?
- What will be defined as value for the customer?

At first glance it seems logical to classify the final design as the product, it is what the design process leads to and it is the deliverable of the design department. However, the design process is part of a bigger process; the realization (and often maintenance) of a project, in the case of this research project a overpass. When a client issues a project, financial close will only be achieved when the project is completed. The final design and the design process are vital to the completion of the project, but there are more processes that eventually all together lead to the successful realization of the project. Therefore, the definition of product for this VSM-analysis will be the realization of the project for which the client issued the contract. So not only the realized project, but also the realization process.

When looking at LEAN manufacturing, the definition of customer is pretty clear most of the time. A production line creates a certain product that can be sold to the end user. A design process in civil engineering is different from the production process as it adds value in a different way and it can be argued that there are two customers; the client and the construction team. The client is the party issuing the project and paying for it, the construction team uses the design to construct the project. In some cases, mainly with smaller contractors, the design process is outsourced to design firms which are payed by the contractor. Considering there are two customers, the value the design process offers to each of them is different. For the client, the main value will be the design verification and validation of their requirements, the client wants a testable design whereas the construction team is looking for buildability, a set of clear drawings and design assumptions. Some value aspects have overlap between the two customers or carry through the entire project process; a shorter lead-in time offers value for both clients. Down below, the value aspects for both customers will be defined.

Value aspects for Customer 1: The client

<u>Design verification</u>

When issuing the project, the clients states a number of requirements that need to be met. This list of requirements sets a contractual framework that gives the contractor the, sometimes specific and sometimes abstract, information on what the contractor should design and build, how it should be build and how it should function. The client uses the design to perform a first verification on the stated requirements. By meeting the design requirements, the client gets assurance that "everything goes according to plan".

<u>Design validation</u>

The design verification executed by the client also serves as a design validation. It gives the client the chance to determine if the design, and thus the final product, meets what they had in mind with the project. It can happen that certain smaller parts of the project have been designed by the contractor in a way that meets the stated requirements, but that the client prefers another solution. By validation the design, the client has a chance to request (often against a fee) a change of design. These changes are normally very small details such as a certain tile that is used, or a color that needs to be a shade darker.

Lead time
The design process, together with the permits, dictates the project planning in the early phases of the project. The faster the design process can be completed, the faster the construction team can start building and the faster the project is completed. A new train bridge that increases capacity or a road adaptation to increase road safety, shortening the lead time will result in an earlier completion date of the project and thus an earlier solution to the problem that required the issuing of the project. With 99% of clients being governmental bodies, solving problems faster usually leads to less disruption to the environment/stakeholders which in turn leads to more satisfaction about the current policy and increases public opinion.

Risk reduction
The need for verification is a result from a low predictability of civil engineering projects. When looking at "normal" commercial products such as toothpaste, the customer know exactly what to expect; the product is the same every time. In this case, the products are much more subject to irregular circumstances because the products are much more complex. Keeping in mind that most clients are governmental bodies working with taxpayers' money, clients are dedicated to keep the risks of higher costs, delays, and/or function failure to a minimum. A design focuses on "known" solutions reduces the chance aforementioned risks occur.

Value aspects for Customer 2: The construction team
Buildability
For the construction team, it is essential that they realize the design as cost and time efficient as possible. Familiarity is a very important factor in achieving this. When the construction team is able to use a building method with which they are familiar, it is likely there will be less mistakes or errors than when using a new building method. Mistakes and errors not only result in increased cost and lead time, but can also result in unsafe situations and loss of face with clients. A buildable design can be a very valuable base of which the construction team can build the project.

Lead time
With lead time being such an important aspect to the client, it automatically becomes an important aspect for the construction team. When issuing projects, all offers from contractors are judged on a number of aspects. Lead time is a big aspect in this, where clients often offer bonuses when contractors finish the project before the deadline, and issue penalties when contractors do not meet the deadline. So if the construction team can start earlier because the design process is finished ahead of schedule, it could result in potential bonuses from the client, or at least give the construction team some breathing space in the normally very stressed construction process.

Risk reduction
In conjunction with the aforementioned aspects, creating a design that minimizes risks is very valuable for the construction team. Creating a predictable design makes sure that the chances of certain risks occurring and the impact of said risks can be reduced by using prior experience and data gained from prior projects. Reducing risk impact and occurrence is important because most infrastructural projects are realized under a lot of stress. Margins in the civil engineering market

are not great and when a number of risks manifest themselves, it is highly unlikely that any profit will be made from the project.

As said earlier, some of the value aspects overlap for both the customers, but the specific content of these value aspects are different from each other. The next paragraph will analyze the current design process and mark the process steps where value (for either of both) is added.

3.2.2. VSM Data-collection

There are a number of key roles/specialists in the structural design process who provided input for the VSM analysis. Data collection occurred through sessions conducted with specialists, in these sessions the activities of the structural design process were determined and lead times of their respective activities were established, This initial set of data was then processed by the researcher into a process scheme and an organized lead time table. Next, in a second session, the products were verified by the specialists and adapted if needed. The data collection sessions were conducted individually to prevent contamination. The specialists that were interviewed:

Function
Senior Structural engineer
Senior Structural engineer
Engineer/designer
Senior advisor (geotechnical)

Table 7 Specialists used for data collection

The specialist sessions resulted in the structural design process displayed in Appendix 2. The conducted activities and the order of activities provided individually by the specialists were practically identical as there were only very minor deviations in the order of activities due to personal preferences and the way of describing the process. Because of the minor deviations between interviewed specialists, the initial idea to conduct more sessions was waived. The minor deviations in the order of activities were reflected back to the specialists and the most accepted order of activities was followed. The given lead times were more susceptible for differences, although nothing major, mainly because personal interpretation of the case and the efficiency of individual specialists. Together with the management, a representative set of lead times was chosen out of the group.

A separate session with the management was used to discuss the state of the activities (either value adding, necessary waste, or waste). Both the researcher and the management separately filled in the activity states to prevent influencing each other's judgments. The difference between the lists were then discussed before eventually agreeing on a list with classifications. It should be noted that deciding if an activity is value adding or necessary waste will vary from person to person. The researcher and the management agreed that activities are only value adding when activities and their resulting products are directly used or reviewed by the end customer. An example, in this definition all the activities that are required to create a design, such as the calculations, modeling, etc, are regarded as necessary waste as only the design report is used or reviewed by the end customer. One might argue that those prerequisite activities are also value adding because there would not be a design report without those activities.

3.2.3. CURRENT STATE DESIGN PROCESS

The constructive design process for an overpass is only part of the total design process. The overall design is the responsibility of the lead designer where, alongside the constructive design, all needed design products come together (e.g. road design, cable management, installations). There are 2 major key roles in the constructive design process, namely the geo-engineer and the structural engineer. The geo-engineer is a specialist in ground based constructions such as sheet piling and foundations. The structural engineer is responsible for the structural integrity of the overpass. Together they work out the constructive design of the overpass. For this cooperation, a lot of communication between the two engineers is needed because the engineers exchange data that is needed for calculations.

Process mapping

Because there was no detailed mapped standard structural design process, the conducted specialist sessions were also used to map the structural design process in detail. This information was used to create the current state design process depicted in Appendix 2. To stay as close to the contractors way of process modeling, and to not alienate the contractors employees without process modeling knowledge, the decision was made to slightly "dumb down" the standard BPMN way of process modeling. Appendix 2 shows two processes; the first is an abstract depiction of the current general design process, with swim lanes featuring the client, the internal design team, and the subcontractors & suppliers. The process starts with the general initialization phase and ends in the final design (DO) phase, it also shows the scope of the process map of the structural design process depicted in the second process map. The second process map show the design process from the start of the preliminary design until the creation of the final design. It features swim lanes for the design team, the structural engineer, the geo-engineer. and the designer. Although the designer is not part of the scope, its swim lane is included to show the entire range of the design process.

Two documents in the structural design process have been marked; The T.O.M.'s (Trade-Off Matrixes) resulting from step 10, and the Risk analysis resulting from step 20. The documents have been picked in order to create two exchange requirements that serve as an example. An exchange requirement describes, in a very detailed manner, what purpose a document serves, when the document is used, what information the document should contain, and where this information should come from. Exchange requirements are especially useful when documents and products are transferred between coworkers, so that the general content of a document of product will always be the same. Exchange requirements are needed when one wants to create a standardized process in order to enhance the overall quality of the process and the results of said process. The exchange requirements are shown in Appendix 4.

Value stream mapping will be used to analyze the current state structural design process and a distinction will be made between value for the two customers; the client and the construction team. The hard part will be determining what activities actually add value to the product because the civil engineering branch differs from standard production. The client expects a base level of quality in the form of a stated set of requirements, which the contractor has to meet. If the contractor does not meet these requirements, he does not get paid. So the base quality has to be delivered, activities that improve the product (the realization of the project) beyond the base quality will be considered value adding. Activities that are needed to reach a final product, but which do not actually add value to the product will be considered necessary waste.

Current state map – Client

Appendix 2 shows the complete current design process that is analyzed. However, because this visualization is too large to show, the process will also be visualized in tables 8 and 9 which will be used in this paragraph to explain and discuss the current state map.

The process has a total of 50 blocks (activities) of which 16 classify as value adding activities, 28 classify as necessary waste, and 0 can be classified as waste. These numbers do not add up to 49 because a number of activities are located outside of the scope but are included in the process to ensure its completeness.

VSM Current state analysis - Client

Phase	Activity indicator	Description	Lead time (min)	VSM classification
CO - Phase	1	Start	0	N/A
	2	Inventarisation project conditions	360	Necessary waste
	3	Geographical inventarisation	60	Necessary waste
	4	Provide expert judgement	60	Necessary waste
	5	CPT analysis	60	Necessary waste
	6	Provide input design alternatives	960	Value adding
	7	Concept design (CO)	390	Necessary waste
VO - phase	8	Provide input T.O.M. (structural)	240	Value adding
	9	Provide input T.O.M. (geo)	180	Value adding
	10	Create Trade-Off Matrix	390	Value adding
	11	Input other disciplines (Road, K&L, etc)	N/A	N/A
	12	Create global spatial design	N/A	N/A
	13	Decision on design alternative	240	Value adding
	14	Pre-verification of design	480	Necessary waste
	15	Determine global dimensions	960	Necessary waste
	16	Calculate global construction weight	1440	Necessary waste
	17	Determine pile type	30	Necessary waste
	18	Preliminary design (VO)	780	Value adding
DO - phase	19	Setting up SE process	600	Value adding
	20	Risk analysis	600	Value adding
	21	Environmental management plan	600	Value adding
	22	Collect specific requirements for calculations	240	Necessary waste
	23	Create starting note (uitgangspunten notitie)	960	Necessary waste
	24	Identify global loads	1920	Necessary waste
	25	Create SCIA model	960	Necessary waste
	26	Calculate Pile bearing capacity	120	Necessary waste

	27	Calculate horizontal bedding	30	Necessary waste
	28	Calculate global veerconstante	30	Necessary waste
	29	Calculate definitive loads	1440	Necessary waste
	30	Verify definitive loads	60	Necessary waste
	31	Calculate/assume definitive veerconstante	30	Necessary waste
	32	Adapt SCIA model	480	Necessary waste
	33	Optimize global geometry	480	Necessary waste
	34	Determine pile plan	480	Necessary waste
	35	Finalize SCIA model	30	Necessary waste
	36	Coordination with supplier reinforcement	180	Value adding
	37	Calculate reinforcement	1200	Necessary waste
	38	Additional calculations (vleugelwanden)	480	Necessary waste
	39	Start final design report (DO)	1440	Value adding
	40	Design verification (structural)	240	Necessary waste
	41	Design review second line (OKR)	720	Value adding
	42	Start final geotechnical report (DO)	420	Value adding
	43	Design verification (geo)	60	Necessary waste
	44	Design review second line (OKR)	120	Value adding
	45	Assumption check Structural - Geo	120	Value adding
	46	Create Realization assumptions based on derivative requirements	240	Necessary waste
	47	Start final design drawings (DO)	N/A	N/A
	48	Develop 3D model	N/A	N/A
	49	Create 2D sections	N/A	N/A
	50	Finish Final design (DO)	1200	Value adding
		Total lead time	22110	**Percentage of total**
		Total value adding	8790	39,76%
		Total necessary waste	13320	60,24%
		Total waste	0	0,00%

Table 8 VSM Current state analysis - Client

Current state map – Construction Team

Appendix 2 shows the complete current design process that is analyzed. However, because this visualization is too large to show, the process will also be visualized in a table which will be used in this paragraph to explain and discuss the current state map.

The process has a total of 50 blocks (activities) of which only 13 classify as value adding activities, 37 classify as necessary waste, and 0 can be classified as waste. These numbers do not add up to 49 because a number of activities are located outside of the scope but are included in the process to ensure its completeness.

VSM Current state analysis - Construction Team

Phase	Activity indicator	Description	Lead time (min)	VSM classification
CO - Phase	1	Start	0	N/A
	2	Inventarisation project conditions	360	Necessary waste
	3	Geographical inventarisation	60	Necessary waste
	4	Provide expert judgement	60	Necessary waste
	5	CPT analysis	60	Necessary waste
	6	Provide input design alternatives	960	Value adding
	7	Concept design (CO)	390	Necessary waste
VO - phase	8	Provide input T.O.M. (structural)	240	Value adding
	9	Provide input T.O.M. (geo)	180	Value adding
	10	Create Trade-Off Matrix	390	Value adding
	11	Input other disciplines (Road, K&L, etc)	N/A	N/A
	12	Create global spatial design	N/A	N/A
	13	Decision on design alternative	240	Value adding
	14	Pre-verification of design	480	Necessary waste
	15	Determine global dimensions	960	Necessary waste
	16	Calculate global construction weight	1440	Necessary waste
	17	Determine pile type	30	Necessary waste
	18	Create preliminary design (VO)	780	Value adding
DO - phase	19	Setting up SE process	600	Necessary waste
	20	Risk analysis	600	Value adding
	21	Environmental management plan	600	Value adding
	22	Collect specific requirements for calculations	240	Necessary waste
	23	Create starting note (uitgangspunten notitie)	960	Necessary waste
	24	Identify global loads	1920	Necessary waste
	25	Create SCIA model	960	Necessary waste
	26	Calculate Pile bearing capacity	120	Necessary waste
	27	Calculate horizontal bedding	30	Necessary waste
	28	Calculate global veerconstante	30	Necessary waste

	29	Calculate definitive loads	1440	Necessary waste
	30	Verify definitive loads	60	Necessary waste
	31	Calculate/assume definitive veerconstante	30	Necessary waste
	32	Adapt SCIA model	480	Necessary waste
	33	Optimize global geometry	480	Necessary waste
	34	Determine pile plan	480	Necessary waste
	35	Finalize SCIA model	30	Necessary waste
	36	Coordination with supplier reinforcement	180	Value adding
	37	Calculate reinforcement	1200	Necessary waste
	38	Additional calculations (vleugelwanden)	480	Necessary waste
	39	Start final design report (DO)	1440	Necessary waste
	40	Design verification (structural)	240	Necessary waste
	41	Design review second line (OKR)	720	Value adding
	42	Start final geotechnical report (DO)	420	Necessary waste
	43	Design verification (geo)	60	Necessary waste
	44	Design review second line (OKR)	120	Value adding
	45	Assumption check Structural - Geo	120	Value adding
	46	Create Realization assumptions based on derivative requirements	240	Value adding
	47	Start final design drawings (DO)	N/A	N/A
	48	Develop 3D model	N/A	N/A
	49	Create 2D sections	N/A	N/A
	50	Finish Final design (DO)	1200	Necessary waste
		Total lead time	22110	**Percentage of total**
		Total value adding	5370	24,29%
		Total necessary waste	16740	75,71%
		Total waste	0	0,00%

Table 9 VSM Current state analysis - Construction Team

Current state analysis & differences between customers

The first thing that will be noticed is the absence of activities that classify as waste. One might presume that because of this lack, the design process is actually productive. Whilst the design process is definitely well thought out, there is hidden waste. The hidden waste will be discussed in more detail in paragraph 3.2.4.

Large percentage of necessary waste are calculations

The value stream mapping analysis shows rather high percentages of activities that classify as necessary waste, 60% in the Client variant, and 76% in the Construction team variant as shown in figures 10 and 11.

This can be explained by looking at the product definition combined with the boundary condition that a base project quality has to be delivered. A lot of activities have to be carried out to achieve this base project quality, but do not add any value beyond this base quality. A large number of these necessary waste activities are calculations done by the structural- and geo-engineer, and these calculations are prime candidates to standardize via automation. Activities like creating the starting note (#23 in tables 8 and 9) or design verification (#40 and #43 in tables 8 and 9) are activities that require a lot of human interaction and reflection and are much harder to automate. So there is an opportunity to decrease the amount of time spent on necessary waste activities by automating them.

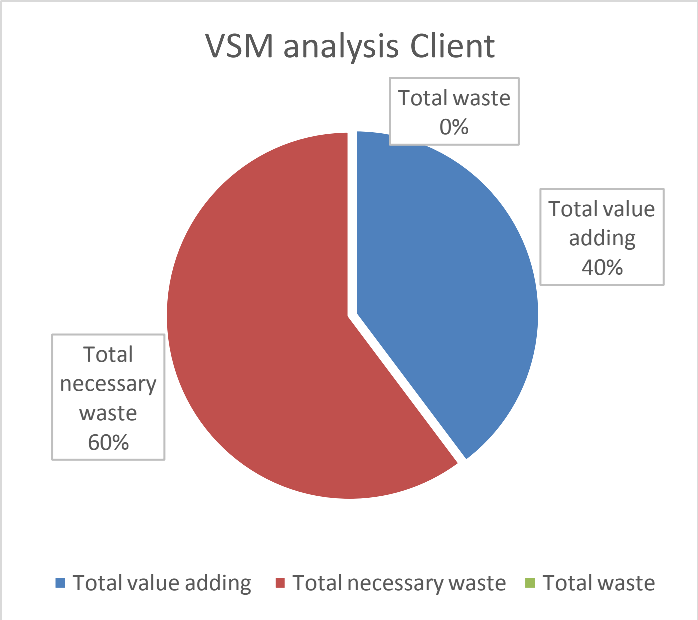


Figure 11 Distribution VSM Current state analysis - Client (visual representation of table 8)

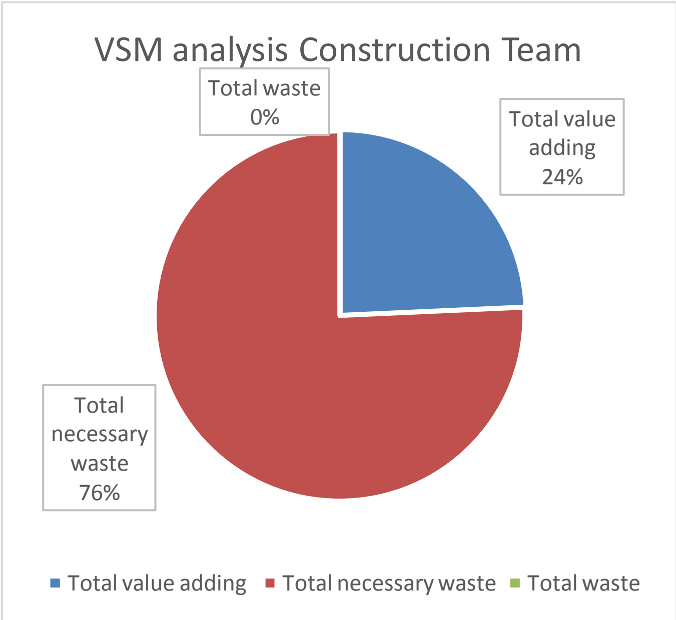


Figure 10 Distribution VSM Current state analysis - Construction Team (visual representation of table 9)

<u>CO/VO phase vs DO phase</u>

When looking at tables 8 and 9, it looks like the majority of value adding activities are clustered in the beginning of the design process, and at the end of the design process. This is because the activities where decisions such as design solutions and building methods are being made, the T.O.M.'s (Trade-Off Matrix'), are located at the start of the process. When comparing the value adding - necessary waste distribution of the CO and VO phase to the DO phase, the differences are almost non-existing. However if we assume activities #15 and #16 are pollution (they are calculation activities that take up a lot of time), the ratio value adding - necessary waste changes drastically.

Current state - Client	Complete process	CO - Phase	VO - Phase	DO - Phase	CO+VO - #15 and #16
Total Lead time (min)	22110	1890	4740	15480	4230
Value adding (min)	8790	960	1830	5820	2790
Value adding (%)	**39,76%**	**50,79%**	**38,61%**	**37,60%**	**65,96%**
Necessary waste (min)	13320	930	2910	9480	1440
Necessary waste (%)	**60,24%**	**49,21%**	**61,39%**	**61,24%**	**34,04%**

Table 10 Phase breakdown Current state analysis - Client

Current state – Construction Team	Complete process	CO - Phase	VO - Phase	DO - Phase	CO+VO - #15 and #16
Total Lead time (min)	22110	1890	4740	15480	4230
Value adding (min)	5370	960	1830	2400	2790
Value adding (%)	**24,29%**	**50,79%**	**38,61%**	**15,50%**	**65,96%**
Necessary waste (min)	16740	930	2910	12900	1440
Necessary waste (%)	**75,71%**	**49,21%**	**61,39%**	**83,33%**	**34,04%**

Table 11 Phase breakdown Current state analysis - Construction Team

The high amount of activities that are classified as necessary waste is especially worrisome in the final design phase (DO) as 70% (15480 of 22110 total minutes) of the total invested time is located in that phase. This block of necessary waste activities will be prime candidate to improve in the proposed improved design process.

<u>Interaction between geo-engineer and structural engineer</u>

There is a lot of interaction between the geo-engineer and the structural engineer, this interaction is mainly focused in the final design phase (DO) because this is where the bulk of their activities are located. The interaction between the two engineers is required because data from the structural engineer provides input for the calculations and vice versa. While the process overview shows the activities of both engineers as at least necessary waste, there is actually a lot of hidden waste located in this interaction between both engineers. Section 3.2.3 will address this hidden waste alongside other hidden waste cases in the current design process.

Differences between client and construction team as customer

In paragraph 3.2.1, two different customers were identified, and with them two different views on value adding activities in the current design process. The difference are projected in table 12 below;

Activity indicator	Description	Lead time (min)	VSM classification Client	VSM classification Construction team
19	Setting up SE process	600	Value adding	Necessary waste
39	Start final design report (DO)	1440	Value adding	Necessary waste
42	Start final geotechnical report (DO)	420	Value adding	Necessary waste
46	Create Realization assumptions based on derivative requirements	240	Necessary waste	Value adding
50	Finish Final design (DO)	1200	Value adding	Necessary waste

Table 12 Classification differences

It is remarkable to notice that multiple activities which are regarded value adding for the client, are not perceived as such by the construction team. This shows a problem that has been persistent in the build environment sector for a very long time; the construction team "outside" gets a lot of data input from the design and management teams "inside", which almost always ends up lying in some filing cabinet gathering dust. The construction teams disregard a lot of information by simply claiming they "do not have time to read all those reports, just give us the drawings and we will build!”. That is generally regarded as “old” behavior. The new approach of the contractor is one of a single development process where all processes progress together because the old lackluster approach resulted in problems and construction faults in the realization phase which could have been prevented. Another difference is the VSM classification of activity 19 Setting up SE process, again this activity is perceived by the construction team as "something for the client that is done by the team inside". This state of mind can be linked to the age of most employees; the older employees have always worked with RAW-contracts where they received the drawings from the client, they build whatever needed to be build, and the client checked the building process. The business model was to use as less and as cheap material as was possible. Nowadays the contracts are different, far more activities and responsibilities lie with the contractor meaning that the role of the construction team changed as well.

The only activity that is regarded as value adding by the construction team, in contrast to the client, is activity 46; the creating of realizations assumptions. This activity is executed to streamline the project transfer from the design phase to the realization phase, it brings the construction team up to speed on the choices and assumptions that have been made by the design team to make sure the construction team can start right away and no duplication of effort (and thus time and money) occurs. Whilst the activity offers value to the construction team, no value is added to the client. The activity merely helps the contractor to finish the project within the set borders so for the client, the activity classifies as necessary waste.

3.2.4. Hidden waste

As mentioned in the previous paragraph, the current design process contains waste that is not visible in the VSM analysis; the so called hidden waste. The existence of this waste becomes clear when comparing the scheduled project lead time to the actual hours spent on the design. The total clean (so without hidden waste) lead time of the design process is 23130 minutes which translates to 385.5 hours, figure 12 shows the distribution among specialists. The allocated project lead time is 800 hours. So somehow more than 50% of allocated hours is not accounted for. A part of this loss could be contributed to (the unanimous) misjudgment from the specialists in estimating their lead time per activity, but a large portion of the missing hours seems to be contributed to hidden waste.

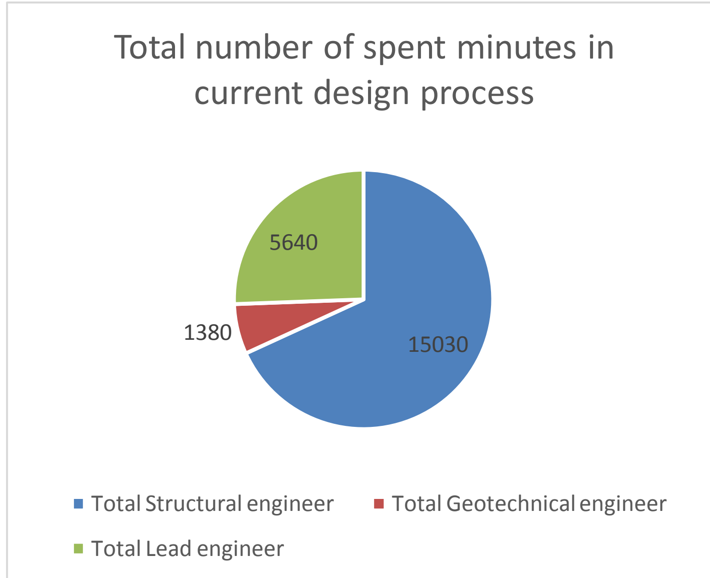


Figure 12 Time distribution Current design process

Waste in discipline data exchange

The biggest waste in data exchange between disciplines is waiting, for instance on input data, calculations, meeting requests, etc. The ideal situation would be that activities would follow each other without delay, however the engineers have multiple projects and need to fit everything to their schedule. It is possible that the structural engineer finishes a calculation that the geo-engineer needs on Tuesday afternoon, but that the quickest that the geo-engineer can start with the following activity is Thursday morning. This may not seem as a big problem, the structural engineer has other projects to work on, but it severely lengthens the design process which can easily lead to problems with suppliers who need data to manufacture prefab elements and even delay with the acquisition of permits, all of which can escalate to suspending the realization starting date.

Waste in design interfaces

Complex projects usually have a lot of interfaces (intersections where multiple design disciplines interact), examples of these interface can be; expansion joints, implementation of cables and pipes, lighting, drainage, and boundary elements. The design coordination of these interfaces are not part of the core design path and are often tackled at the wrong moment, partly because they have to be arranged between several parties who all have different schedules. This means that the coordination is often initiated too late which results in needed reengineering of already finished calculations and/or designs. Reengineering leads to delays in the design process and loss of effort which can result in frustration. Figure 13 shows a simple visualization of what happens when necessary attunement is late.

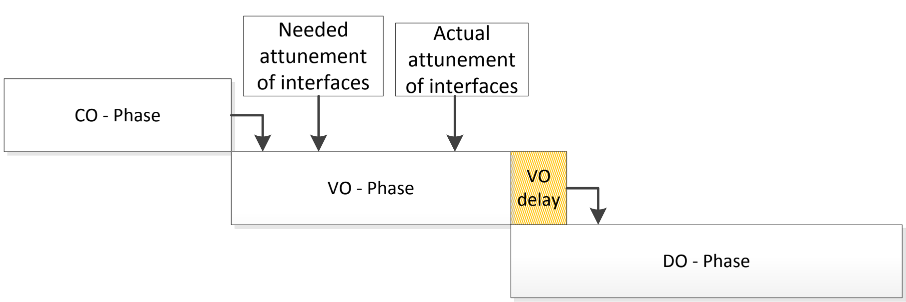


Figure 13 Influence of needed attunement

Waste in supplier coordination

Similarly to the coordination of interfaces, the coordination with suppliers and subcontractors can be cause for waste in the design process. When the decision about the design direction has been taken, both the design department and the procurement department start their activities. The procurement department will, if required, ask suppliers to think about possible improvements to the design or the design choices in the specialized field of the supplier. It is possible that the supplier suggest an improvement, and after this improvement is validated, the improvement can be adapted into the design. When this happens in the early stages of the design process, it is hardly a problem. But when the design process is already in an advanced stage, it is very possible that significant changes to the design are needed to adapt the improvements of the supplier. As with the attunement of interfaces, the needed reengineering is often cause for delays in the design process which in return can cause delays in the permit procedures, contract procuring and the start of realization.

3.2.5. Analysis conclusion and improvement possibilities

This paragraph will be used to sum up the biggest concerns of the current design process and it will indicate the first possibilities for improvement. Paragraph 3.3 will continue to build upon this initial indication.

Discrepancy between scheduled and actual hours

When looking at the difference between the actual times spent on activities and the time scheduled for them, a rather large discrepancy can be noted. The scheduled time is twice the actual time spent, somewhere something is off. Whilst the possibility of interviewer bias is rather low because of the limited knowledge of the activities, a clear danger with qualitative research in the form of interviews is the susceptibility of interviewees to overestimation and subjectivity. But even if you take that factor into account, the difference is still alarming. It means that there is a lot of hidden waste located in the current design process. A possible way to reduce this hidden waste is the introduction of standardization and automation of activities or parts of the process that contain a lot of hidden waste. Especially the hidden waste located in the interaction between the geo-engineer and the structural engineer can be reduced by automating calculations. A possible solution for the hidden waste located in the attunement of interfaces and the coordination with suppliers could be module based designing; when modules are used for certain design element, it creates familiarity in the design process and with that a lower chance that the attunement of interfaces or the coordination with suppliers takes place at the wrong (too late) time.

High amount of necessary waste

A high amount activities that are classified as necessary waste is not necessarily bad, but the large quantity of time (and thus money) that is spent on these activities raises the question if the time is not better spent on activities that actually add value to the product. To reduce the amount of time spent on necessary waste, one can either shorten the time required for those activities, or one can try to transform those activities to value adding activities. Since the latter is almost unmanageable (the contractor has to adhere to the basic quality of the client, trying to make activities add value for the client requires investment while the client will most likely not pay for them), reducing the time spent on activities that qualify as necessary waste will be the focus. Reducing the time spent can be achieved by standardizing and automating, much in the same way as to reduce the hidden waste.

Structural design process offers little value to construction team

Only 24,29% of the activities are considered value adding to the construction team, this indicates a serious issue; Somehow, a lot of data gathered and created in the structural design process is not used by the construction team whilst the data can certainly help the construction team in understanding design choices and the risks that have been derived from those choices. This adoption failure can be explained by the number of things; the mentality of "just let us build things", a lack of time to read all the documents, and a lack of interest to read all the documents.

To fix the adoption failure, an important aspect is involving the construction team in the design process. A nice opportunity for this is the proposed module based designing, creating the modules will have much better results with the input from the construction team. At the contractor, the project development process rests on three pillars; feasibility, buildability and maintainability. The construction team will offer priceless insights for the buildability pillar. Involving the construction team in an earlier stage will help to increase commitment for the design choices that will be made. The implementation plan in Appendix 4 will go into detail on implementing the improved state and maximizing commitment.

3.3. WORKING TOWARDS THE IMPROVED STATE

3.3.1. MODULE BASED DESIGNING

Now that has been established where the biggest waste is concentrated, it is clear what that focus point of improving the design process should be. The path towards more standardization has been taken, this research is only a part of it. In the goals and achievements map for 2016, management has decided that they want to "develop at least 2 standardized products and parameterized designs", "at least 3 tenders have to be submitted with inclusion of standardized products", and "at least 1 standardized product has to be used in a project". The literature study established that 100% is simply not possible in the civil engineering branch and that, in order to standardize, the focus should be on reducing variety in design.

The first step to improve the current state (structural) design process will be to implement module based designing and create standardized design modules for certain elements, and to automate a part of the process to reduce the amount of necessary waste activities and make the process more efficient. This automation will result in the Overpass Design Tool (ODT), the conceptualization of this tool will be explained in chapter 4.

As has been mentioned briefly in chapter 2, module based designing breaks down the end product into elements for which modules will be designed. When the design process is started, a module per element can be selected and step by step the end product will be built. The decisions on the path of element selection can be based on the expert knowledge and experience of the engineers that handle module selection, or flowcharts can be used to select a certain module with input from project conditions. It is likely that in the early stages of development, the decisions will be made based on knowledge and experience, and that in later stages, in combination with the structural design tool, a more automated selection of modules can be created. In the early stages of development, the decision path will be very limited with only 1 or 2 possible paths to test the concept and the tool, these paths should envelop the most common compositions in order to achieve the highest validation possible.

The big important word in the expansion of the module library will be applicability; on the one hand, the new modular concept should have a wide scope so that the modular concept, in combination with the automated structural design tool, is applicable to the highest amount of projects. On the other hand, a contractor must ask itself if the investment into the creation of a certain module is justified if the module facilitates only 2 overpasses in 5 year. The aim should be the age-old 80/20 rule where the concept should envelop 80% of the overpasses that are put on the market. The modular concept, again in combination with the automated structural design tool, should also prove of value to the tender phase as different alternatives can be easily calculated and analyzed. And when the concept is used more and more, more data will be available to increase the reliability of prognosis done in the tender phase. This data is not only data on material use and procurement prices, but for instance also data that is about the maintenance of supplies materials or prefab elements.

3.3.2. AUTOMATED STRUCTURAL CALCULATIONS

Automating the structural calculations via a design tool does not only facilitates the use of module based designing, more importantly it reduces the amount of necessary waste in the design process. The first step with starting automating structural calculation and improving the design process is identifying which activities from the current design process are suitable to automate.

VSM Current state analysis - Automation			
Activity indicator	**Description**	**Lead time (min)**	**Possible to automate?**
16	Calculate global construction weight	1440	NO (Later stage)
17	Determine pile type	30	NO (Later stage)
24	Identify global loads	1920	**YES**
25	Create SCIA model	960	**YES**
26	Calculate Pile bearing capacity	120	**YES**
27	Calculate horizontal bedding	30	**YES**
28	Calculate global veerconstante	30	**YES**
29	Calculate definitive loads	1440	**YES**
30	Verify definitve loads	60	**YES**
31	Calculate/assume definitive veerconstante	30	**YES**
32	Adapt SCIA model	480	**YES**
33	Optimize global geometry	480	**YES**
34	Determine pile plan	480	**YES**
35	Finalize SCIA model	30	NO (Later stage)
37	Calculate reinforcement	1200	NO (Later stage)
38	Additional calculations (vleugelwanden)	480	NO (Later stage)
39	Start final design report (DO)	1440	NO (Later stage)
42	Start final geotechnical report (DO)	420	NO (Later stage)
50	Finish Final Design (DO)	1200	NO (Later stage)

Table 13 Possible activities for automation

The table above shows the activities that can be automated and there is a distinction between activities that can be automated in the first version of the tool and activities that can be added later but are left out to make sure that the tool is not too complex in the early stages. This analysis will serve as input for chapter 4 where will be started with development of the tool. It is good to notice that not only activities that are qualified as necessary waste should be automated, value adding activities can be automated as well to ensure greater efficiency of the design process.

Data collection automated calculations

To determine and validate the lead times of the automated activities, one would need to have a working design tool that has been used in several projects. Since this research project is exploring the concept of a overpass design tool, no validated data is available yet. However by using the expertise and experience of people who have been working on- and with similar automated design tools, it should be possible to create a set of projected data that, with a high probability, approaches the would-be validated lead times. To achieve a set of projected data, a number of specialists have been consulted. These specialists were involved in creating an automated design tool for Wintrack foundations for TenneT and, together with their already present knowledge of the overpass design process, used their experience to create a set of projected lead times that have been used in the improved state analysis. The specialists involved were;

Function
Lead engineer
Project engineer/programmer
Senior advisor (geotechnical)

Table 14 Specialists used for data collection

3.3.3. Improved state design process

Process mapping

For creating the improved state structural design process, the current state structural design process from chapter 3.2.3. has been used as a base. The analysis of the current state process and the suggested improvements have been used to create a more efficient and more value adding structural design process. The implemented changes, in regards to the current state process, are highlighted in blue. These changes envelop the automated calculation described above and the process steps will use the Overpass Design Tool (ODT). The tool will be used for T.O.M. inventarization in the preliminary design phase so that multiple design options can be considered quickly using standard design modules. When the preferred alternative is selected, the tool will be used to perform the global design calculations in the preliminary design phase by using information supplied by both the structural and geo-engineer. And finally the tool will be used for the final design calculations, finalizing the structural design.

Improved state map – Client

Appendix 3 shows the improved design process that has been devised. However, because this visualization is too large to show, the process will also be visualized in a table which will be used in this paragraph to explain and discuss the current state map.

The process has a total of 50 blocks (activities) of which only 13 classify as value adding activities, 37 classify as necessary waste, and 0 can be classified as waste. These numbers do not add up to 50 because a number of activities are located outside of the scope but are included in the process to ensure its completeness.

VSM Improved state analysis - Client

Phase	Activity indicator	Description	Lead time (min)	VSM classification
CO - Phase	1	Start	0	N/A
	2	Inventarisation project conditions	360	Necessary waste
	3	Geographical inventarisation	60	Necessary waste
	4	Provide expert judgement	60	Necessary waste
	5	CPT analysis	60	Necessary waste
	6	Provide input design alternatives	960	Value adding
	7	Concept design (CO)	390	Necessary waste
VO - phase	8	Provide input T.O.M. (structural)	240	Value adding
	9	Provide input T.O.M. (geo)	180	Value adding
	10	T.O.M. inventarisation design possibilities using Overpass Design Tool (ODT)	480	Value adding
	11	Create Trade-Off Matrix	390	Value adding
	12	Input other disciplines (Road, K&L, etc)	N/A	N/A
	13	Create global spatial design	N/A	N/A
	14	Decission on design alternative	240	Value adding
	15	Pre-verification of design	480	Necessary waste
	16	Determine global dimensions	960	Necessary waste
	17	Calculate global construction weight	1440	Necessary waste
	18	Module selection	30	Value adding
	19	Input Dfoundation file	60	Necessary waste
	20	Global design calculations for preliminary design (VO) using Overpass Design Tool (ODT)	480	Necessary waste
	21	Determine pile type	30	Necessary waste
	22	Preliminary design (VO)	780	Value adding
DO - phase	23	Setting up SE process	600	Value adding
	24	Risk analysis	600	Value adding
	25	Environmental management plan	600	Value adding

	26	Collect specific requirements for calculations	240	Necessary waste
	27	Create starting note (uitgangspunten notitie)	960	Necessary waste
	28	Final design calculations (Preliminary to Final VO -DO) using Overpass Design Tool (ODT)	960	Necessary waste
	29	Finalize SCIA model	30	Necessary waste
	30	Coordination with supplier reinforcement	180	Value adding
	31	Calculate reinforcement	1200	Necessary waste
	32	Additional calculations (vleugelwanden)	480	Necessary waste
	33	Start final design report (DO)	1440	Value adding
	34	Design verification (structural)	240	Necessary waste
	35	Design review second line (OKR)	720	Value adding
	36	Start final geotechnical report (DO)	420	Value adding
	37	Design verification (geo)	60	Necessary waste
	38	Design review second line (OKR)	120	Value adding
	39	Assumption check Structural - Geo	120	Value adding
	40	Create Realization assumptions based on derivative requirements	240	Necessary waste
	41	Start final design drawings (DO)	N/A	N/A
	42	Develop 3D model	N/A	N/A
	43	Create 2D sections	N/A	N/A
	44	Finish Final design (DO)	1200	Value adding
		Total lead time	18090	**Percentage of total**
		Total value adding	9300	51,41%
		Total necessary waste	8790	48,59%
		Total waste	0	0,00%

Table 15 VSM Improved state analysis - Client

Improved state map – Construction Team

Appendix 3 shows the improved design process that has been devised. However, because this visualization is too large to show, the process will also be visualized in a table which will be used in this paragraph to explain and discuss the current state map.

The process has a total of 50 blocks (activities) of which only 13 classify as value adding activities, 37 classify as necessary waste, and 0 can be classified as waste. These numbers do not add up to 50 because a number of activities are located outside of the scope but are included in the process to ensure its completeness.

VSM Improved state analysis - Construction Team

Phase	Activity indicator	Description	Lead time (min)	VSM classification
CO - Phase	1	Start	0	N/A
CO - Phase	2	Inventarisation project conditions	360	Necessary waste
CO - Phase	3	Geographical inventarisation	60	Necessary waste
CO - Phase	4	Provide expert judgement	60	Necessary waste
CO - Phase	5	CPT analysis	60	Necessary waste
CO - Phase	6	Provide input design alternatives	960	Value adding
CO - Phase	7	Concept design (CO)	390	Necessary waste
VO - phase	8	Provide input T.O.M. (structural)	240	Value adding
VO - phase	9	Provide input T.O.M. (geo)	180	Value adding
VO - phase	10	T.O.M. inventarisation design possibilities using Overpass Design Tool (ODT)	480	Value adding
VO - phase	11	Create Trade-Off Matrix	390	Value adding
VO - phase	12	Input other disciplines (Road, K&L, etc)	N/A	N/A
VO - phase	13	Create global spatial design	N/A	N/A
VO - phase	14	Decision on design alternative	240	Value adding
VO - phase	15	Pre-verification of design	480	Necessary waste
VO - phase	16	Determine global dimensions	960	Necessary waste
VO - phase	17	Calculate global construction weight	1440	Necessary waste
VO - phase	18	Module selection	30	Value adding
VO - phase	19	Input Dfoundation file	60	Necessary waste
VO - phase	20	Global design calculations for preliminary design (VO) using Overpass Design Tool (ODT)	480	Necessary waste
VO - phase	21	Determine pile type	30	Necessary waste
VO - phase	22	Preliminary design (VO)	780	Value adding
DO - phase	23	Setting up SE process	600	Necessary waste
DO - phase	24	Risk analysis	600	Value adding
DO - phase	25	Environmental management plan	600	Value adding
DO - phase	26	Collect specific requirements for calculations	240	Necessary waste

	27	Create starting note (uitgangspunten notitie)	960	Necessary waste
	28	Final design calculations (Preliminary to Final VO -DO) using Overpass Design Tool (ODT)	960	Necessary waste
	29	Finalize SCIA model	30	Necessary waste
	30	Coordination with supplier reinforcement	180	Value adding
	31	Calculate reinforcement	1200	Necessary waste
	32	Additional calculations (vleugelwanden)	480	Necessary waste
	33	Start final design report (DO)	1440	Necessary waste
	34	Design verification (structural)	240	Necessary waste
	35	Design review second line (OKR)	720	Value adding
	36	Start final geotechnical report (DO)	420	Necessary waste
	37	Design verification (geo)	60	Necessary waste
	38	Design review second line (OKR)	120	Value adding
	39	Assumption check Structural - Geo	120	Value adding
	40	Create Realization assumptions based on derivative requirements	240	Value adding
	41	Start final design drawings (DO)	N/A	N/A
	42	Develop 3D model	N/A	N/A
	43	Create 2D sections	N/A	N/A
	44	Finish Final design (DO)	1200	Necessary waste
		Total lead time	18090	**Percentage of total**
		Total value adding	5880	32,50%
		Total necessary waste	12210	67,50%
		Total waste	0	0,00%

Table 16 VSM Improved state analysis - Construction Team

3.3.4. COMPARISON BETWEEN CURRENT STATE AND IMPROVED STATE

With the improved state design process established, the differences between the current state and the improved state can be analyzed to show what effect automating the structural calculations, by using the Overpass Design Tool (ODT), has on the design process. Down below table 17 shows what activities are eliminated from the design process (depicted in orange), and what activities are added (depicted in blue).

VSM Current state analysis		VSM Improved state analysis	
Activity indicator	**Description**	**Activity indicator**	**Description**
		10	T.O.M. inventarisation design possibilities using Overpass Design Tool (ODT)
10	Create Trade-Off Matrix	11	Create Trade-Off Matrix
11	Input other disciplines (Road, K&L, etc)	12	Input other disciplines (Road, K&L, etc)
12	Create global spatial design	13	Create global spatial design
13	Decision on design alternative	14	Decission on design alternative
14	Pre-verification of design	15	Pre-verification of design
15	Determine global dimensions	16	Determine global dimensions
16	Calculate global construction weight	17	Calculate global construction weight
		18	Module selection
		19	Input Dfoundation file
		20	Global design calculations for preliminary design (VO) using Overpass Design Tool (ODT)
17	Determine pile type	21	Determine pile type
18	Preliminary design (VO)	22	Preliminary design (VO)
19	Setting up SE process	23	Setting up SE process
20	Risk analysis	24	Risk analysis
21	Environmental management plan	25	Environmental management plan
22	Collect specific requirements for calculations	26	Collect specific requirements for calculations
23	Create starting note (uitgangspunten notitie)	27	Create starting note (uitgangspunten notitie)
24	Identify global loads		
25	Create SCIA model		
26	Calculate Pile bearing capacity		
27	Calculate horizontal bedding		
28	Calculate global veerconstante		
		28	Final design calculations (Preliminary to Final VO -DO) using Overpass Design Tool (ODT)
29	Calculate definitive loads		
30	Verify definitve loads		
31	Calculate/assume definitive veerconstante		
32	Adapt SCIA model		
33	Optimize global geometry		
34	Determine pile plan		

35	Finalize SCIA model	29	Finalize SCIA model
36	Coordination with supplier reinforcement	30	Coordination with supplier reinforcement

Table 17 Comparison Current-Improved

By automating the structural calculations, a lot of manual calculations and communication between specialists are eliminated from the process. This communication has not been taken into the process leadtimes because it is hidden waste, as discussed in paragraph 3.2.4. So in reality, the reduction of leadtime is probably even greater. Another benefit of the improved state design process, is the possibility to adapt to proposed changes in a quick matter. In the design process, changes are not uncommon, and with the data already stored in the design tool, adapting the design to these changes will be easier and quicker. For instance in cases where a chance only effects the construction, there is no need to consult the geotechnical engineer because the soil and foundation data remain the same. The structural engineer can just adapt the construction and run the calculations without needing to run it by the geotechnical engineer again.

Even though the improved process is conservative on what activities will be included into the tool, the prognoses are exciting; overall the total lead time of the design process will be reduced by **18.2%** and the ratio value adding – necessary waste activities swings **23,3%** and **16,42%** (respectively for the client and the construction team) towards more time spent on value adding activities. When more and more activities are assimilated into the structural design tool, these percentages will increase even further.

Further improvements to the design process will be adding more data to the design tool; not only adding calculations, but also adding dependencies and relations between activities. For instance, determining the pile type is not yet added in the tool. Adding this activity could not only speed up the design process, it could be linked with data from other activities to automatically generate a preferred solution. Another example; Linking the chosen modules with standard risks for those specific modules, could also lead to an automatically generated risk analysis.

	Current state				Improved state			
Client	**Complete process**	**CO-Phase**	**VO-Phase**	**DO-Phase**	**Complete process**	**CO-Phase**	**VO-Phase**	**DO-Phase**
Total Lead time (min)	**22110**	1890	4740	15480	**18090**	1890	5790	10410
Value adding (%)	**39,76%**	50,79%	38,61%	37,60%	**51,41%**	50,79%	40,41%	57,64%
Necessary waste (%)	**60,24%**	49,21%	61,39%	61,24%	**48,59%**	49,21%	59,59%	42,36%
Construction Team	**Complete process**	**CO-Phase**	**VO-Phase**	**DO-Phase**	**Complete process**	**CO-Phase**	**VO-Phase**	**DO-Phase**
Total Lead time (min)	**22110**	1890	4740	15480	**18090**	1890	5790	10410
Value adding (%)	**24,29%**	50,79%	38,61%	15,50%	**32,50%**	50,79%	40,41%	24,78%
Necessary waste (%)	**75,71%**	49,21%	61,39%	83,33%	**67,50%**	49,21%	59,59%	76,66%

Table 18 Comparison Current state - Improved state

3.4. Ensuring continuous development of standardized products

3.4.1. Module improvement

Applicability is the key word in this entire process; the contractor can create all the modules it likes, if the client does not value the modules, all has been in vain. Structurally, it is generally very clear to what conditions the modules have to meet, but it is likely that there is another important aspect that is of importance to clients. The esthetics of the overpass have to meet the requirements of the client as well. One type of sober overpass may not suit a client who wants a overpass that blends into the landscape. To verify this assumption regarding what clients' value, an interview with the contractors biggest client, Rijkswaterstaat, has been conducted. This interview revealed that RWS not only values a functional overpass, build within budget and time, but the esthetics of the overpass are of importance as well. Henryk Nosewicz formulated the view of RWS in a clear way: "A overpass has to be functional and sober, but cannot be ugly".

In order to fill the needs of RWS, it may be a good idea to hire an architect to design several esthetic modules that fit a certain situation. The architect can work with elements that determine the exterior esthetic of the overpass such as the columns, the edge-elements, and the fencing. Together with a structural engineer, the architect can design multiple theme's that can be used depending on the situation. Examples of this can be a sober theme, an intercity theme or a landscape theme.

Esthetic modules add to module based designing, but to keep the structural modules in fighting shape, there has to be periodical evaluation of the modules. The senior staff member that lead the module creation will be the "owner" of that specific module, and he or she has ensure development of the module so that the module will result in the best price and quality for tender. Each time a module is used and data is gathered, the module owner can call an evaluation meeting with his or her power group to evaluate the module. Based on the new experience, possible shortcomings can be fixed, the efficiency of the module van be improved, and new developments can be added to the module. This way, the contractor ensures that the modules face continuous improvement and that the contractor can be competitive with its module based designing.

3.4.2. Organization and Market adaption

Where module based designing will start as a concept for the design department, the rest of the organization has to join in to truly enjoy all benefits. This starts with integrating members from the construction team into the power groups to supply the designers with valuable information about work at the building site. When modules are created, and data is being gathered from project where the modules are used, the calculation department will be able to make more precise calculations on lead time and costs. With the same data, risk analysis can be optimized because of past experiences with the modules. All in all, the tender process will achieve levels of standardization as well where the tender phase will be more efficient and predictable. In the procurement department, the use of standardized modules means that it becomes appealing to start looking for preferred suppliers that produce common elements used in the modules. This means that better deals can be achieved in both cost and delivery time, and that preferred suppliers may be called in to help further develop certain modules.

Where the appeal of module based designing is pretty clear to the contractor internally, it is imperative that the new approach appeals to the outside world as well. The contractors' clients have to be convinced that module based designing brings benefits to them as well. Clients will get cleaner and more predictable building processes and results where they know what they get. But the clients must really want the concept if they are to allow certain changes to their contract that are needed to enable the use of the contractors' Modular Overpass when the contract initially has some requirements that hinder the use. Creating this hype can be helped by the marketing department as they did for a number of the contractors' new concepts.

The initial benefits are focused solely around the design phase of the project but when the modular approach is adopted and implemented into more phases of the project, more and more USP will be added. The modular approach may even prove an opportunity for the contractor to establish a strategy for more durable infrastructural building where the concept of circular economy comes into play. With all the new developments in the building sector, 3D printing being one of them, it is not strange to at least consider the possibility of prefab modules that can be disassembled and reassembled at another project, increasing the life cycle of the module, in true Lego fashion.

3.4.3. The next step: Future state

Value Stream Mapping assumes three states; the current state, the improved state, and the future state. Chapters 3.2 and 3.3 discussed the current state of the design process and the improved state of the design process. The improved state is a first step towards the perceived future state of the design process which is a parameterized structural design tool that, with just one click of a button, will produce all required calculations, drawings, and the reports that need to be handed in. The operator of the tool just has to input the project conditions and the structural design tool will produce the most efficient solution. The biggest difference with the module based design tool is that a parameterized tool finds the most cost efficient solution, while a module based design will always have a certain overdesign in the module to increase applicability.

Whilst a parameterized tool certainly offers a lot of benefits to the design department, it is no longer standardization and the other involved departments would have to revert back to the old method of working without modules. This would mean that all the line-benefits, emanating from module based designing would seize to exist. Module familiarity for the construction team, prefabrication of modules at preferred suppliers, extensive predication data on costs and planning for tendering, and the list goes on, it would all disappear when the departments have to revert back to old ways.

A better way to strive for a parameterized structural design tool would be to use the module based approach as a base to achieve variant reduction and use parameterization within the modules. Certain variables within the module will have to be standardized whilst other variables will be used in parameterization to achieve the most efficient module possible, an example of this could be the type and number of foundation piles needed, This way both the methods, module based and parameterized, will serve the contractor to be at fighting strength in tenders.

3.5. PROCESS IMPROVEMENT DISCUSSION

The first results, based on the expertise judgment from several specialists, are promising. Even when the number of activities automated by the structural design tool is conservative, the overall lead time can be reduced and more time can be spent on activities that actually add value to the end product. As table 18 depicts, overall the total lead time of the design process will be reduced by **18.2%** and the ratio value adding – necessary waste activities swings **23,3%** and **16,42%** (respectively for the client and the construction team) towards more time spent on value adding activities. It has to be noted though, that all data is based on human estimation and interpretation and is thus subjective. If other engineers would have been consulted, the results would probably be different. That being said, the differences would be small and the results would have still been positive. Another influence to the results that has to be considered is that deciding if an activity is value adding or necessary waste will vary from person to person. The researcher and the management agreed that activities are only value adding when activities and their resulting products are directly used or reviewed by the end customer. An example, in this definition all the activities that are required to create a design, such as the calculations, modeling, etc, are regarded as necessary waste as only the design report is used or reviewed by the end customer. One might argue that those prerequisite activities are also value adding because there would not be a design report without those activities. When, instead of the first definition, the second definition would have been used, the results would show more value adding activities and less activities that are considered necessary waste. The afore-mentioned swing in the value adding – necessary waste ratio would be lower.

The biggest problem points with the current design process are the rather large amounts of activities that are classified as necessary waste, and the hidden waste that is located within the process. Whilst the necessary waste activities are quantifiable, the hidden waste is not. There is no reliable data on how much time in the process is wasted through waiting and interaction between disciplines. The only way to generate somewhat reliable data is to monitor the actors in the process minute by minute, something which is undesirable. Generating data on waste as a result from interfaces and supplier coordination should be easier. Each time reengineering is needed, this should be recorded with the amount of time it costs. When this is done for multiple projects, an average time wasted on reengineering should be able to be calculated.

The module based designing concept, in combination with the structural design tool offers a solid possibility to reduce the time spent on necessary waste activities and thus increase the efficiency of the process. Through the structural design tool, the amount of hidden waste from waiting and interaction can be reduced, and the concept of module based designing should reduce the amount of reengineering. the contractor should focus on both creating a testable structural design tool with just 1 module path, and on collecting data on the current design process (#times reengineering is needed and if possible an educated guess on waiting/interaction time) and the improved process (what inter-department benefits can be achieved through the use of modules). Creating and implementing the module based design approach with the structural design tool will cost a certain amount of money, and those costs have to be justifiable with projected benefits and improvements.

4. Case study: Conceptualizing the structural design tool

4.1. Introduction

With the structural design process analyzed and the implementation of more standardization justified, work can start on development of the recommended automated structural design tool. The tool offers a second level of standardization; standardizing the structural design process is the first level of standardization, standardizing certain variables within those calculations via the use of modules is the second level. The purpose of the automated structural design tool will be to benefit from both levels of standardization; By using the tool, the structural design process can be completed more efficiently meaning that more valuable time can be spend on "specials", and it allows for the use of modules which offers the possibility to benefit from the use of standard products.

Due to the complexity of the structural design process and the calculations involved, and the available time for this thesis, a scope will be formulated For this scope, this chapter will focus on the preparation work for the tool so that the specialists who are actually going to develop the tool (structural engineers, geo-engineers and programmers) will have a base that can be used as a handle during development process. The system breakdown structure of the overpass will be used to explain the composition of the overpass and to choose a section to go into more detail with. For the chosen scope, a BPMN diagram (business process model and notation) will be used to map the transfer of data and to create the needed exchange requirement which will help setting up a data structure for the structural design tool. The BPMN and the derivative data structure will help the contractor in ensuring that all the needed variables for the tool have the required data to execute the calculations. The method of structuring data should also be used for subsequent projects and tool developments so that a standard in data structuring can be adopted and used in a broader way such as in BIM modeling.

4.2. Overpass System Breakdown

Overpasses come in all shapes and sizes, but they all have the same characteristics. Each overpass can be broken down into a number of components that are the same in nearly all overpasses, whereas each individual component may vary from overpass to overpass. In Systems Engineering, this can be visualized in a SBS, a System Breakdown Structure; A SBS decomposes the system of an object, in this case a overpass, into the components of which it consists. Each component is then further decomposed into the properties of said component. The main reason to create a SBS is to manage and control the many requirements that are allocated to different levels of detail. Instead of bunching up all the requirements under one main object (the overpass), a SBS allows for structuring of requirements into smaller and detailed components which means the requirements can be managed in an more orderly fashion. Down below, the System Breakdown Structure for a overpass, is explained in more detail in figure 14. The numbers in figure 14, and in the text below, are used to apply order into the breakdown structure.

In the System Breakdown Structure, a distinction can be made between four main parts, or modules; Land abutment 1 (#2111), intermediate pier (#2112), land abutment 2 (#2113), and the deck (#2114). Figure 15 shows where these four main parts are located in the overpass.

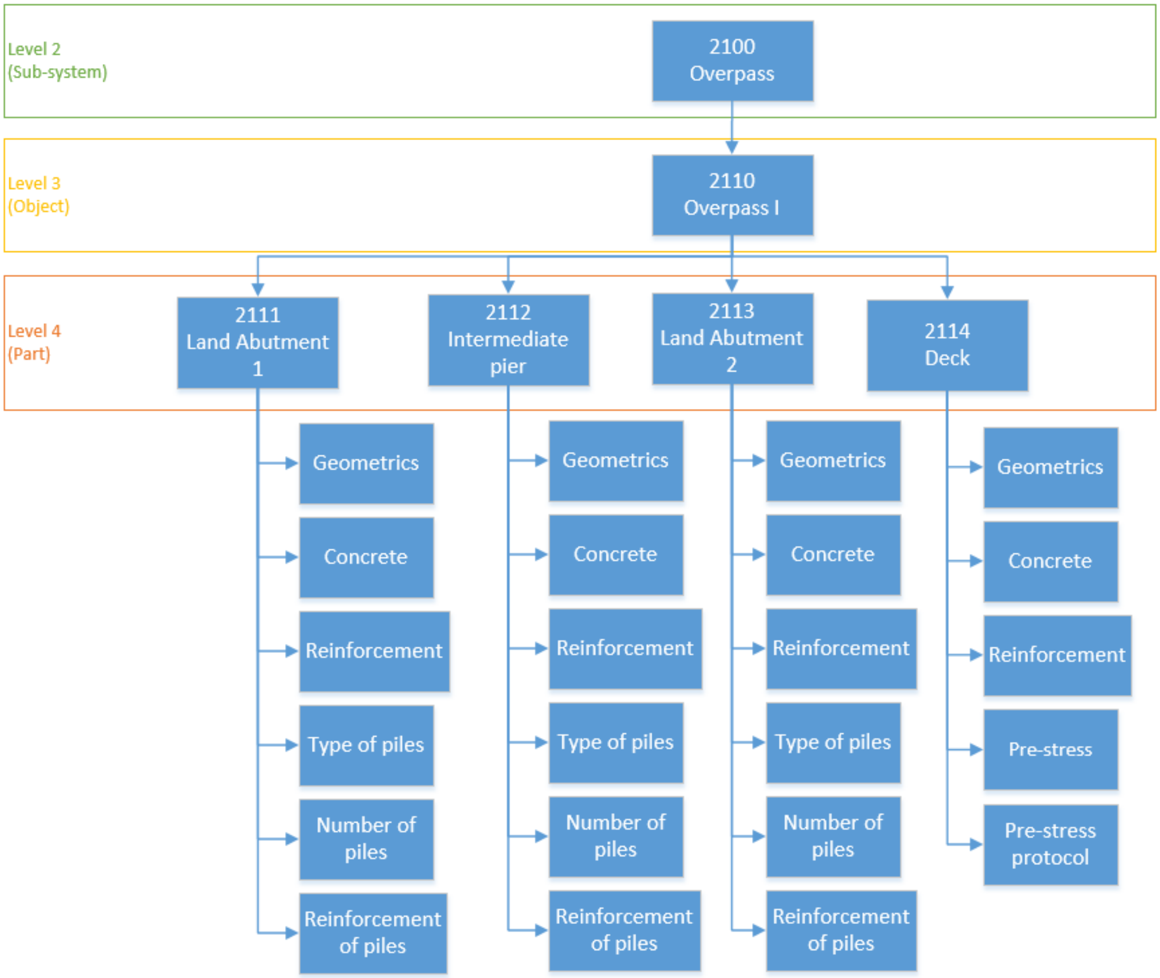


Figure 14 System Breakdown Structure (SBS) of an Overpass

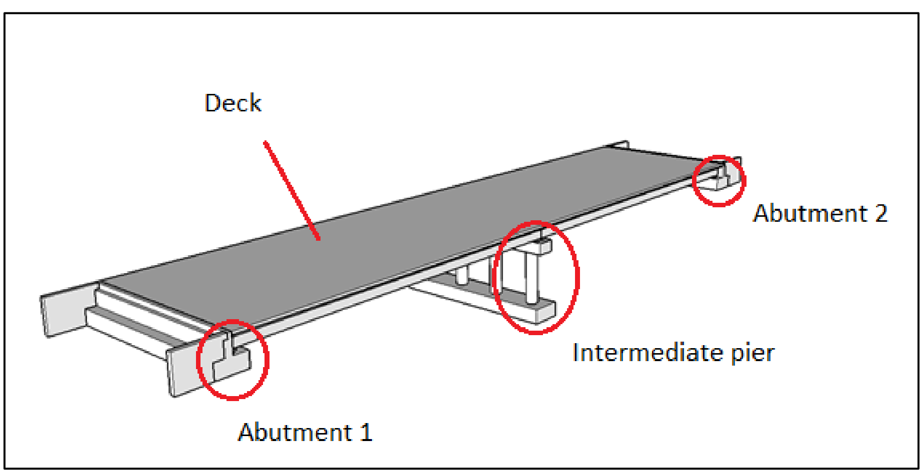


Figure 15 Four main parts of an Overpass

The land abutments serve as the connection between the landmass and the overpass, they are the point where the overpass begins. Single-span bridges and overpasses have abutments at each end which provide vertical and lateral support for the bridge, as well as acting as retaining walls to resist lateral movement of the earthen fill of the bridge approach. Multi-span bridges and overpasses require piers to support ends of spans unsupported by abutments (Abbet, 1957). The abutment consists of number of parts; the abutment slab is the main section, wing walls retain the soil, and the approach slabs serve as transition and are used to counteract prolapse. Abutments can be either high- or low founded, and the foundation of abutments can either be via pile foundations (often used in combination with a high founded abutment) or via block foundations. Figure 16 shows an example of an abutment.

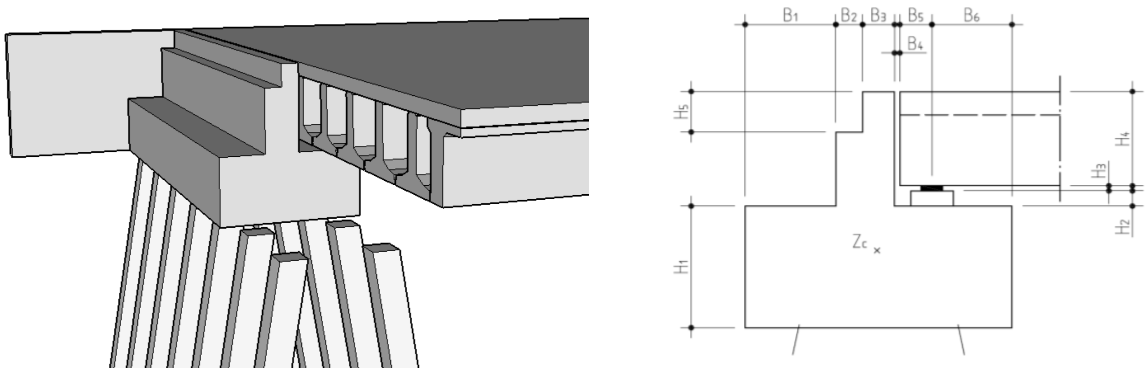


Figure 16 Abutment visualization

The intermediate pier comes into play when span of the overpass is too large to only be carried by the land abutments. The pier functions as extra support to the loads resulting from the deck. Intermediate piers also allow for shorter prefabricated beams which result in lower overall costs (shorter beams + intermediate pier < longer beams). Figure 17 shows an example of an intermediate pier.

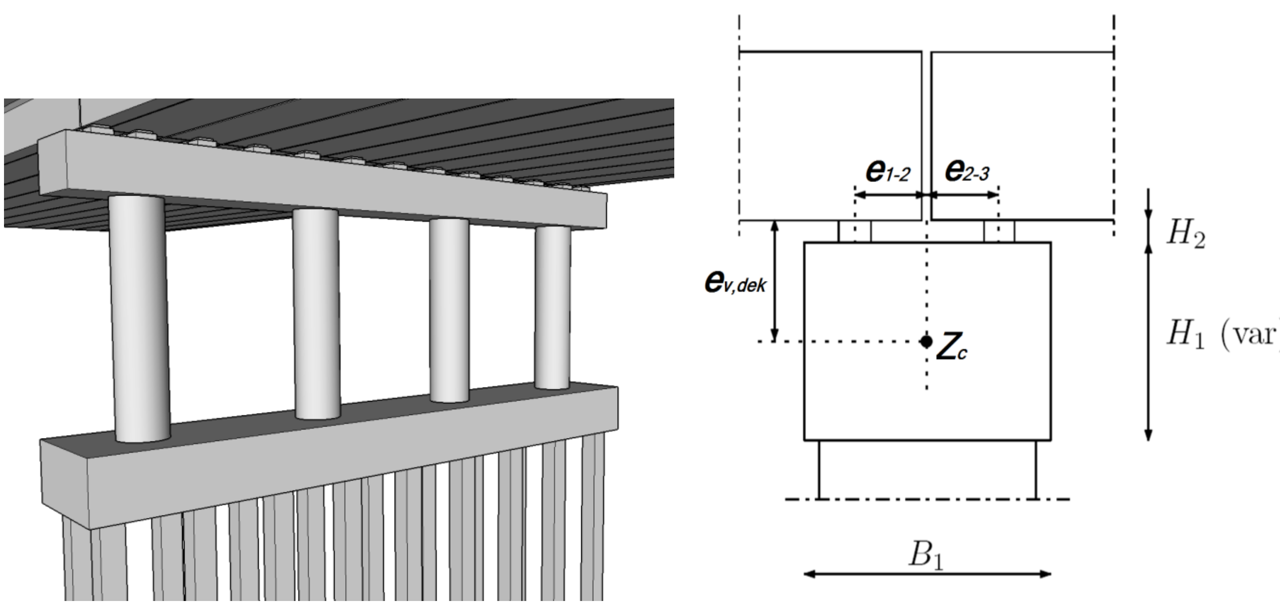


Figure 17 Intermediate pier visualization

Whereas the abutments and piers are considered part of the substructure, **the deck** is part of the superstructure. The deck is made up of the prefabricated beams, the asphalt construction and the edge elements. A large percentage of all loads that the overpass has to bear, occur in and on the deck. Figure 18 shows an example of a deck.

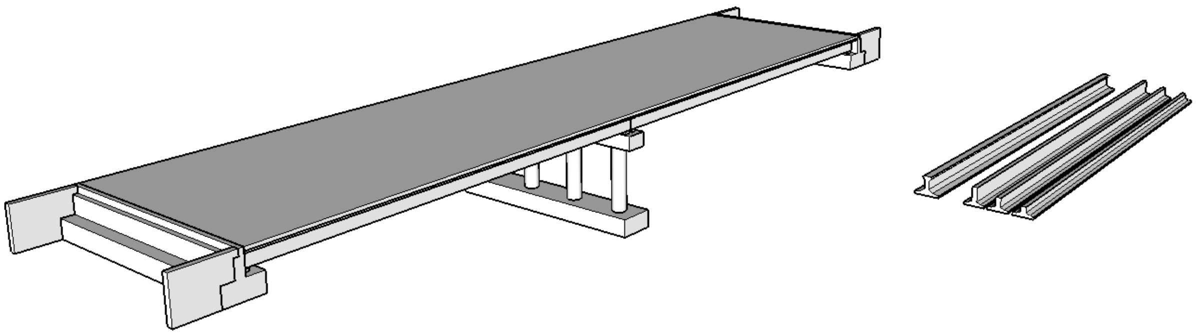
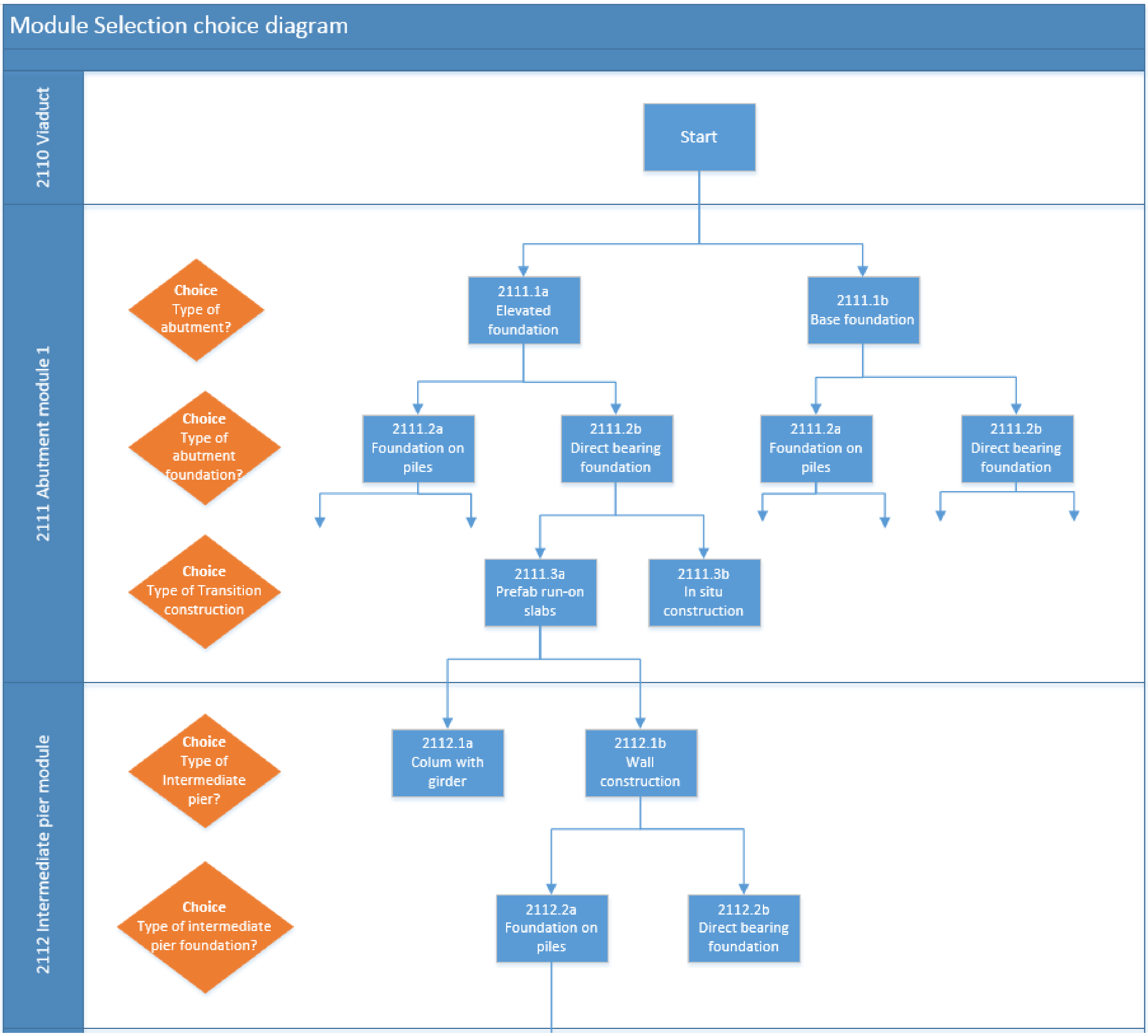


Figure 18 Deck visualization

4.3. MODULE SELECTION

Much like the system breakdown structure, the overpass structural design tool will breakdown the overpass into different elements where each element has a number of possible modules choices. Based on the information that is available (project specific information such as requirements and conditions, or information derived from norms and regulations), the structural engineer can make an informed decision into which module best fits the current situation.

On this and the next page, figure 19 shows an example of the module selection choice diagram. The diagram uses the SBS (System Breakdown Structure) notation to ID modules. Because the model would be too large to display otherwise, only one “selection path” is shown in the figure.



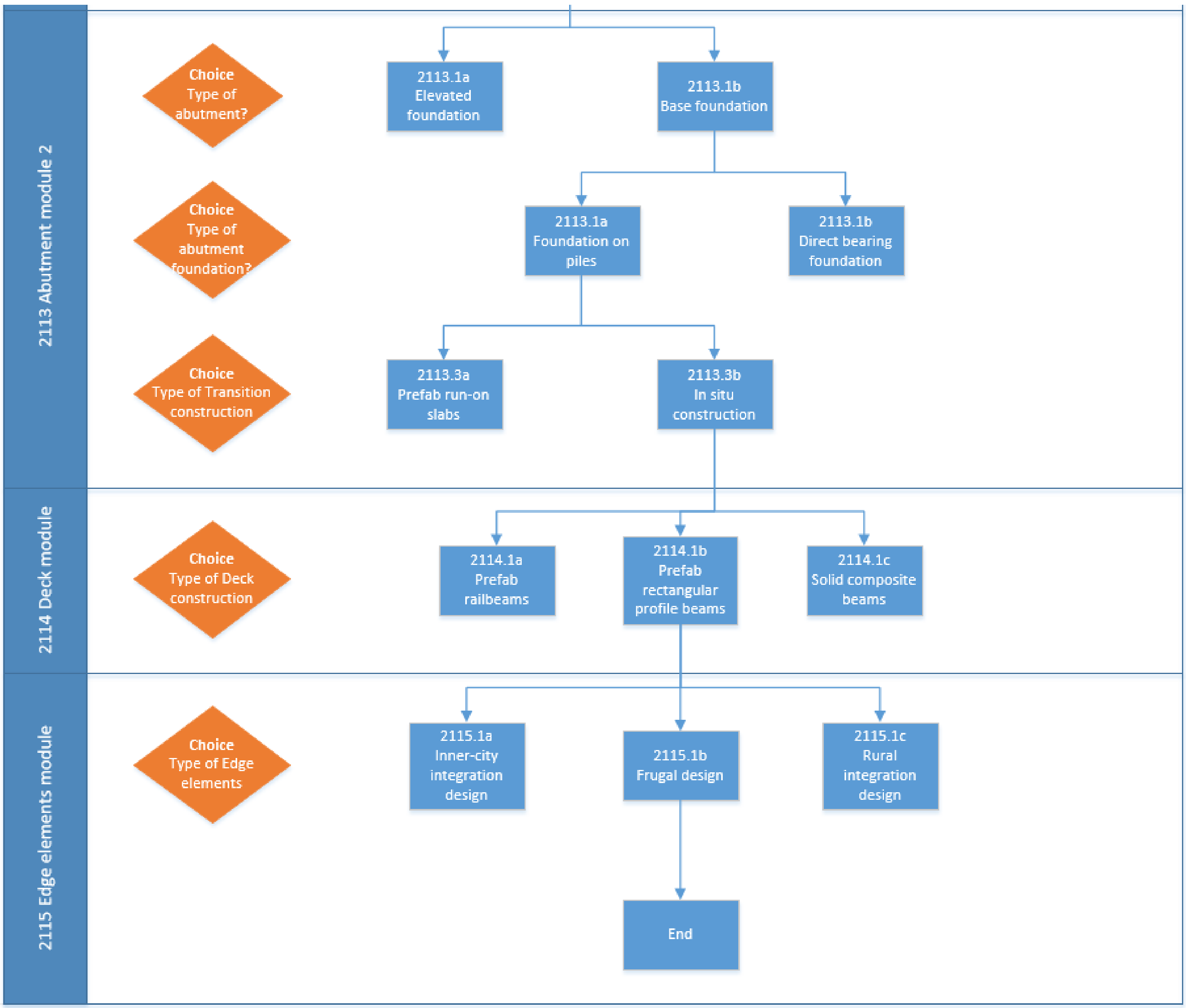


Figure 19 Example of module selection

4.4. CONCEPTUALIZATION OF THE STRUCTURAL DESIGN TOOL

This paragraph will address how the structural design tool for the structural calculations should be going to work. It will explain the vision of joining modular standardization and automated structural calculation into a structural design tool and it will try to find a balance between standardization and parameterization. The first part of the paragraph will go into the model conceptualization; how is the tool going to work, how will data be processed, and what data should eventually be outputted? The second part will continue on this path by looking at the targeted operators, the people who are going to work with the structural design tool; what is their interface going to be like and what data are they going to have to input? The last part of this paragraph will decide on an element that is going to be explored more deeply, for this element a BPMN diagram and exchange requirements will be made which will go into detail on input -and output data, and what properties the data should have.

4.4.1. MODEL CONCEPTUALIZATION

The structural design tool will be aiming to find the balance between a parameterized design solution which provides the most optimal structural design for the structural design department, and a more standardized design solution which provides benefits throughout the chain. This will mean that both the profits from a parameterized design (a sleek and optimal design with the lowest costs) and a standardized design (benefits from the use of standard products) will be combined to a best of both worlds scenario for the contractor.

To ensure this balance, the structural design tool will operate on a modular basis; the operator of the tool will select a certain module per element of the overpass. All these modules will together form the overpass which, with all the required project data, can be used for calculation. Within the modules themselves, part of the variables used for the calculations will be standardized, and part of the variables will be parameterized. By standardizing some of the variables, the connection between elements of the overpass can be standardized which means predictability during the building process. Examples of variables fit for standardizing are discussed in the textbox below.

Example variables fit for standardizing
The edge elements of the overpass have to be assembled onto the overpass deck, this assembly uses a certain type of anchorages that are positioned in a certain way. By standardizing the position and the type of the anchorages, the project can take advantage of the benefits of standardization that are mentioned earlier in this thesis; for instance the construction crew will know how and where the edge elements should be assembled onto the overpass deck and can take this into account during construction, resulting in less faults. The calculation department knows beforehand which type of anchorages will be used during the project and can make better deals with suppliers. By using the same type of anchorages, more maintenance data will be collected resulting in better calculation and lower risk.

Standardizing certain variables does not mean that the operators of the tool should only have 1 option for choice. In the example of the edge elements, the contractor can develop 3 modules for the edge element, for instance one module that is developed for inner-city use, one for landscape integration, and one module that is very basic and minimalistic. Depending on the project, the operator will choose the module that best fits the situation and because the modules are interchangeable, no adaptations are needed.

Some variables cannot be standardized, either because they are highly project specific or because the variables are highly influential on the eventual cost price of the overpass. Trying to standardize these variables will mean that they have to be over dimensioned to ensure that their range fits multiple projects, this is not cost-effective. Examples of variables not fit for standardizing are discussed in the textbox below.

Example variables not fit for standardizing

The foundation piles design for a land abutment is defined by a great number of variables such as type of pile, pile length, pile diameter, type of concrete, number of piles, brace position, and the diameter of the pile plan. Fixing either of these variables into a standard that is usable in multiple projects will result in a over dimensioned standard for most projects. Let's say the range of the variable "pile diameter" in 20 projects is 200mm - 800mm. Standardizing the variable into a pile diameter of 800mm means the standard is usable in all projects. But in 18 of those projects, a lower pile diameter would have sufficed, resulting in unnecessary spending because of the heavier version. A solution would be to create smaller steps or classes of "pile diameter" with a lower range, but this will never be cost-effective as x different standards have to be established, each only applicable to 1, maybe 2 projects. Additionally, creating x standards for only one variable really negates the idea of standardization.

A better solution for the problem of variables that are not fit for standardization, is the parameterization of said variables; let the structural design tool work out the optimal "pile diameter" (the example mentioned above) for the specific project at hand. By standardizing the variables that are fit for standardization and using parameterization for the variables that cannot be standardized, the structural design tool will allow the contractor to achieve and profit from standardization benefits whilst still supplying a competitive design for tender.

To establish which variables are fit for standardization and which variables need to be parameterized in the tool, the contractor should do a study on their already realized overpasses. The variables needed to perform the required structural calculations are known. By creating a clear overview comparing the specific variable input per overpass, an analysis can be done for which variables are fit for standardizing. A small exploratory study, a comparison of 4 overpasses, already has been done with a different goal in mind, but a number of variables have been included in the study. Some of those variables that can and cannot be standardized are shown below as an example;

Variable	Standardized value
Shape of the abutment	Symmetrical
Width of the abutment (Btot)	2500mm
Height of the retaining wall	Needs to be parameterized
Construction class	S5
E-modules	11000 N/mm2
Concrete grade	C30/37
Environmental class roadside	XC4, XD3,XF4

Table 19 Standardizable variables resulting from exploratory contractors study

4.4.2. TARGET OPERATORS AND INTERFACE

The people who are going to have to operate the structural design tool will be the structural engineers. The structural engineers are going to decide on the module choices and they will provide all required input data. The input data can be either project specific data derived from the requirements or the project conditions, or choices for certain modules that contain certain standardized variables.

The interface that the operators are going to use to input data should be easy to use and, even more important, should be user friendly. Using an (excel)tool means that there is a clear risk of "errors through tampering", basically errors that surface when operators accidentally change parameterized formula's. To counteract this risk, the interface should work with 3 type of cell colors; one color for cells where operators are allowed to input data (either project data or module choices), one color for cells that are parameterized and generate their own values, and one color for cells with standardized data dependent on module choices. An example of this is given in figure 20 below; The color orange indicates cells where operators are allowed to input data and blue is for standardized cells based on module selection. On the next page, figure 20 is a screenshot of the first concept of the tool further described in chapter 4.4. It covers steps 8 and 9 in the BPMN diagram which can be found in Appendix 6.

Besides the initial input tab, there should be a number of other tabs available for the operators where, per element, the modules are covered in more detail. This will help operators decide on the best module for the situation on hand. The last basic tab should be the output tab where the unity checks are displayed and all the data that is used to create a rapport is displayed. Facilitating these basic tabs will be a number of specialist tabs; Tabs where the geotechnical engineer can input the required geotechnical data and where excel can communicate with D-Foundations, tabs for load calculations, tabs for calculating reinforcement, and tabs where excel can communicate with SCIA Engineer. In a later development stage, tabs for cost calculations and planning can be added to further expand the use of the structural design tool.

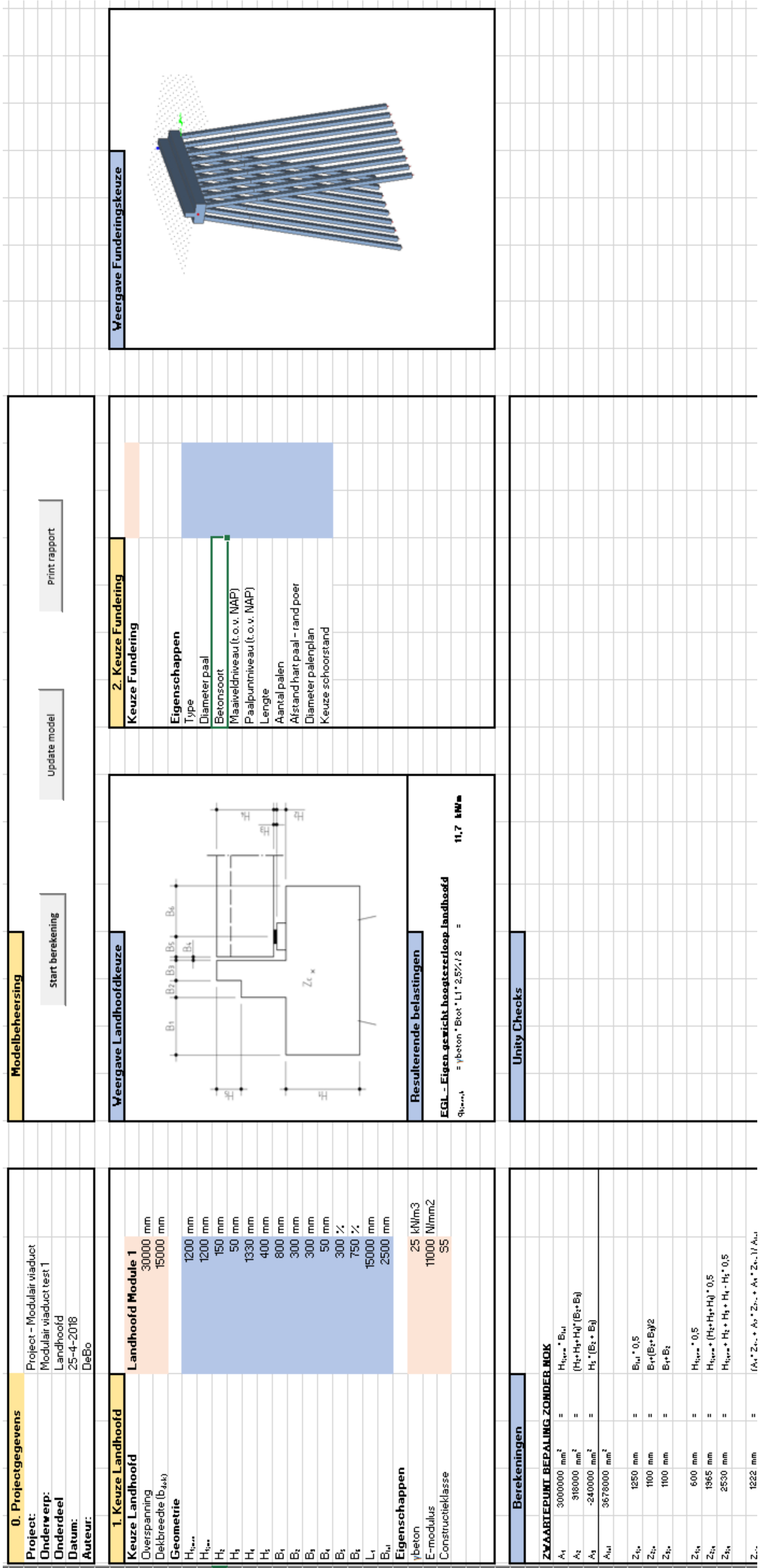


Figure 20 Example of structural design tool interface

4.4.3. Tool development scope

The input of the operators, both in project data and in module choices, depends on the required data needed to perform the calculations which will result in added value for the client. The programmers who are going to create the structural design tool will also need to know the data requirements for the calculation steps, this will ensure that they can create a proper and complete interface for the operators to input their data. The programmers will also need to know how to present the resulting output in such a way that is acceptable for the client.

To aid the programmers, section 4.4.4. will provide a first concept of the tool. This concept will show one set of modules; the abutment (landhoofd) modules and one load that is calculated. This first concept will give programmers a base off which to expand from.

To help the contractor establish the required data and the characteristics of this data to aid the programmers in expanding the tool, chapter 4.5 will be used to create a BPMN diagram to visualize how the structural design tool will work, where data is in- and outputted, and where that data comes from. Exchange requirements will be used to go into detail on what specific data should in- and outputted, and what the characteristics of that data should be. Using the exchange requirements also requires the creation of a data structure; a means with which all data that is inputted, outputted, or processed through the structural design tool, is structured in a clear and predicable way for all users.

For the data structure, all information required is provided in a set of information units. An information unit typically deals with one type of information or concept of interest. An information unit may be composed of an entity alone such as project and beam or an entity (e.g. project) and its attribute (e.g. name) such as project name and wall lengths. Information units should be specified further to provide the following:

- An identifying name: The name should not overlap with names of other information units at least within an IDM document;
- A description about the information unit: The description should be as explicit as possible and unambiguous enough not to confuse users with other concepts;
- The information which needs to be exchanged for the provisions of this information unit to be satisfied. This should include any special provisions, propositions or rules related to the information.

An exchange requirement is built from multiple information units and it describes a set of information that is needed to perform a certain process, in this case structural calculations. A clear data structure does not only help programmers to reduce errors whilst building the structural design tool, it also offers the possibility to create a library which can be used in subsequent design tool projects and it offers the possibility to connect the structural design calculations to the use of BIM (Building Information Modeling).

As said earlier, to take a first step in the development of the tool and to aid the specialist who are going to develop the tool, a BPMN diagram and corresponding exchange requirements will be created. Because of the complexity and the extent of the process, and the limited time available for this thesis, only a section of the process will be addressed. The results from this first step should however provide a base which can be further build upon. The BPMN diagram and corresponding exchange requirements can be found in Appendix' 5 and 6 and are further discussed in chapter 4.5.

The **scope** will be as followed; A first concept will be created which will define how the tool is going to work. One module type will be included in the tool and one load will be automatically calculated and prepared for export to SCIA. The BPMN diagram and the corresponding exchange requirements will cover the calculation process for the loads resulting from the deck into the bearing blocks of the abutments and the intermediate pier, and all the variables related to that. The loads resulting from the ground and the foundations will be included in the BPMN diagram, however the exchange requirement for the geotechnical exchange requirement . For SCIA, a bar model will be assumed. A bar model means that the overpass is depicted as a standard bar on which line loads and point loads are projected. This is the most standard model that is used for these types of calculations. The bar model will show how the results of the loads are transferred to the rest of the structure and eventually the ground. SCIA will also calculate resulting internal forces, the normal force, resulting shear, and resulting torque on the abutment.

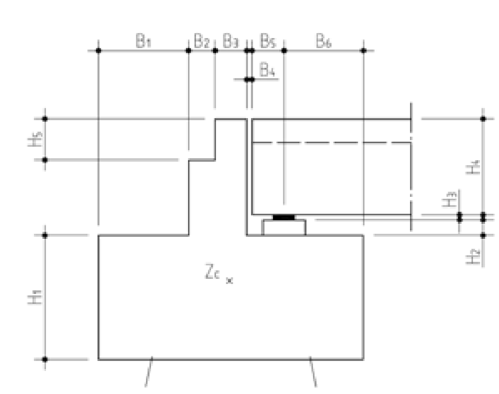
4.4.4. THE FIRST CONCEPT

As said in the previous chapter, a concept of the Overpass Design Tool (ODT) is created to aid the programmers who are going to further develop the tool. The concept will show one module type and will have one load which is calculated based on the variables of the chosen module. The chosen load for the concept is the load resulting from the deadweight; the own weight of the abutment.

In this example, abutment module 1 has been chosen from the three possible modules. Next, the span of the overpass and the width of the deck is inputted in the orange cells. Based on the chosen abutment module, the geometrics of the abutment are loaded into the blue cells. Finally the volumetric mass density of the concrete used is inputted into the tool. This number may vary when different kinds of concrete are used, hence why this is not a standardized cell. Next to the input block, the position of the variables is displayed on an image. In the future this, as of yet, static image can be replaced by a interactive display of the abutment that changes with the chosen abutment module.

1. Keuze Landhoofd		
Keuze Landhoofd	**Landhoofd Module 3**	
Overspanning	30000	mm
Dekbreedte (b_{dek})	15000	mm
Geometrie		
H_1 [illegible]	1200	mm
H_1 [illegible]	1200	mm
H_2	150	mm
H_3	50	mm
H_4	1400	mm
H_5	400	mm
B_1	1000	mm
B_2	350	mm
B_3	300	mm
B_4	50	mm
B_5	400	%
B_6	800	%
L_1	15000	mm
B_{tot}	2900	mm
Eigenschappen		
γbeton	25	kN/m3
E-modulus		
Constructieklasse		

Weergave Landhoofdkeuze



Resulterende belastingen

EGL - Eigen gewicht hoogteverloop landhoofd

q [illegible] = γbeton * Btot * L1 * 2,5% / 2 = **13,6 kN/m**

Figure 21 Screenshot of abutment module selection tab

The data of the different modules is stored in a different tab. Adding new modules or changing/adapting current modules can be done here. In de table on the bottom (see figure 22), the data from the different modules is gathered into one table to help displaying the current data whenever a certain module is selected in the input tab. This is done by making use of the horizontal lookup (HLOOKUP) formula in Excel. The modules can be expanded with more variables when the tool is being build, the formula's that are already in place can be used to further expand the input tab as well.

Landhoofd Module 1		
GEOMETRIE LANDHOOFD		
$H_{1;max}$	1200	mm
$H_{1;min}$	1200	mm
H_2	150	mm
H_3	50	mm
H_4	1330	mm
H_5	400	mm
B_1	800	mm
B_2	300	mm
B_3	300	mm
B_4	50	mm
B_5	300	mm
B_6	750	mm
L_1	15000	mm
B_{tot}	2500	mm

Landhoofd Module 2		
GEOMETRIE LANDHOOFD		
$H_{1;max}$	1400	mm
$H_{1;min}$	1400	mm
H_2	200	mm
H_3	100	mm
H_4	1600	mm
H_5	400	mm
B_1	1000	mm
B_2	300	mm
B_3	300	mm
B_4	50	mm
B_5	300	mm
B_6	750	mm
L_1	15000	mm
B_{tot}	2700	mm

Landhoofd Module 3		
GEOMETRIE LANDHOOFD		
$H_{1;max}$	1200	mm
$H_{1;min}$	1200	mm
H_2	150	mm
H_3	50	mm
H_4	1400	mm
H_5	400	mm
B_1	1000	mm
B_2	350	mm
B_3	300	mm
B_4	50	mm
B_5	400	mm
B_6	800	mm
L_1	15000	mm
B_{tot}	2900	mm

HLOOKUP				
Modules		Landhoofd Module 1	Landhoofd Module 2	Landhoofd Module 3
Landhoofd Module 1	$H_{1;max}$	1200	1400	1200
Landhoofd Module 2	$H_{1;min}$	1200	1400	1200
Landhoofd Module 3	H_2	150	200	150
	H_3	50	100	50
	H_4	1330	1600	1400
	H_5	400	400	400
	B_1	800	1000	1000
	B_2	300	300	350
	B_3	300	300	300
	B_4	50	50	50
	B_5	300	300	400
	B_6	750	750	800
	L_1	15000	15000	15000
	B_{tot}	2500	2700	2900

Figure 22 Screenshot of Abutment module data tab

In the block below the choice of abutment module, the required calculations to determine the deadweight load and the eccentricities that are used in the SCIA calculations and thus need to be exported, are depicted. The calculations are automated so whenever a different module is chosen, the results of the calculations will change alongside. When the tool is build further, more and more calculations will be added to ensure all needed loads are included.

Berekeningen				
ZWAARTEPUNT BEPALING ZONDER NOK				
A_1	3480000	mm^2	=	$H_{1;gem} * B_{tot}$
A_2	1040000	mm^2	=	$(H_2+H_3+H_4)* (B_2+B_3)$
A_3	-260000	mm^2	=	$H_5 * (B_2 + B_3)$
A_{tot}	4260000	mm^2		
$Z_{1;x}$	1450	mm	=	$B_{tot} * 0{,}5$
$Z_{2;x}$	1325	mm	=	$B_1+(B_2+B_3)/2$
$Z_{3;x}$	1350	mm	=	B_1+B_2
$Z_{1;y}$	600	mm	=	$H_{1;gem} * 0{,}5$
$Z_{2;y}$	2000	mm	=	$H_{1;gem} + (H_2+H_3+H_4) * 0{,}5$
$Z_{3;y}$	2600	mm	=	$H_{1;gem} + H_2 + H_3 + H_4 - H_5 * 0{,}5$
$Z_{c;x}$	1426	mm	=	$(A_1 * Z_{1;x} + A_2 * Z_{2;x} + A_3 * Z_{3;x}) / A_{tot}$
$Z_{c;y}$	820	mm	=	$(A_1 * Z_{1;y} + A_2 * Z_{2;y} + A_3 * Z_{3;y}) / A_{tot}$
EXCENTRICITEITEN				
$e_{h;dek}$	674	mm	=	$B_{tot} - Z_{c;x} - B_6$
$e_{h;stoot}$	326	mm	=	$Z_{c;x} - B_1 - 100$
$e_{v;dek}$	530	mm	=	$H_{1;gem} + H_2 - Z_{c;y}$
$e_{v;stoot}$	1580	mm	=	$H_{tot} - H_5 - Z_{c;y}$

Figure 23 Screenshot of calculations in the abutment selection tab

With the calculations ready, the results have to be exported to SCIA for the next calculations. For that purpose, a number of tabs have been added to the tool. These tabs will hold all necessary information of the different loads, which will be used in the SCIA calculations. For our example, the deadweight results in a line load. Down below, the resulting information is displayed in the corresponding tab. These tabs can then be imported to SCIA to create the load model of the overpass. When the module variables and the corresponding load calculations are being expanded, the export data tabs can also be further expanded with the formula's already in place.

LIJNLASTEN LANDHOOFD

Naam	Type	Verdeling	Richting	Waarde - p1 [kN/m]	Waarde - p2 [kN/m	Staaf	Belastingsgeval
Eigen gewicht	Kracht	Gelijkmatig	Z	-13,6		S19	EGL - eigen gewicht hoogteverloop landhoofd

Coördinaatdefinitie	Reikwijdte	Positie x1 [m]	Positie x2 [m	Excentriciteit ez [m	Excentriciteit ey [m	Oorsprong
Rela	vol	0	1	0,380	-0,176	Vanaf begin

Figure 24 Screenshot of data in one of the export tabs

4.5. BPMN DIAGRAM AND EXCHANGE REQUIREMENTS

With the first concept of the structural design tool functioning as a base to expand further upon, the programmers who are going to develop the tool further need to know where which data is required, and how this data should be structured in such a way that it can be used beyond this project. To accomplish this, a BPMN diagram (for the set scope) and corresponding exchange requirements will be created in this paragraph. The data structure that will be used in the exchange requirements and which can function as a base for follow-up projects and the use of BIM, will be discussed in the next paragraph.

4.5.1. SHORT THEORETICAL DESCRIPTION

A standard Business Process Model and Notation (BPMN) will provide businesses with the capability of understanding their internal business procedures in a graphical notation and will give organizations the ability to communicate these procedures in a standard manner.[1] BPMN is a notation, it is used in creating process maps, it defines how the process map is created, what rule set must be used. The most common notation is IDEF0, this notation has been used to create the process maps in chapter 3 of this thesis. While both notations are perfectly viable, BPMN excels in defining information by using a separate swim lane for information exchange, it offers the use of exchange requirements.

An exchange requirement is a set of information that needs to be exchanged to support a particular business process at a particular stage of a project. It is intended to provide a description of the information in non-technical terms. The principal audience for an exchange requirement is the end user (architect, engineer, constructor, etc.). It should however also be used by the solution provider since it provides the key to the technical detail that enables the solution to be provided. An exchange requirement represents the connection between process and data. It describes a set of information from a process that has been performed by an actor in the role of initiator to enable a downstream process to be performed by another actor in the role of executor.[2]

4.5.2. PROCESS MAP & EXCHANGE REQUIREMENTS

For the aforementioned scope, a BPMN with corresponding exchange requirements has been created. Whilst the BPMN and exchange requirements do not cover the complete process, it provides the contractor with a valuable first step into the development of the structural design tool and it offers the contractor a structured method to establish the required data and the characteristics of this data to aid the programmers in creating the interface of the tool. This small part of the development process that has been carried out should prove a helpful aid along the rest of the development process. The entire process map and exchange requirements document that has been created can be found in Appendix 5, this paragraph will explain the document. Appendix 6 show the process diagram of the BPMN.

Process Map

The process map document describes the scope of the created BPMN diagram and provides a general description of how the BPMN diagram fits in the process improvement development suggested in chapter 3. The process map document explains what lanes are present in the BPMN diagram, what tasks and gateways are displayed, and it gives a specification of the data objects present in the BPMN diagram, both library data objects and exchange requirement data objects.

[1] http://www.bpmn.org/

[2] ISO 29481-Part 1 IDM CommitteeDraft-2014-04-10

The process map visualizes the process of using the automated structural design tool by projecting the tasks (in blue) that need to be executed, and more importantly, the information that is required to perform those tasks. The exchange requirements (in orange) function as a umbrella where all the required data is gathered and structured so that the engineers (the top and bottom swim lanes) know exactly what data should be supplied to the tool operator (the middle swim lane) and what the characteristics of that data should be. The green tasks are tasks that will be automated, this is where the calculations are carried out according to the conceptualization of the structural design tool described in paragraph 4.3. The full BPMN diagram can be found in Appendix 6, part is displayed in figure 25.

As an example and for clarification, a set of geometrical data of the abutment will be followed through the tasks. Each task described further below will mention how the set of geometrical data is handled, what it is used for, and what it results in. As this example is part of the structural engineer, the tasks of the geotechnical engineer are not included. The description of the tasks below is an addition on the task descriptions in the process map of Appendix 5.

[2] Define project data & provide T.OM. input
Based on the available modules, the structural engineer creates a number of abutment designs with different geometric data which are used in the T.O.M. The T.O.M. will eventually result in a preferred design alternative.

[3] Decide on module choices
Based on the project data and the preferred design alternative from [2], the structural engineer makes an informed decision on which abutment modules best fits the project and thus what the geometric values of the abutment will be. Exchange Requirement 1 describes what data should be inputted into the tool, and which variables are standardized in available modules and what data the structural engineer should input specifically for the project.

[6] Determine global dimensions
Based on the chosen module and the resulting geometric values, the structural engineer determines the global dimensions of the project, information which will be used in task 7.

[7] Calculate global construction weight
Based on the global dimensions determined in task 6, the structural engineer calculates the global construction weight of the project. This information is needed by the geotechnical engineer to determine the correct pile type for the project.

[8] Input Project data
The project data and the abutment module choices are inputted by the tool operator as shown in the first concept from chapter 4.4. Based on the chosen module, the geometric data is loaded into the input tab of the tool. This data will be used for the automated calculations of the tool, in the case of the first concept; the calculation of the deadweight.

[9] Automated Tool Calculations Excel
The automated structural design tool performs structural calculations in excel to calculate the deadweight of the abutment, the centre of gravity, and the eccentricity. This data is automatically inputted in the export tab of the tool to be exported to SCIA.

[11] Output Data Excel + [12] Input Data SCIA
The data resulting from the structural calculations is automatically inputted into export tab and then imported to SCIA via an import/export functionality between Excel en SCIA. Exchange Requirement 2 describes the required data.

[13] Automated Tool Calculations SCIA
With the necessary data imported to SCIA, SCIA creates a bar model of the abutment with the deadweight load and all of its characteristics projected on it. SCIA will then calculate resulting internal forces, the normal force, resulting shear, and resulting torque on the abutment.

[14] Output Data SCIA
The results from the second set of structural calculations is outputted back to Excel according to Exchange Requirement 3.

[15] Unity Checks Calculations
The results from step [13] need to be matched to the permissible forces and torques to make sure the overpass meets norms and regulations.

Gateway
[16] Meet standards?
The results from the unity checks offer two possible outcomes; If the results do not meet the norms and regulations, the input data has to be adapted and the process has to be start again. If the results meet the norms and regulations, the tool process finished and the results can be used in the rest of the design process.

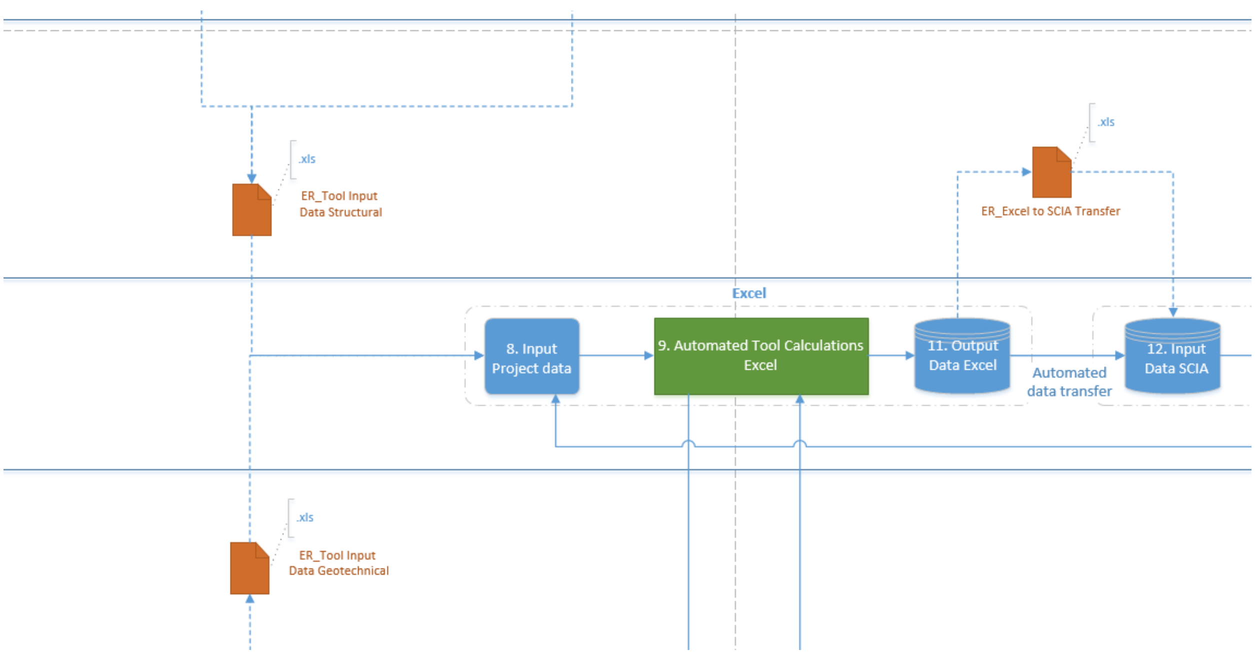


Figure 25 BPMN diagram structural design tool

Exchange requirements

The process map document further elaborates on the exchange requirements in their own sections of the document where the scope of the exchange requirement is discussed and where a general description of the exchange requirement is given. This general description discusses where the exchange requirement is placed in the BPMN diagram, when and by who it is used, and how the exchange requirement is structured. Finally the chapter gives the detailed exchange requirement with all the required data for the certain task at hand. The variables contained in the Exchange Requirements were collected from the calculation guidelines of the contractor which in turn are based on scientific theory. Based on the set scope of this thesis, first concept of the tool. and the BPMN, research has been done into which variables are needed to perform the main line- and point load calculations for the structural design of the overpass (Exchange Requirement 1). Also, the data characteristics of the resulting line- and point loads (Exchange Requirement 2), and the data characteristics of the resulting SCIA calculations (Exchange Requirement 3) were researched. To prevent the Exchange Requirements becoming too specific, extensive, and complex, the data characteristics of the loads and the resulting SCIA calculations were generalized to describe the needed data characteristics for, for example, a line load instead of each individual line load.

Down below, a part of the first exchange requirement “ER_Tool Input Data Structural" is displayed. The complete exchange requirement can be found in the process map document in Appendix 5. The exchange requirement uses the system breakdown structure of the overpass to structure the variables required for the input data. The numbers, as mentioned before, are used to apply order to the breakdown structure. 2110 Brug/Overpass is decomposed into elements 2111 and 2113 which are both abutments so they share the same information requirements. 2112 is the intermediate support and 2114 is the deck. For each element, the variables are grouped into geometric variables, and variables used to determine loads. 2114 deck has an extra grouping in load factors that are used in the calculations. The grouping material properties are structured under the object 2110 as they applicable to all elements.

Heijmans
Constructies & Geotechniek

heijmans

Project: Standaardisering viaducten
Onderdeel: Ontwerptool viaducten
Auteur: D. Boterman

* M – Mandatory | O – Optional | R – Recommended | N – Shall not be used
** Boolean, Integer, Real, String, Relation, Object type etc.

Exchange requirement for "ER_Tool Input Data Structural"

Object	Element	Grouping	Name	Variable	Definition	Variable mapping	Existance*	Value type**	Unit	Origin
2110 Brug/Viaduct										
		Materiaal-eigenschappen								
			Soortelijk gewicht beton	γ_{beton}	Het soortelijke gewicht van beton.	Mat_yBeton	M	Real	kN/m³	Eurocode
			Soortelijk gewicht asfalt	γ_{asfalt}	Het soortelijke gewicht van asfalt.	Mat_yAsfalt	M	Real	kN/m³	Eurocode
			Soortelijk gewicht grond	γ_{grond}	Het soortelijke gewicht van grond.	Mat_yGrond	M	Real	kN/m³	Eurocode
			Soortelijk gewicht water	γ_{water}	Het soortelijke gewicht van water.	Mat_yWater	M	Real	kN/m³	Eurocode
	2111/2113 Landhoofd									
		Geometrie								
			Overspanning		De totale overspanning van het viaduct.	LH_Geo_overspanning	M	Real	m	Project informatie
			$H_{1;max}$		Een afstandsvariabele voor de bepaling van het landhoofd.	LH_Geo_H1max	M	Real	mm	Module selectie
			$H_{1;min}$		Een afstandsvariabele voor de bepaling van het landhoofd.	LH_Geo_H1min	M	Real	mm	Module selectie
			H_2		Een afstandsvariabele voor de bepaling van het landhoofd.	LH_Geo_H2	M	Real	mm	Module selectie
			H_3		Een afstandsvariabele voor de bepaling van het landhoofd.	LH_Geo_H3	M	Real	mm	Module selectie
			H_4		Een afstandsvariabele voor de bepaling van het landhoofd.	LH_Geo_H4	M	Real	mm	Module selectie
			H_5		Een afstandsvariabele voor de bepaling van het landhoofd.	LH_Geo_H5	M	Real	mm	Module selectie
			B_1		Een afstandsvariabele voor de bepaling van het landhoofd.	LH_Geo_B1	M	Real	mm	Module selectie
			B_2		Een afstandsvariabele voor de bepaling van het landhoofd.	LH_Geo_B2	M	Real	mm	Module selectie
			B_3		Een afstandsvariabele voor de bepaling van het landhoofd.	LH_Geo_B3	M	Real	mm	Module selectie
			B_4		Een afstandsvariabele voor de bepaling van het landhoofd.	LH_Geo_B4	M	Real	mm	Module selectie
			B_5		Een afstandsvariabele voor de bepaling van het landhoofd.	LH_Geo_B5	M	Real	mm	Module selectie
			B_6		Een afstandsvariabele voor de bepaling van het landhoofd.	LH_Geo_B6	M	Real	mm	Module selectie
			L_1		De totale lengte van het landhoofd.	LH_Geo_L1	M	Real	mm	Project informatie
			B_{tot}		De totale breedte van het landhoofd.	LH_Geo_Btot	M	Real	mm	Automatisch berekend
			Lengte oplegblok	a	De lengte van het oplegblok.	LH_Geo_a	M	Real	mm	Module selectie
			Breedte oplegblok	b	De breedte van het oplegblok.	LH_Geo_b	M	Real	mm	Module selectie
			Hoogte oplegblok	T_e	De hoogte van het oplegblok.	LH_Geo_Te	M	Real	mm	Module selectie
			Glijdingsmodulus oplegblok	G	Het effect van het aanbrengen van schuifspanning op een oplegblok.	LH_Geo_G	M	Real	N/mm²	Automatisch berekend
			Hart op hart oplegblok	x	De hart op hart afstand tussen 2 oplegblokken.	LH_Geo_x	M	Real	mm	Eigen bepaling constructeur
		Belastingen								
			Eenheidslast	q_e	Een last die op het landhoofd en tussensteunpunt wordt gezet				kN/m	

Figure 26 Partial representation of exchange requirement: ER_Tool Input Data Structural"

4.6. TOOL DEVELOPMENT DISCUSSION

As has been discussed earlier in this chapter and also in the process map and exchange requirement document, the scope for the tool development only envelops a small part of the entire structural design process. The reasons for this have been discussed, but it is important to mention the limitations of said scope. The current scope allows for the calculation of the loads occurring on the bearing points of the abutments and the intermediate pier. The geotechnical part of the calculations, the influence of the foundations choice and the soil type on the construction, are included in the process diagrams but are not specified in the exchange requirements or in the first concept of the tool. This geotechnical part calculates what the maximal acceptable loads on the construction are going to be and these calculations are used to check the results of the occurring loads in the unity checks. Another important part not included in the scope is the determination of material of the construction; the entire overpass is not constructed in the same concrete class, each element has different characteristics which influence the maximum acceptable forces and torques on the construction. The same goes for reinforcement which is calculated in a later stage of the calculation process.

With the creation of power groups for module designing as discussed in chapter 3, the power groups do also have to establish which variables will be made standard and what variables will be parameterized. This chapter (4) has given an indication as to what type of variables are fit for standardizing and what variables are fit for parameterization, which can be used as a handle to further specify the conditions corresponding to either standard or parameterized variables.

Even though the overpass tool development has a long way to go, this chapter has provided the first step into said development. The first concept of the tool, the process map and exchange requirements that have been created can be used as a starting point to expand upon and keep adding more and more parts with their own exchange requirements to eventually create all the needed exchange requirements for the tool development and the tool operation. In the bigger picture, the develop data structure can be used to create an information library and in time may facilitate the inclusion of the structural calculations into the BIM models of the contractor.

5. Conclusion & Discussion

5.1. Research conclusions & scientific relevance

The research problem that sparked this research was:

"How can end product standardization improve civil building development and how can the design process be standardized in order to develop and implement end product standardization at a contractor?"

End product standardization, in the form of module based designing, can offer a lot of improvements over the current structural design process. By using the LEAN manufacturing technique Value Stream Mapping and translating the technique to the civil engineering branch, the design process of the contractor has been analyzed. This analysis showed a lot of room for improvement, mainly in the large amount of activities that have been classified as necessary waste and the amount of waste hidden in the process. To try and solve the problems of the current design process, an improved state design process has been proposed which includes an automated structural design tool. The structural design tool works, according to the modular approach, with standardized modules which consists of both standardized and parameterized variables. A first concept of the tool has been created to provide base on which the tool can be developed further. The operator inputs the project conditions and selects the modules to compose the overpass. For the question on what specific data is required by the tool and how the data should look like, a process map with a BPMN diagram and corresponding exchange requirements has been created for an established scope of the overpass structural design tool. To facilitate the exchange requirements, a data structure has been created based on the system breakdown structure of a overpass. The data structure of the overpass design tool proves to be a solid base but can be further enhanced by working together with the programmer to translate the data structure meant for defining input and output data, into a data structure that can also be used in coding. For the other users of the data structure, the structural engineer and the tool operator, the structure offers a solid and clear way to exchange required data. The data structure developed can also be used as a start of an information library where all data regarding the structural design calculations can be stored in a structured way. With the library, the mapping of variables in calculations all over the department can be equalized so that everyone works with uniform mapping. In the future, the library can be used on subsequent tool development projects and even with the implementation of BIM in the structural design process.

This conservative improved design process, a number of calculation activities have not been adopted into the structural design tool, is projected to reduce the overall total lead time of the design process by **18.2%.** The ratio value adding – necessary waste activities swings **23,3%** and **16,42%** (respectively for the client and the construction team) towards more time spent on value adding activities. When more and more activities are assimilated into the structural design tool, these percentages are expected to increase even further.

To implement the improved state design process, an implementation plan has been developed which can be found in Appendix 4. In it, a series of steps based on the Golden Circle Model of Simon Sinek has been proposed. This implementation process also utilizes Whole Scale Change theory opposed to more common change management theories. Whole Scale Change theory is deemed more suitable because it offers a wide approach to engage all stakeholders in the process of change.

If the contractor wants this initiative to succeed, it is imperative that there is a sufficient base among employees, even more so if the contractor wants to expand the modular approach from only the design phase to the procurement and realization phases as well (which they should because it will only increase the amount of advantages the approach brings to the table). Whole Scale Change will aid to create a sufficient base by involving stakeholders in an early stage.

End product standardization should be able to fit in the current market and contracts as long as the contracts allow sufficient design freedom and the clients are willing to void or change a few requirements to allow for the standardized end product. Talks with Rijkswaterstaat indicate that it is prepared to meet these conditions as long as contractors can prove the extra value standardized end products bring. It is up to the contractor to ensure enough variation range in the modules to make sure that the standard product is no 1-trick pony. It is also advisable for contractors to work together with an architect to design esthetic modules (for instance for the edge elements of a overpass) so that the tender meets the esthetic requirements of the client.

The civil engineering branch has been plagued by the high amount of failure costs for a long time now, resulting in very low margins across the market. A number of solutions have been tried, LEAN engineering is the latest and probably most successful technique used to decrease the failure costs. LEAN is already being used by a number of organizations in the civil engineering branch, but it has been used mainly to improve management processes and project schedules. Part of the LEAN philosophy, standardization has been used to create standard documents and standard approaches for relatively simple processes. This research offers an example how organizations can use LEAN and Value Stream Mapping to improve their more complex processes and try to reduce the high failure costs of the organization. It also offers an example of using BPMN to create a process map and exchange requirements with corresponding data structure for tool operation processes.

5.2. SOCIETAL RELEVANCE

This research also offers more societal benefits; building use a lot of resources, most of which cannot be recycled resulting in a massive drain on fossil materials. The initial benefits of this research are focused solely around the design phase of the project, creating more efficient processes and more efficient designs which already reduces the materials needed. But when the modular approach is adopted and implemented into more phases of the project, more and more USP will be added. The modular approach may even prove an opportunity for the contractor to establish a strategy for more durable infrastructural building where the concept of circular economy comes into play. With all the new developments in the building sector, 3D printing being one of them, it is not strange to at least consider the possibility of prefab modules that can be disassembled and reassembled at another project, increasing the life cycle of the module, in true Lego fashion. This would have major impact on the drain of fossil materials and would allow the civil engineering branch to move towards incredible durable projects.

5.3. Research discussion & Recommendations

During the thesis writing period, the direction of the thesis has been changed a number of times. Especially the tool development part has seen multiple action plans and corresponding research questions. These changes were partially to be expected because the scope of the research was very abstract, but some of the changes also occurred because of developments in the contractors' structural design department. As a result of the research done in this thesis, periodic consultations between management and researcher, and development targets set by the management, the decision has been made to start a first exploration into the viability of developing the automated structural design tool. While being part of change and innovation is great, this meant that certain goals of the thesis had to be re-assessed and adapted.

For the process management part of the research, all data gathered is based on human estimation and interpretation and is thus subjective. If other engineers would have been consulted, the results would probably be different. That being said, the differences would be small and the results would have still been positive. To improve the reliability of the results, more engineers should be interviewed. In an ideal situation the engineers should also be followed on a day-to-day basis to provide more insights into the hidden waste occurring in the process. Another influence to the results that has to be considered is that deciding if an activity is value adding or necessary waste will vary from person to person. The researcher and the management agreed that activities are only value adding when activities and their resulting products are directly used or reviewed by the end customer. An example, in this definition all the activities that are required to create a design, such as the calculations, modeling, etc, are regarded as necessary waste as only the design report is used or reviewed by the end customer. One might argue that those prerequisite activities are also value adding because there would not be a design report without those activities. When, instead of the first definition, the second definition would have been used, the results would show more value adding activities and less activities that are considered necessary waste. The swing in the value adding – necessary waste ratio would be lower. To verify and possibly solidify the used definition of value adding and necessary waste activities, a commission with design specialists from the contractor and people of the end customers, so both client and the construction team, should establish a definition on this subject for the contractor. It might even be lifted to a higher level by establishing a widely supported definition for the entire branch by including specialists from other contractors.

Because of time constraints, the scope for the tool development part was limited. The resulting first concept, BPMN diagram and exchange requirements should be further expanded with the parts of the automated structural design process that were outside the scope. The data structure that is developed and used for the existing exchange requirements can be used throughout the entire process. Another addition to the tool development part of the thesis would be the inclusion of the coding side of the data structure. The current focus has been on the front end of the automated structural design tool; the exchange requirements describe the needed input and output data for the tool, but it would also be valuable to create exchange requirements for the data moving inside the tool (back end) to give the programmers more structure.

If the contractor wants to continue with the development of the module based designing process and the implementation of the automated structural design tool, it is imperative that a solid plan of action is created that uses this master thesis as a base before anything is developed. The first step will be the expansion of the BPMN diagram and all the exchange requirements, both front end and back end. Then the formed power groups from the implementation plan should start with module designing and determining what variables are going to be standard, and what variables are going to be parameterized. The first modules to be created should be the ones with the highest use-rate, modules that are going to be used only once are not viable and should only be developed with high exception. With the first modules designed, creation of the automated structural design tool can start with guidance of the exchange requirements and the data structure. Over time, when the basis of the tool is working and the benefits are tested and clear, more modules can be added to the tool to increase the use-range of the tool. The contractor can then also start to utilize the standard product benefits described in chapter 2 by working together with preferred sub-contractors and by gathering more and more data on the standardized modules.

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7. APPENDICES

Appendix 1 – Research Design
Appendix 2 – Current Design Process
Appendix 3 – Improved Design Process
Appendix 4 - Implementing the Improved state structural design process
Appendix 5 - ER_Design Process_RiskAnalysis+TOMs
Appendix 6 - BPMN_Process Map and ER Structural design tool
Appendix 7 - BPMN - Structural design calculations ODT