Application of the principles of mass customization: standardisation and modularization, for an infrastructural object: a viaduct

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SUMMARY

Introduction

Within the current highly competitive and complex market of the construction industry, it is essential to be able to deliver projects that meet the requirements of the client in an effective and efficient way. However, traditional design practices in the construction industry seem to be unable to cope with the increased demands. The traditional way of delivering projects is not sufficient anymore; a new way of working will have to be adopted. In the construction industry, the possible implementation of the principles of the mass customization industry is one of the recurring themes to improve the current practices. It has been argued in recent studies that the performance of the construction industry can be improved by adopting methodologies that are applied in mass customization industries to increase the industrialisation and standardisation of design and production processes.

Companies within the construction industry are becoming increasingly aware of the potential that the implementation of the principles of mass customization, because of the potential advantages it can bring in time-efficiency and cost-efficiency. The expected benefits include greater flexibility in product design, efficiency in both product development and realisation, and effectiveness in both communication and market positioning. Even though the benefits of the principles of standardisation and modularization are promising, methods and practices that are successful in other industrial contexts cannot readily be transferred to the construction industry. The implementation of the principles of standardisation and modularization within the infrastructure construction industry are more complex compared to other industries, and it is questionable whether or not these are suitable for the construction industry. It has been emphasised that changes are needed to adapt the traditional project work processes and products to be able to apply these principles and create an optimum environment for the broader and more effective use of standardisation and modularization.

This thesis has researched the feasibility of implementing the principles of standardisation and modularization in the infrastructural sector in the construction industry, focusing on the infrastructural object: a viaduct. It investigates if a viaduct is suitable for the application of the principles and aims to explore possibilities, opportunities, barriers and limitations for the implementation of the principles of standardisation and modularization in the construction industry. The associated problem definition to this subject is: "*The company BAM Infra misses out on opportunities for the application of the principles of standardisation and modularization in the design and realisation phases of construction projects*".

In response to the problem defined a solution has been proposed: “*Implementing the principles of mass customization, by application of the principles of standardisation and modularization*". Various researchers have argued that the principles of standardisation and modularization can also be of value in the construction industry. The implementation of the principles can be beneficial for BAM Infra, as it thought they will: lower capital costs, improve schedule performance increase productivity, increase product quality, increase safety performance, reduce waste, as well as have better environmental performance, and communication benefits. This all comes down to the perceived main advantage of standardisation and modularization; the end product can vary in shape and have different functions while the design and production of components and modules within a product family can be shared. No design from “scratch” has to be made every time, designs can be pre-engineered and a constant process of optimisation can occur.

From this point of view, it is valuable to research if the principles of standardisation and modularization that are successful in other industrial contexts can be transferred to the construction industry. The main research question is thus: "*What are the opportunities/possibilities for BAM Infra to apply the principles of standardisation and modularization for viaducts?*" To achieve the objectives and answer the research question, the following three sub-questions have been formulated:

1. *What is already known in the literature about the application of the principles of mass customization within the construction industry?*
2. *Which components of a viaduct, can be identified that are suitable for standardisation and/or modularization?*
3. *How can the principles of standardisation and modularization be implemented, within the current strategy of BAM Infra?*

The research objectives have been achieved by evaluating answers to the sub-questions. The research objective of this research is formulated as follows: *Increase the flexibility and effectiveness of the utilisation of resources of BAM Infra, to stay competitive in the dynamic market.* The objective of this research is formulated as follows: *Propose how BAM Infra can implement the principles of standardisation and modularization for a viaduct.* From this objectives, four deliverables have been derived, and are included in this thesis. These deliverables are as follows:

1. *Analysis whether or not the principles of standardisation and modularization are suitable and can be beneficial for the application in the infrastructural sector of the construction industry.*

2. *Development of a method for the identification whether or not the application of the principles of standardisation and modularization for objects in the civil infrastructure sector are suitable, and to identify which components are interesting to standardise or to modularize.*
3. *Identification of viaduct components that are suitable for the application of the principles of standardisation and modularization (including general design and decomposition of a viaduct).*
4. *Advice for BAM Infra on how they can increase the flexibility and effectiveness of the utilisation of resources, by the implementation of the principles of standardisation and modularization in current circumstances within the company.*

Various steps have been taken to answer the formulated research questions. A literature review was conducted, to answer sub-question one. To answer sub-question two, the general design of a viaduct was analysed, and the approach of Vanessa Veenstra has been used as a guideline for the development of a method to identify which components of an infrastructural object are suitable for the standardisation and/or modularization. The method developed has been applied to a viaduct. In order to get a thorough understanding of the identified problem and the point of view of the proposed solution to implement the principles of standardisation and modularization, during all the phases of the research meetings took place and interviews were conducted with experts of BAM Infra. In addition, a survey was sent out, and interviews with other parties in the construction industry were held.

Literature review

The literature review has addressed sub-question one. As discussed in the previous section: the introduction, it has been argued that the implementation mass customization does have potential for the construction industry, and has been emphasised that modularity can be essential. The basic idea of mass customization is to improve the flexibility of the end product while maintaining standardisation and economies of scale. One of the most important core elements is that flexibility is needed, to counter possible causes of reluctance to standardisation. The flexibility can be maintained within standardisation by the application of the principles of mass customization: combining standardisation and modularization.

Projects within the infrastructural construction sector are engineered-to-order complex projects (CoPS) and are more one-off than mass-produced commodity goods. This makes it more complex to establish a product platform. The various characteristics of the construction industry hamper the implementation of the principles of standardisation and modularization. In addition, other barriers for the implementation have been identified, the main barriers considered are conservative industry culture, limited design freedom in current contract forms, strong focus on lowest bid price, norms and rules of governmental organisations, and lack of large-scale and repetition possibilities. However, the implementation of the principles is considered to be technically feasible. Removal of barriers is perceived to be essential for the implementation of the core elements of industrialised construction. However, out of the literature study it came that the main barriers perceived are caused by the client. This implies that to implement and benefit from industrialisation in the infrastructural sector, first, the client needs to adjust their approach. Also, the implementation of industrialisation requires cultural and attitudinal changes within the entire industry. It is essential that a mind-shift occurs. Identifying similarities among projects instead of merely their uniqueness is the first step towards increased industrialisation. The understanding, commitment, and cooperation by all parties are considered to be vital for successful implementation.

Identification of components and method developed

Based on the method of Vanessa Veenstra (Veenstra, Halman, & Voordijk, 2006), a method has been developed for the identification of components of an infrastructural object that are suitable to standardise or modularize. To identify whether or not a viaduct is suitable for the application of the principles of standardisation and modularization, and to identify which components are suitable, the developed method is applied. The method contains four phases:

- *Phase 1: Determine product architecture*
- *Phase 2: Examine interface: apply Design for variety method of Martin and Ishii.*
- *Phase 3: Determine coupling indexes*
- *Phase 4: Draw conclusion*

For the identification of components of a viaduct that are interesting to standardise or modularize, within phase 2 and phase 3, tables of the method were developed and filled in by five structural engineers. In the final phase, the outcomes of the tables were combined and analysed. By the analysis of the data, it was identified which components are interesting to standardise, standardise parametrical, to modularize or no clear conclusion can be derived. The outcome of the method is not leading. Going through the entire process provides the different participants with new insights that can be used for the application of the principles of standardisation and modularization. The structural engineers have become more aware of circumstances that have an influence on the design, the way the various components are connected and influence each other and what the consequences of certain design decisions are. These insights gained can contribute to the creation of new innovative ideas. The outcome of the applied method should be seen as a starting point for the implementation of the principles of standardisation and modularization, to eventually develop a product platform for a viaduct and should be discussed within the company. The method developed can also be applied to other infrastructural objects, to analyse if the application of the principles of standardisation and modularization are suitable, and components that are interesting to standardise or modularise can be identified.

Implementation and advice

To advice on the implementation of the principles of standardisation and modularization several steps have been taken. First, the established initiative where some form of standardisation and/or modularization has been applied were analysed. By having meetings and conducting interviews with experts that were involved in these initiatives, insights were gained considering why initiatives have been successful or unsuccessful. Lessons learned were identified and should be considered when a new initiative is launched. In addition, based on the lessons learned, literature and interviews, criteria that the new approach should meet were identified. These are: *establish a learning curve: constant feedback loops, client = king, continuously adapting and improving product and processes, clear trade-offs need to be made, clear communication and transparent information exchange, project team, should work autonomously, flexibility is needed: right balance is essential, early involvement of all disciplines, and a protocol should be applied.* In addition, the main changes in the market that are needed for implementing and fully benefiting from the new approach are: *more freedom in design, functional project description, a new way of working, and movement from market pull towards market push.* It requires effort from all parties involved, and a mind-shift will be required, to fully benefit from the principles of standardisation and modularization. Implementing the principles will not be easy, the construction industry has been a stable industry for many years, and current processes are based on this stable market.

Considering the implementation of the principles of standardisation and modularization within BAM Infra, there are various opportunities and possibilities. If BAM Infra decides to implement the principles for a viaduct or other infrastructural object, an advise is proposed to implements the principles gradually in two phases. Some steps need to be taken to improve current processes and some change in the way of working should be made to enable implementation of the principles in the future and make it less complex. The way of working needs to change; clear protocols need to be provided; a standardised interface needs to be developed; data most be gathered in a structural way by labelling current projects; people within the company need to be convinced and need to experience that the principles can contribute to their current practices.

Main points that need to be considered by BAM Infra if they want to implement the principles of standardisation and modularization are identified, these are the following:

- *Balance standardisation with flexibility*
- *Application of the method developed*
- *Knowledge management is vital: gather data in structured way*
- *Feedback loops are essential for optimisation*
- *A mechanism has to be developed to apply the principles based on the data gathered (configurator)*
- *Provide protocol: steps to take*
- *Create support and change the way people analyse problems and design solutions*
- *Development of a standardised interface independently of the tenders or projects.*
- *Possible for employees to suggest improvement: collect ideas*
- *Cooperation is essential: within and outside BAM Infra*
- *Trade-offs need to be made: management team eventually has to decide*

In addition, other points that will have influence on the possible implementation of the principles of standardisation and modularization that lay out-side the company are identified, these are the following:

- *Requires effort from all parties in the construction industry, and a mind-shift is needed*
- *Data is not the only constraint: Maturity of BIM*
- *Future is unknown: conduct market analysis on a regular basis*

Conclusion

Based on this research, it can be concluded that it is technically feasible to develop a viaduct composed out of standardised and modularized components by the application of a standardised interface. Although it will be complex to develop a standardised interface and develop a new way of connecting components. However, it was found that, despite the high complexity, the implementation of the principles of mass customization, standardisation and modularization, within the infrastructural sector of the construction industry has a very promising future. There are many opportunities and possibilities for construction firms to benefit from the application of these principles.

To benefit from the principles of standardisation and modularization, the way the current construction industry works has to change. This requires effort from all parties involved, and a mind-shift is needed. Within this research, the assumption is made that the current construction industry will change from a responsive pull market towards a more pro-active push market. Several developments can be observed affirming this assumption. Therefore, it is essential that BAM Infra already starts investing in this new approach, to be able to benefit from the change of the market situation when the described change will occur. If BAM Infra wants to implement the principles of standardisation, it advised to implement this gradually in two phases. The steps that need to be taken within these phases, considering short-term actions and long-term possibilities are formulated. New processes will need to be implemented, data needs to be collected in a structured way and a standardised interface needs to be developed. The lessons learned, criteria for a new approach and main points to consider identified in the research need to be taken into consideration.

Although the current circumstances in the construction industry hamper the implementation of standardisation and modularization, the main constraints identified for the implementation come from within the company. To successfully implement the principles the current way of working will have to change significantly. Processes need to be adapted, and clear protocols and databases need to be developed. However, the main barrier perceived is that the employees are sceptical. People within the company need to be convinced, they need to accept the new approaches and should change their way of thinking. Making people aware, providing clear protocols, constant feedback loops, application of trade-off matrixes and decision models, and effective and efficient knowledge management are identified as essential factors for BAM Infra to implement the principles of standardisation and modularization. By application of the principles, BAM Infra will be able to work in a more project-exceeding and facilitates continuously optimization of products and processes in an effective way, to stay competitive within the dynamic market of the construction industry. By implementation of the principles, BAM Infra will be able to cope with the increasing complexity and competition currently present.

PREFACE & ACKNOWLEDGEMENT

This thesis is the result of my research conducted for the completion of the Master program of the master Civil Engineering and Management at the University of Twente, carried out at the department multidisciplinary contract of BAM Infra in Gouda. This research investigates the potential application of the principles of mass customization: standardisation and modularization, for an infrastructural object: a viaduct.

This research is the final part of a two-years Master program, where I combined technical courses of the Master Civil Engineering and Management, and more management related courses of the Master Construction Management and Engineering. In my second year of my Master, I followed the course “Industrialization & Innovation in Construction” given by Joop Halman. This course made me very enthusiastic about industrialisation in the construction industry, considering the principles of mass customization and product platform development. Although the principles of standardisation and modularization are successfully applied in other industries, it is not clear if the application of these principles are also suitable and will be beneficial in the construction industry. Therefore, this research field has been proposed to BAM Infra for the assessment of a research. I wanted to investigate this manner and get a thorough understanding of the theoretical background and opinions within the literature of this research field and analyse the research field in practice. This with the goal in mind to provide a valuable scientific contribution to the research field, as delivering a valuable contribution to the company.

This research could not have been conducted without the academic and practical knowledge present in my graduation committee as my supervisors at BAM Infra. To mention the first, I want to thank my supervisors of the University: Joop Halman and Erwin Hofman, for their support and advice during this graduation route. Furthermore, I would like to thank BAM Infra and especially Jeroen Dunnebacke for providing me with the opportunity and freedom to perform this research at their company. An opportunity for which I feel very lucky. It was a great experience that would not have been possible without all the people that have contributed to this research. First of all thanks to my supervisors of BAM Infra for their support during the research and their valuable insights from the practices in the construction industry: Jeroen Dunnebacke, Bart Simons, and Gerard Waayer. Secondly, special thanks goes out to all colleagues at the department multidisciplinary contract, where I have conducted my research. From the beginning of the graduation project, I felt very welcome. In addition, I would like to thank the various professionals at BAM Infra. They were very helpful and open to share their knowledge, experience, and expertise. The enthusiasms, interests for my research and the willingness to share their experience, participate in interviews and the questionnaire survey shows a positive attitude of BAM Infra, and have been of great help.

Although the last six and a half years of studies, and in particular the graduation route has not always been easy. I, fortunately, found myself in the last stage of finishing the master Civil Engineering and Management. However, I could not have reached this stage without the support of my family and friends. Special thanks to Wouter for his everlasting support and relaxing moments during this journey. And last but not least, special thanks to my parents and sister, who have always been patient with me, pushed me to develop myself, and kept me motivated by pointing out to me that nothing is impossible.

After ten months of extensive research about the potential application of the principles of standardisation and modularization within the infrastructural sector of the construction industry, I can honestly say that the approach has a very promising future. However, the implementation of the principles of mass customization in the infrastructural sector of the construction industry will not be easy, and there is still a lot we do not know. We are only at the beginning of this journey.

Thank you all, and enjoy reading!

Ancella Stout
Delft, December 2016

TABLE OF CONTENT

DEFINITIONS

In this section definitions that are relevant to this research are given. The definitions are listed in alphabetical order.

BIM
Building Information modelling in this context is a representation of the development and use of process and products computer related model. BIM is the representation of design as parametric objects in 5D (meaning 3D, with planning and costs). Objects are thereby defined as parameters and relations to other objects, such that changes are made consistently throughout each different view, requiring only a singular action. The information accumulated with the building model serves as a shared knowledge resource. This includes data from all different disciplines. BIM-model forms a reliable basis for decisions throughout the total life cycle. A basic premise of BIM is a collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder. (Neelamkavil, 2009)

Complexity
The degree of complexity is concerned with the amount of differing but interrelated parts. (Cambridge dictionary online, 2016). *This definition implies that a project's complexity is defined by differentiation and interdependencies. Wood and Gadibo* (Wood & Gadibo, 2006) *suggest that there seem to be two perspectives of product complexity in the construction industry: a)The managerial perspective, this involves the planning of bringing together numerous parts of work to form workflow, b)The operative and technological perspective, this involves the technical intricacies or difficulties of executing a complex production process.*

Configurator
A Configurator is a design support system. Configuring a product is "putting together a product from well-defined building blocks (modules) according to a set of predefined rules and constraints. (Hvam, Martensen, & Riis, 2008). *Configurators exist to standardise and expedite the engineering design process by enabling the reuse of existing results and knowledge.*

Design rules
Design rules comprise testing standards to evaluate the modules' relative performance, and these standards allow a designer to verify whether a model conforms to the design rules and make sure it will function in the end-system (Baldwin & Clark, 2000).

Design for variety – method
Design for variety is a series of structured methodologies to help design teams reduce the impact of variety on the life-cycle costs of a product. It is a step-by-step method that aids companies in developing a robust product platform architecture that results in reduced design effort and time-to-market for future generations of the product, by using the concept of specification "flows" within a product development project. (Martin & Ishii, 2002)

Feedback
Feedback is the interaction between a system and its surroundings. When experience from practical use of a system is fed back, it becomes an input that shapes future improvements of the system correcting actions from actual to desired performance (Aström & Murray, 2009)

Flexibility
Flexibility within this research is twofold. Flexibility has been defined as: the ability to change or be changed easily according to the situation (Cambridge Dictionaries Online, 2016). *This definition means flexibility is the degree in which an infrastructural object can be adapted to changing circumstances over time, with as low required effort and as low environmental influence as possible. And secondly, flexibility has been defined as: the ability of a system, such as a manufacturing process, to cost effectively vary its output within a certain range and given a timeframe.* (Businessdictionary.com, 2016) *In this research content, flexibility means a quality enabling effective functioning of a system in terms of existing external conditions and with respect to internal operating capacity.* In other words, flexibility is the ability to response with an existing system on external influences. (Paslawski, 2008) In such a complex environment as the construction industry, a degree of flexibility is desirable.

Industrialization
Within this research industrialisation is defined as: a) producing more components of an infrastructural object by prefabrication (under factory conditions), the components that can be transferred to the construction site for fast assembly. Industrialisation considered to result in high quality, and for the assembly on the site less skilled craftsmanship is needed. The assembly of the different components is performed on the construction site. Therefore, the interfaces need to be easy to assembly. b) Various firms can develop and produce components that can be combined and together firm and infrastructural object. To achieve the interchangeability of components, the interfaces need to be standardised.

In-situ and precast concrete
There are two methods of fabricating reinforced concrete: 1) In situ concrete: pouring of concrete, pour the liquid material into moulds at the building site. 2) Precast concrete components (also called prefabricated concrete components) are manufactured in a central plant and later brought to the construction site for assembly.
Integral design
An integral architecture includes a complex (non-one-to-one) mapping from functional elements to physical components and/or coupled interfaces between components. (Ulrich, 1995)

Interface
A coupling between one or more components. In the context of an infrastructural object, an interface is a physical and functional coupling (a connection or joint) between the different components of the object. Interfaces ideally should be standardised to facilitate modularity. Gibb argues that standardisation works by ensuring accurate and interchangeability of components. Gibbs implies that the most important area for standardisation is the interface between the components rather than the components themselves. (Gibb, 2001)

Inter-firm modularity
An industry is characterised by inter-firm modularity when different firms are responsible for designing and developing the various subsystems of the industry's products. (Schilling, Toward a general modular system theory and its application to interfirm product modularity, 2000)

Mass customization
Mass customization in construction can be defined as an intermediate between mass production systems based on a make-to-stock approach to product realisation, and one of a kind engineer-to-order systems. In such intermediate systems, the structure and composition of the product (product architecture), must be designed and organised in a way that balances the contradiction between product variety and production volume (Blecker & Abdelkafi, Mass customization: State-of-the-art and challanges, 2006)

The definition given by Hart is "the use of flexible processes and organisational structures to produce varied and often individually customised products and services at the low cost of a standardised, mass-production system." (Hart, 1995)

Modular architecture
A modular architecture includes one-to-one mapping from functional elements in the functional elements structure to the physical components of the product and specifies decoupled interfaces between components. (Ulrich, 1995). *In a modular architecture, the components are interchangeable as long as the interfaces remain standardised. The interfaces are loosely coupled, providing possibilities for operations between the modules in the product architecture like substituting, augmenting or excluding* (Baldwin & Clark, 2000).

Modularity
In this thesis the definition of modularity comes from Shilling*: Modularity is a general system concept: it is a continuum describing the degree to which a system can be separated and recombined, and it refers both to the tightness of coupling between elements and the degree to which the rules of the system enable the mixing and matching of components' capabilities* (Shilling & Paparone, 2005). Shilling argues at the most abstract level modularity refers to the degree to which a system's components can be separated and recombined and the effect this has on the functionality of the system. In addition, *Langlois describes modularity as: "a very general set of principles for managing complexity. By breaking up a complex system into discrete pieces, which then can communicate with one another only through standardised interfaces within a standardised architecture. One can eliminate what would otherwise be an unmanageable spaghetti tangle of systematic interconnections"* (Langlois, 2002). *Furthermore, Baldwin describes modularity as: A strategy for organising complex products and processes efficiently. A modular system is composed of modules that are designed independently, but function as an integrated whole. Modularity can be distinguished in three aspects that are interrelated, namely: modularity in use, modularity in production and modularity in design.* (Baldwin & Clark, 2000)

Module
A module is a unit whose structural elements are powerfully connected among themselves and relatively weakly connected to elements of other units. Clearly, there are degrees of connection. Thus there are graduations of modularity. (Baldwin & Clark, 2000)

Parametric modelling
Parametric comes from the mathematics and is defined as a constant or variable term in a function that determines the specific form of the function but not its general nature, as a is f(x)=ax, where a determines only the slope of the line described by f(x). (Dictionary.com, 2016) *Within this research, parametric modelling is the process of object creation with defined parameters:*

involving distances, angles, and rules like attached, parallel to or distance from. By parametric modelling, a general design can be adapted (type appropriate) and scaled to dimensions that fit the specific situation occurring.

Dimensions
Dimensions are a measurement of length, width, and thickness. Within an infrastructural object, this also refers to the weight of components, depending on the materials applied. Parameters of the specific locational circumstances or parameters within the design of a viaduct will have an influence on the dimensioning of the design. By parametric modelling, a general design can be adapted to the specific situation occurring, by application of different types and scales of the components. The different types will have various dimensions. A component can be scaled to fit the specific circumstances, but this is not always optimal or possible. Another type of component can be better suitable. This means that the design can be adapted by changing its dimensions, but there are boundary conditions.

Process
Within this research, the definition of a process that was defined by Zairi (1997) is followed, namely: "A process is an approach for converting inputs into outputs. It is the way in which all the resources of an organisation are used in a reliable, repeatable and consistent way to achieve its goals". Zairi argues that a process has four key features (Zairi, 1997)*:*

1. *Predictable and definable inputs*
2. *A linear, logical sequence of flow*
3. *A set of clearly definable tasks or activities*
4. *A predictable and desired outcome or result*

Product architecture
The product architecture comprises (Ulrich, 1995)*:*
1. The arrangement of functional elements
2. The mapping from functional elements to physical components.
3. The specifications of the interfaces among interacting physical components
Ulrich makes a distinction between to different product architectures: modular and integral. For this research, the modular product architecture is the most important.

Product platform
Defined by McGrath as; "set of subsystems and interfaces that form a common structure from which a stream of related products can be efficiently developed and produced. (McGrath, 1995). *The leading principle behind the platform concept is to balance the commonality potential and differentiation needs within a product family.* (Halman, Hofer, & van Vuuren, 2003)

Quality
Quality is defined as: A measure of excellence or a state of being free from defects, deficiencies, and significant variations. It is brought about by a strict and consistent commitment to certain standards that achieve uniformity of a product to satisfy specific customer or user requirements. ISO 8402-1986 standard defines quality as "the totality of features and characteristics of a product or service that bear its ability to satisfy stated or implied needs." (Businessdictionary.com, 2016) *Within this research, quality reflects on the durability, significant variations and the ability to satisfy the different needs. In addition, within BAM Infra quality is also concerned with the quality of the processes on-site, referring to safety during construction.*

Standardisation
Standardisation is a work approach that is widely applied in different fields and sectors. Standardisation can be defined as, "the extensive use of components, methods or processes in which there is regularity, repetition, and a background of successful practice and predictability". (O'Conner, O'Brien, & Choi, 2015).

Standardisation is two-fold; a) the process of establishing the standard, and b) the process of complying with the standard. In this research, the standardisation is focused on the repetitive nature of a viaduct (concrete bridge) and revolves around the process of establishing the standards. It focuses on interface coupling and development of product platforms. The standardisation in this sense means the development of structures and structural elements based on the selection of the most technically and economically viable designs and therefore can be utilised for construction multiple times. (Kazbek-Kaziev, 1989)

Sustainability
Sustainability is defined as meeting the needs of the present without compromising the ability of the future generation to meet their own needs. (Brundtland, 1987) *Within this research, this refers to design civil constructions that have a low environmental impact (low use of materials, energy, and low construction waste). To accomplish this, the interfaces (platform) need to enable re-use and recycling of different elements of the design. This enhances the optimisation, which reduces waste.*

System Engineering
The general definition of a system is: A set of interrelated components working together as an integrated whole to achieve some

common objective. The System Engineering concept is a way of working that must guide and coordinate the design of each individual element as necessary to assure that the interactions and interfaces between system elements are compatible and mutually supporting. (Kossiakoff, Sweet, Seymour, & Beimer, 2011)

Viaduct (also can be name and overpass)
A Viaduct is defined in the dictionary as: A long elevated roadway, usually consisting of a series of short spans supported on arches, piers, or columns. With functions as a bridge.
In this research, the infrastructural viaducts of BAM Infra are reviewed. These viaducts are robust constructions made out of concrete with pre-tensioned steel inside. The components can be prefabricated in a factory and transported to the site for assembly. Or the viaduct can be constructed by an in-situ process.

PHASE ONE

Introduction

1 INTRODUCTION

In this Master thesis, the results of a research on the applicability of the implementation of the principles of standardisation and modularization within BAM Infra, mainly considering a viaduct, are presented. This research has been conducted in cooperation with the BAM Infra. This research is the final step for the completion of the master' program in Civil Engineering and Management at the University of Twente.

1.1 BRIEF DESCRIPTION OF THIS RESEARCH

The European construction industry is lagging behind other industries in taking advantages and benefits of new technologies and innovative practices (Nadim & Goulding, 2011) (Harty, 2008). In many industries, the concept of modularity is rapidly further developed. However, the use and development of the modularization concept in the construction industry are still limited (Teichholz, 2001). The companies within the construction industry are constantly struggling with the power of flexibility given by project management of complex systems and the efficiency of using standardisation of product and process (Jansson, Johnsson, & Jensen, 2013). It has been argued in recent research that the performance of the construction industry can be improved by adopting methodologies that are applied in mass customization industries to increase the industrialisation and standardisation of design and production processes (Larsson, Eriksson, Olofsson, & Simonsson, 2014) (McGraw-Hill Construction, 2011).

Even though the benefits of the principles of standardisation and modularization are promising, methods and practices that are successful in other industrial contexts cannot readily be transferred to the construction industry. Changes are needed to adapt the traditional project work processes and products to create an optimum environment of a broader and more effective use of modularization (Bresnan & Marshall, 2001).

Here, insufficiency of already conducted research occurs. It is not clear if the principles of standardisation and modularization are suitable for large civil construction projects. As the principles have not yet been applied in the infrastructural sector, only some small steps towards standardisation have taken place. This research investigates the applicability of the implementation of the principles of standardisation and modularization in large civil construction works. It will be conducted at the company BAM Infra, mainly about one specific object: a viaduct.

1.2 BACKGROUND – CONTEXT

As explained in section 1.1, the application of the principles of standardisation and modularization, in the construction industry, is still limited. Currently, most projects and specific objects in the construction industry are viewed as "one-of-a-kind". Although this is true, as each project has diverse local circumstances and diverse requirements, there is also a certain degree of repetition in the various construction projects. Many construction products are built to a common building code. Many products in a given product category will have similar or identical functional requirements (Jensen, 2014)*. This research investigates whether the implementation of the principles of standardisation and modularization can also be applied to an infrastructural object: a viaduct.*

1.2.1 INDUSTRIALISATION OF THE CONSTRUCTION INDUSTRY

The current construction industry is characterised as an engineer-to-order project-oriented industry. However, the industry is experiencing a paradigm shift to be able to meet the new market requirements from clients (Azhar, 2011). Clients are demanding projects with higher quality, a higher degree of sustainability, reduced life cycle costs, reduced lead times, and higher design efficiency. Within the current highly competitive and complex market of the construction industry, it becomes essential to be able to deliver a project in an effective and efficient way. The construction companies have to deliver projects that meet the requirements of the client, have sufficient quality, and need to be delivered on time and within budget (Davies & Brady, 2000). The traditional design practices in the construction industry seem to be unable to cope with the demanded increased efficiency. Numerous companies are investigating new techniques to remain competitive in the industry. The traditional way of delivering projects is not sufficient anymore, a new way of working will have to be adopted. (Larsson, Eriksson, Olofsson, & Simonsson, 2014)

Companies within the construction industry are becoming increasingly aware of the potential that the implementation of the principles of mass customization can have for the construction industry. The implementation of the principles of mass customization is mainly driven by the time-efficiency and cost-efficiency that this can bring. The expected benefits include greater flexibility in product design, efficiency in both product development and realisation, and effectiveness in both communication and market positioning. According to Halman, Hofer and van Vuuren, the key to staying competitive is to organise business processes in a limited amount of time and this in a time-efficient and cost-efficient manner (Halman, Hofer, & Vuuren, 2003). These possible beneftis resulted in increasing focus on the platform concept. The companies within the construction industry are constantly struggling with the power of flexibility given by project management of complex systems and the efficiency of using standardisation of product and process (Jansson, Johnsson, & Jensen, 2013). The basic idea of mass customization is thus to improve the flexibility of the end product while maintaining standardisation and economies of scale (Tseng & Jiao, 2001). This is also applicable for BAM Infra; it is essential for BAM Infra to deliver variability (different circumstances) in an economical way.

Within literature the need to move from an engineer-to-order, by which we mean pure customization, towards more standardisation by benefiting of the repetition that occurs has been put forward (Jensen, Olofsson, Smiding, & Gerth, 2014). There are diverse opinions about whether or not the principles of mass customization can be applied in the different sectors of the construction industry. Opponents of standardisation contend that it is not applicable because all construction works are seen as unique; they are one-of-a-kind and require customised designs. Moreover, when there is openness for the development of implementing the principles of mass customization within the construction industry, people remain sceptical if the principles can be successfully applied in the construction industry. Opponents of standardisation argue that volumes are too low, as not enough repetition occurs. The inherently one-off nature of the infrastructure sector means that each project is different, making it difficult to achieve the degree of repetition and routinization necessary to benefit from the principles of mass customization. (Bresnen & Marshall, 2001) (Jensen, 2014) (Winch, 2003) (Jensen, Larsson, Simonsson, & Olofsson, 2013). Ulrich (1995) is one of the first who identified the concept of modularization. Although he believes in the principles of standardisation and modularization, he argues that this is only suitable for the housing industry. Ulrich argues that a shift from design processes at the engineer-to-order specification level towards more standardised processes would enable the incremental industrialisation of the other parts of the production realisation process. However, predefined solutions can only be used to address specific functional requirements if the platform architecture is based on a modular design (Ulrich, 1995).

There are also proponents of the implementation of the principles of the mass customisation industry, within the construction industry, and who have emphasised the essence of applying the principles of mass customization in construction (Gerth, 2013) (Malmgren, 2013) (Ballard & Howell, 1998)(Vrijhoef & Koskela, 2005) (Koskela, 2000) (Voordijk, Meijboom, & de Han, 2006) (O'Conner, O'Brien, & Choi, 2015) (Erixon, 1998). Erixon (1998) argues that implementing standardisation and modularization is central to benefit from the occurring repetition (Erixon, 1998). The researchers argued that the principles of mass customization can be employed to increase the effectiveness and efficiency of project and processes in the construction industry. Designs can be pre-engineered, and a constant process of optimisation can occur. This means that there seems to be indeed scope and opportunities for implementing the principles of standardisation and modularization in the construction industry. However, applying the principles of standardisation and modularization in construction is challenging since the requirements generally require more flexibility than the predefined modules can deliver (Jansson, Johnsson, & Jensen, 2013).

This research will analyse the standardisation and modularization potential of a viaduct. It is important to note that BAM Infra intends to use the research on standardisation and modularization of a viaduct for further development, with the vision to eventually develop a product platform. To develop the product platform, research and analysis have to be conducted into how to create and structure a modular design for a viaduct. This research focusses on which elements/components of a viaduct are suitable for applying the principles of standardisation and modularization. Next, it will be determined what the first steps for BAM Infra are to take when implementing the principles of standardisation and modularization for a viaduct. This with the point of view in mind that eventually a product platform for a viaduct will be beneficial and can be established by BAM Infra. However, before we can make such assumptions, we have to investigate further if the principles of standardisation and modularization are possible and preferred.

1.2.2 Main drivers

The main reason why BAM Infra desires to change their way of working is to be able to fulfil the projects the market demands. To that end, the management team of BAM Infra is looking for new ways to compete in the dynamic market. They are seeking ways to distinguish themselves and increase their efficiency and effectiveness; this will be affected by delivering the best value (EMVI: price vs. quality ratio) for the client, compared to other competitors within the current and future market of the construction industry. To establish this, it will require flexibility and effectiveness on the part of the utility of resources, to be able to deliver the best value for the client and to stay ahead of the competition. (BAM, 2016)

Within BAM Infra, time, costs, and quality are the three main elements that their projects will revolve around. Most decisions and trade-offs that need to be made in a project are based on analysing the effect that different choices have on these three main elements. (BAM, 2016)

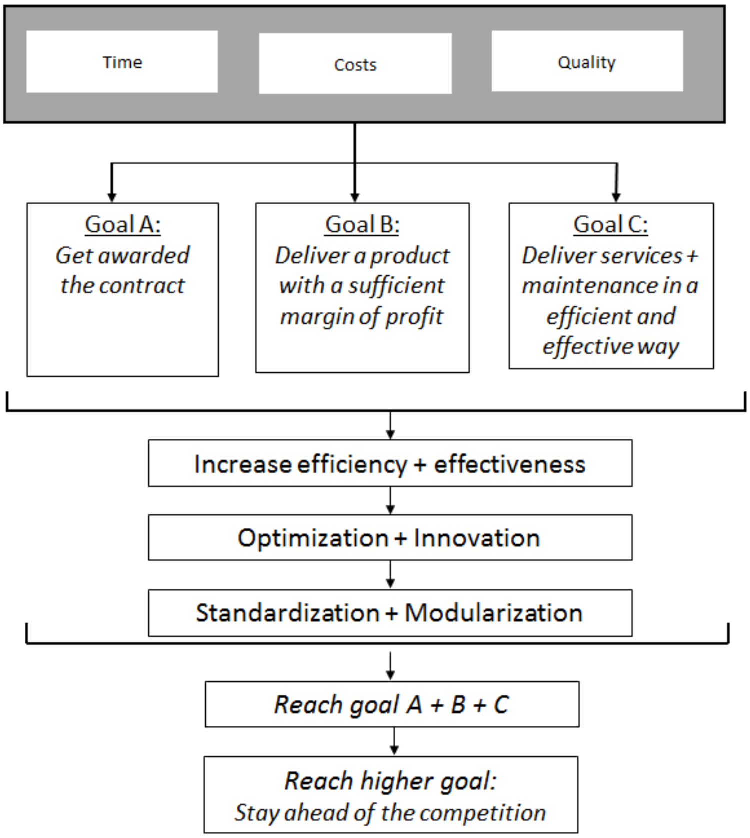
For the continuity of BAM Infra, three points within the total cycle of projects are essential (BAM, 2016).
A*) Goal: Acquisition of projects (Get awarded the contract)*
It is essential that the company can design a project within a limited space of time. The design should meet the listed requirements of the client for the best value, this will be based on the lowest price, considering price vs. quality according to the EMVI criteria. However, this demands an efficient and effective approach and the proposed design should be realistic, in such a way that it can be realised by the construction company. This phase is important for the company, as the goal is to get awarded

the contract and then work it out in a higher level of detail and construct the agreed to design. BAM Infra needs to procure sufficient contracts to create revenue and establish profit, so the organisation can develop itself further and remain competitive.

B*) Goal: Deliver a product with sufficient profit margin*
In addition to being awarded a sufficient number of contracts. In addition, it is essential that these projects are profitable. As explained above, the design of the awarded contract needs to be worked out in greater detail, in view of the product and the process. Here it is important that the tender design is realistic and that it can be constructed for the agreed to budget. The project has to be constructed for less than the budget of the awarded contract; a sufficient profit margin can be realised. Thus, constant trade-offs need to be made, during the further development and planning of construction projects.

C) *Goal: Deliver services and maintenance in an efficient and effective way, considering the total life-cycle of the products.*
Due to the new contract forms, referring to DBFM(O), it has become more important for BAM Infra to consider the total life-cycle of their constructed products. It is essential to consider the maintenance and services aspects already in the early design phase. Trade-offs will need to be made, considering the total life-cycle of the products.

A + B + C) Higher goal: Stay ahead of the competition
BAM Infra is aware that they are "reinventing the wheel" for every project (viewpoint of the management team) (BAM, 2016).The company is, therefore, looking for a way to improve its design and construction processes. Becoming more effective and efficient, through optimisation and innovation, is essential for the continuity of BAM Infra. This will ensure that Goal A, B, and C; to get awarded the contract, deliver a project with sufficient profit and deliver services and maintenance in an efficient and effective way, considering the total life-cycle of the products, can be realised now and in the future.



1—1Flow chart – Main drivers of BAM Infra to reach the higher goal: stay ahead of the competition.

1.3 PROBLEM DESCRIPTION

1.3.1 Changed circumstances

Infrastructural projects become larger and more complex (Pavez, Gonzalez, & Alarcon, 2014). Most companies have problems to deal with this dynamic complexity. Mainly due to the increasing dynamic complexity, the productivity of the construction industry worldwide has been declining over the past 40 years (Aziz & Hafez, 2013). Bertelsen (2003) emphasises that the construction industry should be seen as a dynamic complex system. In the construction industry, market changes rapidly. It has become a dynamic changing industry (Bertelsen, 2003).

The changes observed and analysed by the researcher, can be classified into three categories involving; the market shift increased competition and increased complexity (see Appendix A.1). These new circumstances have a significant impact on construction companies. The way that construction companies worked before are not suitable any longer, as this way of working does not fit with the new circumstances (BAM, 2016). The strategy of BAM Infra will need to be adapted to the new situation, this to stay competitive in the dynamic market of the construction industry.

1.3.2 Problem identification

This research focusses on the company BAM Infra. As discussed in section 1.2.1, the company BAM Infra is struggling with how they should adapt their strategy/way of working to the new circumstances within the construction industry. Their current way of working is not suitable anymore; a new approach is needed (BAM, 2016). To develop a new approach, it is important to analyse the developments within the construction industry (external developments) and the developments within the company (internal developments). In Appendix A.1, the external developments and the internal developments are listed. Based on the external and internal developments two cause-and-effect-diagrams have been presented and explained in section 1.3.4.

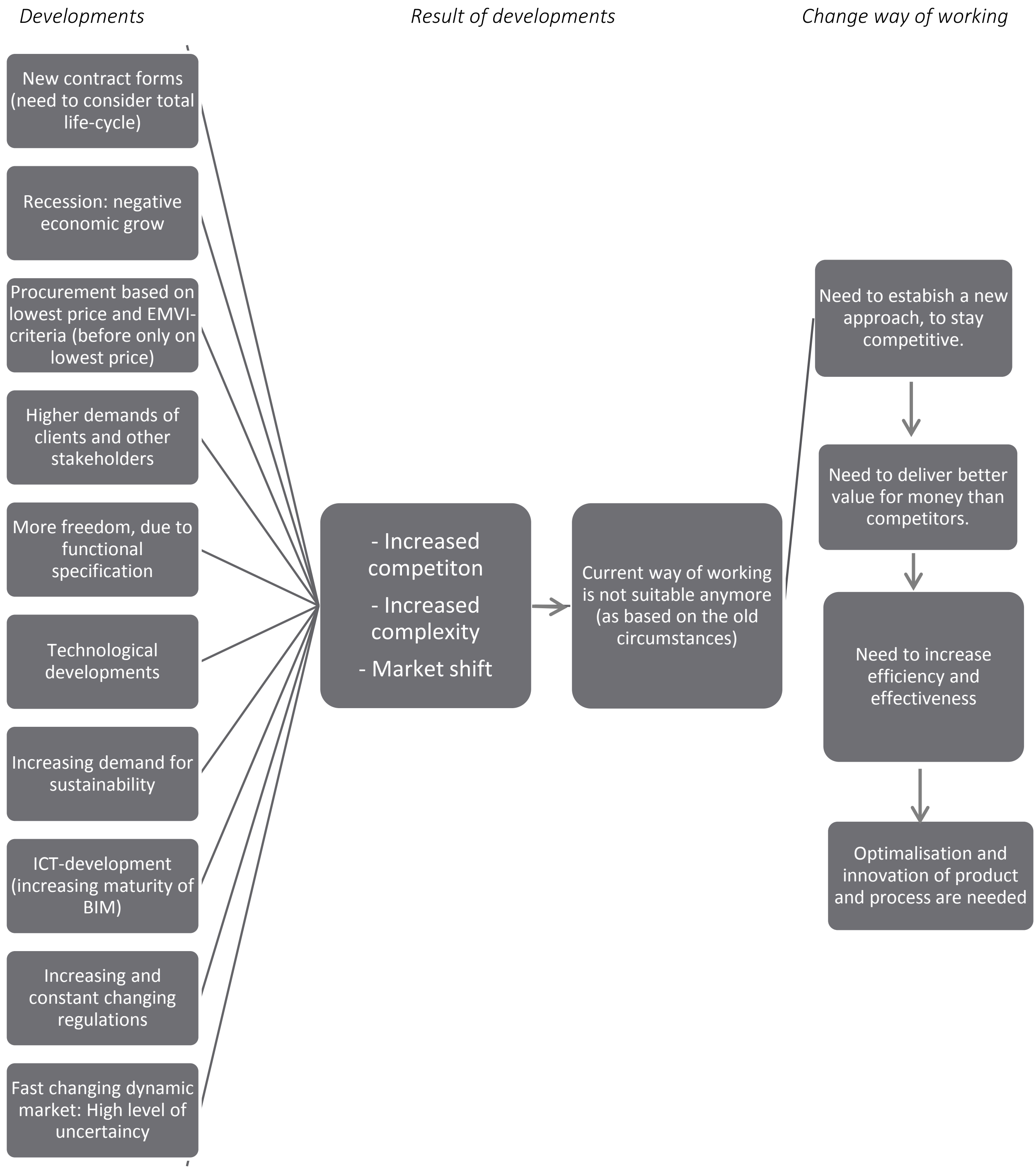
1.3.3 Cause-and-effect-diagram: Changed market situation

The cause-and -effect diagram considering the changed market situation of the construction industry is presented in figure 1-2.The different developments within the construction industry are listed on the left. These are based on a review of the literature, analyses of current practices and the conduction of interviews. In Appendix A.1 and A.2, the identified developments are explained. These developments can be summarised into three main categories: Increased competition, increased complexity and the occurrence of a market shift. The new developments have a significant impact on the current way of working within construction companies. The current way of working is not suitable any longer. For construction companies to remain competitive in the dynamic market of the construction industry, a new approach is needed. The construction companies need to deliver better value for money than their competitors. Therefore, they have to increase their efficiency and effectiveness, considering both product and process. To achieve this, it is essential to optimise and innovate both products and processes constantly. (Jansson, 2013) (Jensen, Olofsson, Smiding, & Gerth, 2014) (Eriksson, Olander, Szentes, & Widen, 2014). (Davies & Brady, 2000). Innovation in infrastructure projects cannot be neglected since it is central to improving productivity referring to both efficiency and quality (Tawiah & Russell, 2008).

1.3.4 Cause-and-effect-diagram: BAM Infra

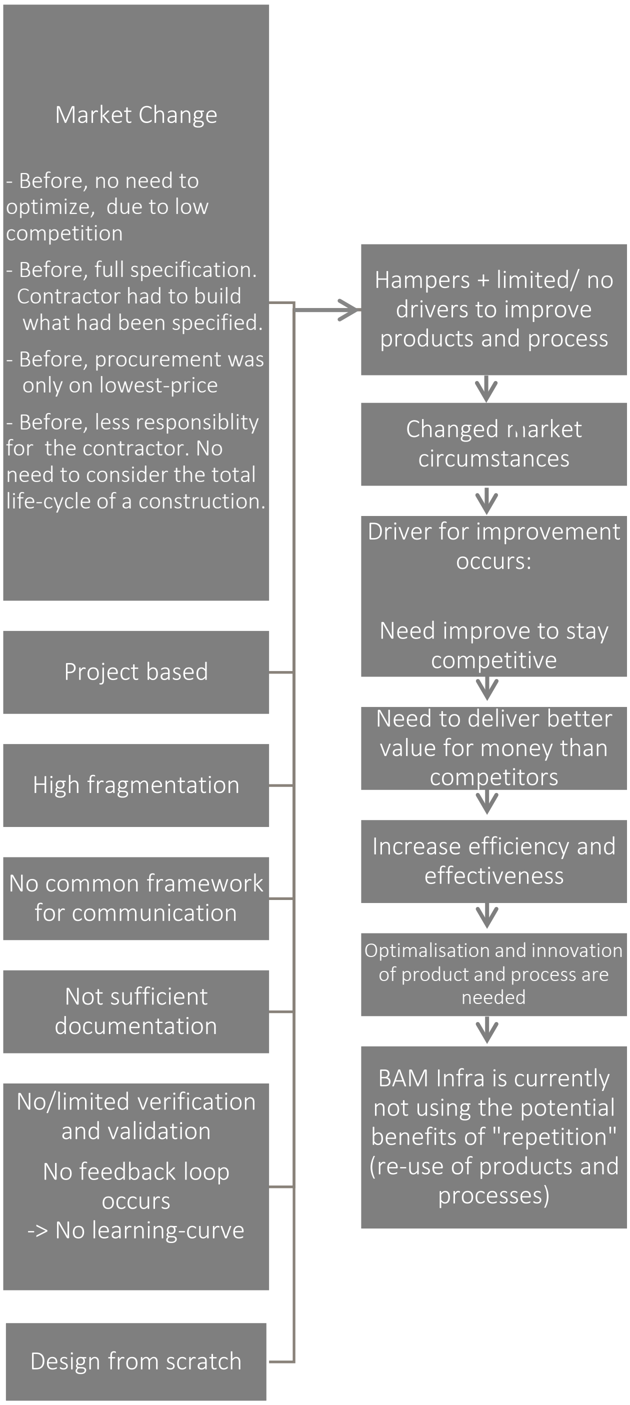
The cause-and-effect diagram considering BAM Infra is presented in figure 1-3. The company's practices are based on the "old" market conditions. These practices should be continuously adjusted to the current situation. The "old" market conditions combined with characteristics and way of working within BAM Infra, do not provide drivers to improve products and processes, and even hampers this process (Larsson, Eriksson, Olofsson, & Simonsson, 2014). Due to the changed market circumstances (as visualised in the cause-and-effect-diagram: changed market conditions), a driver for improvement occurs. This has been discussed in section 1.3.3; the company needs to deliver better value for money than their competitors. The companies need to increase the efficiency and effectiveness of products and processes (Davies & Brady, 2000). The problem of inefficiency in the construction industry is due to repeat routine design tasks without reusing past knowledge, causing unnecessary duplication of effort. To increase the efficiency and effectiveness of construction companies, continuous optimisation and innovation of products and processes are essential (Tawiah & Russell, 2008), (Jansson, 2013) (Jensen, Olofsson, Smiding, & Gerth, 2014) (Eriksson, Olander, Szentes, & Widen, 2014)

<u>*Cause-and-effect-diagram: Changed market situation*</u>
This figure illustrates the changed market situation within the construction industry; this has been explained in section 1.3.3.



1—2 Cause-and-effect-diagram: Changed market situation

Cause-and-effect-diagram: BAM Infra
This figure illustrates the characteristic of BAM Infra combined with the changed market situation within the construction industry. The companies need to increase the efficiency and effectiveness of products and processes to stay competitive. This has been explained in section 1.3.4.



1—3 *Cause-and-effect diagram: BAM Infra*

1.4 Problem Definition

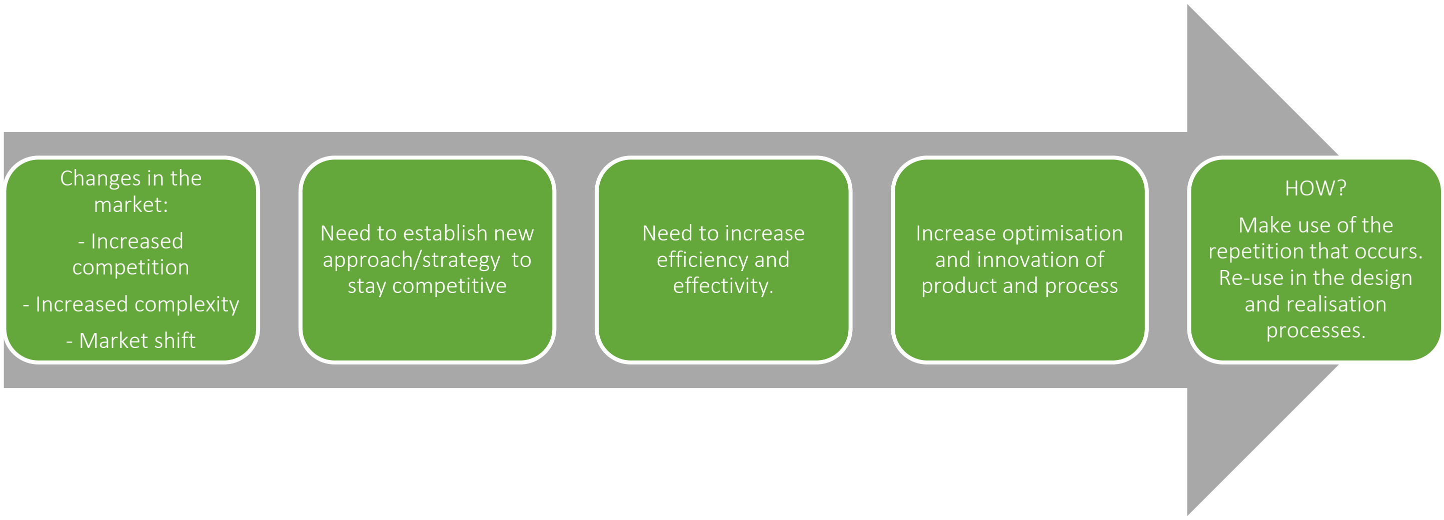
In this research, it has been observed and analysed that BAM Infra is currently not benefiting from the opportunities of repetition in the construction industry. BAM Infra is constantly "reinventing the wheel"; they design every object from scratch, although the repetition of products and processes does occur (BAM, 2016). Since products and processes are not reused, the company misses out on the potential opportunities of repetition. This is based on interviews that have been conducted with the employees of BAM Infra and observation of the current way of working at BAM Infra. The company should use the opportunities that repetition brings, as it will help to optimise and innovate products and processes constantly.

1.4.1 Problem statement

Based on external and internal developments, as listed in Appendix A.1 and visualised in the cause-and-effect-diagrams in paragraph 1.3.4, the following main problem has been identified.

Problem statement:

The company BAM Infra misses out on opportunities for the application of the principles of standardisation and modularization in the design and realisation phases of construction projects.



1—4 Flow chart of the identified problem

The BAM Infra management team is looking for new ways to compete in the dynamic market. They are seeking ways to distinguish themselves and increase their efficiency and effectiveness by delivering the best value (EMVI: price vs quality ratio) for the client, compared to other competitors within the current and future market of the construction industry. This requires flexibility and effectiveness of the utility of resources, to be able to deliver the best value for the client and to stay ahead of the competition. Therefore, within this research a possible solution will be studied: Implementing the principles of mass customization, by applying the principles of standardisation and modularity. BAM Infra intends to use the research on standardisation and modularization of a viaduct to gain insights about the implementation of the principles of mass customization within their current strategy. Implementing the principles of standardisation and modularization is with the vision of eventually develop a product platform for a viaduct.

1.4.2 Proposed solution

Based on the cause-and-effect diagrams, problem statement and the external and internal developments mentioned in section 1.3 and 1.4, a solution in response to the identified problem has been proposed to investigate.

The proposed solution in response to the identified problem*:*
Implementing the principles of mass customization, by application of the principles of standardisation and modularization.

Within this research, three core aspects have been identified: complexity, learning curve and communication. In Appendix A.2 this will be elaborated on further, and the main reason and viewpoints why the implementation of standardisation and modularization needs to be investigated are explained.

1.5 RESEARCH OBJECTIVES AND QUESTIONS

This research will address the potential applicability of the principles of standardisation and modularization for a large infrastructural object: a viaduct. The research design will be discussed in this section. First, the objective of this research is stated, this is the higher goal of this research. Second, the objective of this research will be stated; this is the goal of the proposed research itself. The main research question will be derived from the objectives of this research, hereafter the sub-questions are formulated.

1.5.1 Objective of this research

- *Increase the flexibility and effectiveness of the utilisation of resources of BAM Infra, to stay competitive in the dynamic market.*

1.5.2 Objective within this research

- *Propose how BAM Infra can implement the principles of standardisation and modularization for a viaduct.*

1.5.3 Main research question

In order to achieve the research objective, as previously stated in section 4.1.1 and 4.1.2, the following main research question is defined as:

> ***What are the opportunities/possibilities for BAM Infra to apply the principles of standardisation and modularization for viaducts?***

1.5.4 Sub-questions

To achieve the research objectives and answer the main research question, the following sub-questions are derived from the main research question:

1. ***What is already known in the literature about the application of the principles of mass customization within the construction industry?***
   1. *What is the theoretical background of standardisation, modularization, and a product platform? And what are the main insights that can be derived from literature?*
   2. *What opportunities and risks for implementation of the principles of the mass customization industry are there for firms?*
   3. *Are the principles of mass customization also applicable for the construction industry, considering the characteristics of a civil infrastructure project, and how can these be implemented?*
   4. *Which challenges, circumstances, and perceived barriers make the implementation of the concepts of standardisation and modularization hard to accomplish in infrastructural projects in the construction industry?*
   5. *What factors are considered to be essential for successful implementation of the concept of standardisation and modularization, referring to a product platform?*
2. ***Which components of a viaduct, can be identified that are suitable for standardisation and/or modularization?***
   1. *Is there potential for the implementation of the principles of mass customization in the current market of the infrastructural sector of the construction industry, considering the main characteristics of infrastructural projects?*
   2. *What is a general design of a viaduct? (considering main practices in the Netherlands)*
   3. *What practices, related to standardisation and modularization, in viaduct development have been recently established by BAM Infra?*
   4. *How can it be identified whether or not the application of the principles of standardisation and modularization for objects in the civil infrastructure sector are suitable, and which components of a viaduct can be identified to be suitable for standardisation and modularization?*
3. ***How can the principles of standardisation and modularization be implemented, within the current strategy of BAM Infra?***
   1. *What lessons can be learned from the successes and failures of already established initiatives/projects considering the principles of standardisation and modularization, from within the company BAM?*
   2. *What are the criteria for the new approach, to benefit from the principles of standardisation and modularization, and to eventually establish a product platform for a viaduct?*
   3. *How can the principles of standardisation and modularization be implemented and what are important points to note and steps to take, to be able to benefit from the principles and to provide continuous optimisation and innovation?*

1.6 RESEARCH DESIGN AND FRAMEWORK

1.6.1 Research approach

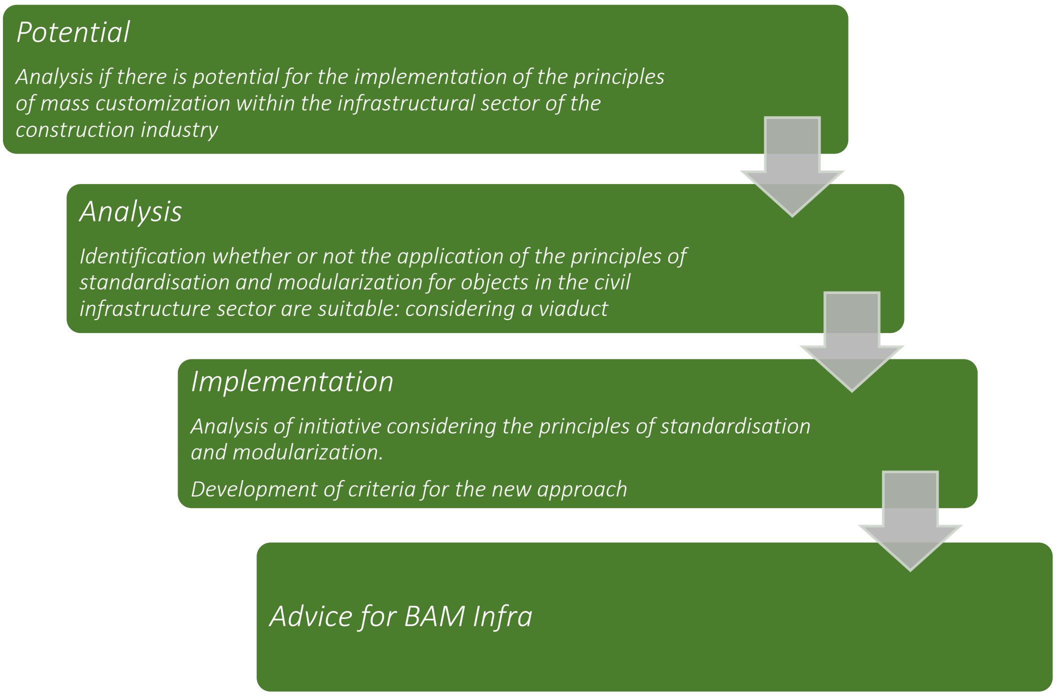
To answer the sub-questions and hereby the main research question, a systematic and scientific approach for the conducting this research is needed. The approach that will be applied to conduct this research will be discussed in this section.

1.6.1.1 Research strategy - Phases

This research has been divided into three phases. The report is divided into five chapters; these are illustrated in figure 1-5.
In figure 1-6, an illustration of the different phase run through in this research is given. In Appendix A.3 an extensive explanation about the research strategy is given.

1—5 Structure of the report

The research can be divided into three phases. The first phase analysis whether or not there is potential for the implementation of the principles within the infrastructural sector of the construction industry, more specific: BAM Infra. The second phase contains the first part of the empirical research. In this phase, the general design of a viaduct and current practices of BAM Infra considering standardisation of viaducts have been analysed. Hereafter, a method was developed for the identification of components that are suitable to standardise or modularize, for an infrastructural object. Furthermore, the method was applied for a viaduct, and components that are suitable for standardisation or modularization are identified. The final phase contains the second part of the empirical research. The phase analysis initiatives within BAM Infra considering the implementation of the principles of standardisation and modularization. Hereafter, criteria for the new approach, to benefit from the principles of standardisation and modularization are identified, and a suggestion for the implementation of the principles and continuous optimisation of products and processes are given. Based on these three phases an advice for BAM Infra has been formulated.



1—6 Phases of this research

1.6.1.2 Literature review – Method

In the first phase of this research, a literature review was conducted on the principles of standardisation and modularization and the application of these principles in the infrastructural sector of the construction industry. The search engines Google Scholar, Scopus, and ScienceDirect are used to search for literature on the research topic. In addition, literature was collected from courses of the Master program Construction Management and Engineering at the University of Twente and literature that has been suggested by Prof. dr. ir. J.I.M. Halman is reviewed. In Appendix A.3, a more extensive explanation of how data for the literature review was collected is given. This in favour of transparency and replicability of the research.

Theoretical framework (and formulating research question and methods) contains the following aspects:

- a. *Background*
- b. *Problem identification*
- c. *State research objectives*
- d. *State research questions*
- e. *Research methodology*
- f. *Literature review*

1.6.1.3 Empirical research: Analysis

In this section, the research approach for the empirical research will be discussed.

Analysis contains the following aspects:

- a. *Analysis if there is potential for the implementation of the principles of mass customization within the infrastructural sector of the construction industry*
- b. *Analysis of general design of viaduct*
- c. *Analysis of current practices of BAM Infra considering a viaduct: review of projects.*
- d. *Identification whether or not the application of the principles of standardisation and modularization for objects in the civil infrastructure sector are suitable.*
    - i. *Development of a method for the identification whether or not the application of the principles of standardisation and modularization for objects in the civil infrastructure sector are suitable, and to identify which of components are interesting to standardise or to modularize.*
    - ii. *Application of the method for a viaduct, to identify components that are suitable and interesting to standardise or modularize.*

1.6.1.4 Empirical research: Implementation

Implementation contains the following aspects:

- e. *Review initiatives within the company BAM Infra, considering standardisation and/or modularization.*
- f. *Development of criteria for the new approach*
- g. *Propose how the principles of standardisation and modularization can be implemented within BAM Infra, and identify important points to note and steps to take, to be able to benefit from the principles and to provide continuous optimisation and innovation.*

1.6.1.5 Synthesis: Advice and Discussion

In this part of the thesis, an advice for BAM Infra is presented. The advice is based on the insights derived in the literature review and empirical research.

The synthesis contains the following aspects:

- a. *Advice for BAM Infra*
- b. *Discussion*
    - i. *Discussion of results - General limitations*
    - ii. *Discussion of results – Technical*
    - iii. *Discussion of results - Advice*
    - iv. *SWOT-analysis*

1.6.1.6 Conclusion

- a. *Conclusion*
    - i. *Summary of the answers to the research sub-questions*
    - ii. *Answer to the main research question*
- b. *Suggestions for further research*

1.6.1.7 Deliverables of this research

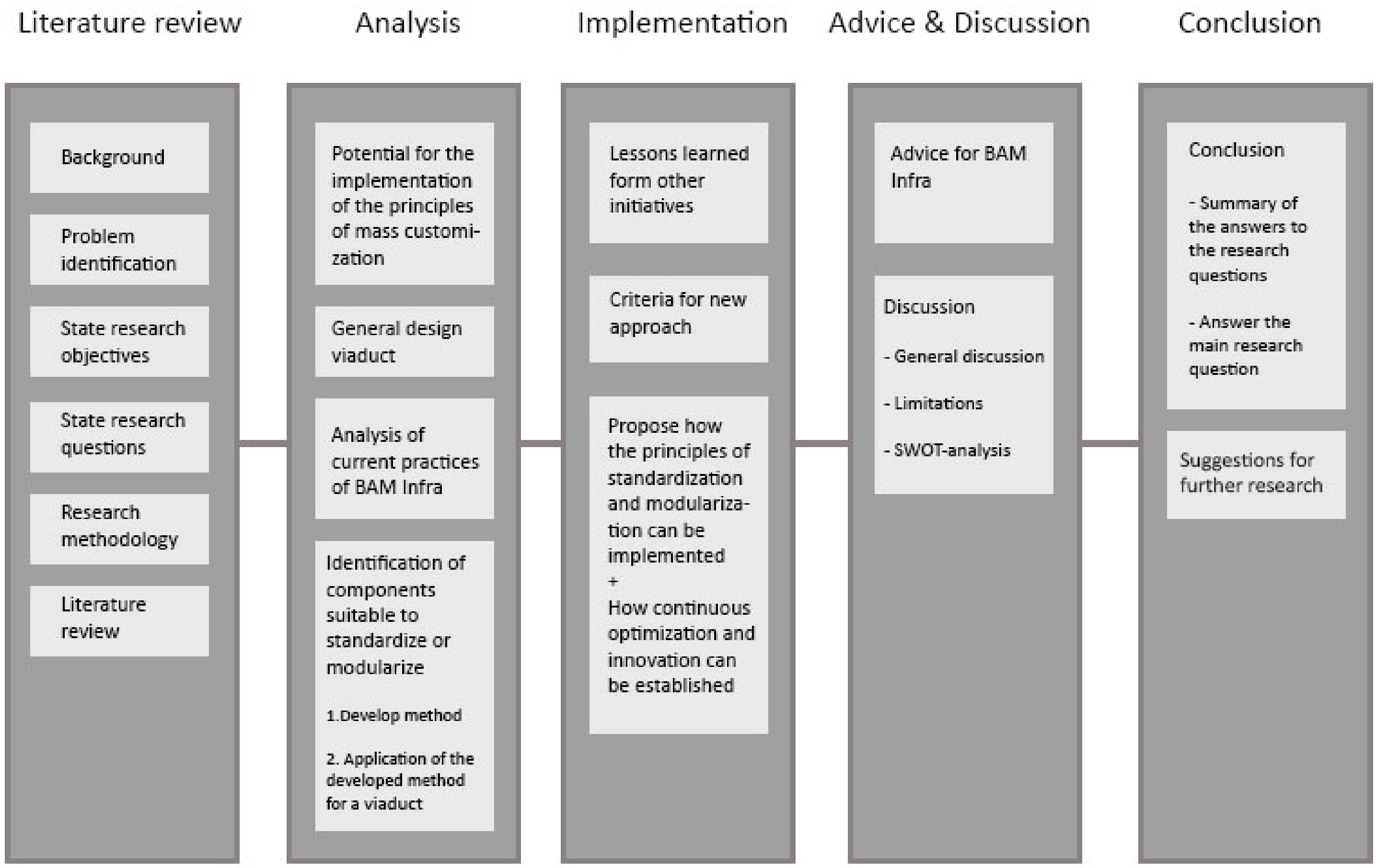
Four deliverables of this research are identified, these are

These deliverables are:

1. *Analysis whether or not the principles of standardisation and modularization are suitable and can be beneficial for the application in the infrastructural sector of the construction industry.*
2. *Development of a method for the identification whether or not the application of the principles of standardisation and modularization for objects in the civil infrastructure sector are suitable, and to identify which components are interesting to standardise or to modularize.*
3. *Identification of components of a viaduct that are suitable for the application of the principles of standardisation and modularization (including general design and decomposition of a viaduct).*
4. *Advice for BAM Infra on how they can increase the flexibility and effectiveness of the utilisation of resources, by the implementation of the principles of standardisation and modularization in current circumstances within the company.*

1.6.2 Overview

To give an overview of this research and all of its elements, figure 1-7 is constructed. The figure provides an overview of the different phases of this research.



1—7 Overview of the phases of this research

1.6.3 Focus of this research

This research will focus on the application of the principles of standardisation and modularization for an infrastructural object: a viaduct. This research will investigate whether or not the principles of standardisation and modularization are suitable for viaducts and how this could be implemented in the current strategy of BAM Infra. Within this research, the process of how BAM Infra can implement standardisation and modularization is investigated to see if this will be beneficial. Furthermore, if eventually establish a product platform will be beneficial, is analysed on a rough scale. The insights gained about the standardisation and modularization of a viaduct (more technical part) will be combined with the insights obtained about the process.

The infrastructural object: a viaduct has been chosen as the object to analyse because the management team of BAM Infra wants to investigate the applicability of the principles of standardisation and modularization for a viaduct. This is a strategic choice. Considering standardisation and modularization, it is advised to start with an object/product that is repeatedly constructed by the company (Jensen, Olofsson, Smiding, & Gerth, 2014). The company will then already experience with the specific object and will have the knowledge and expertise in-house. In addition, to benefit from the repetition that occurs, the amount of objects the company is expected to construct is vital. A viaduct is an object that is constructed by BAM Infra relatively often. Every large infrastructural project contains several structures to handle the different heights that are present (BAM Civiel, 2013). Around 90 to 100 viaducts are constructed in the Netherlands, every four years. Approximately, around 25 viaducts are constructed every year. However, BAM Infra is not the only company who constructs these viaducts. Circa, five viaducts per year are constructed by BAM Infra within the different region departments and around two viaducts are procured. This means BAM Infra constructs approximately seven viaducts a year (BAM Civiel, 2013).

This research will only focus on the development of viaducts from prefabricated parts. Construction of a viaduct by an in-situ process (pouring of concrete), is not suitable for modularization and therefore will not be reviewed. This is concluded because by the pouring of concrete no modular connections (referring to the concept of Lego) can be established. In addition, different studies that have been executed considering the comparison of in-situ and prefabricated viaducts, have concluded that prefabrication is the most suitable alternative to applying in the current situation in the Dutch construction industry (different criteria were considered) (BAM Civiel, 2013) (Bakker, 2014) (Gangaram-Panday, 2012). Furthermore, the general design in this research is based on the mainly practised method. In the Netherlands around 70% of bridges and viaducts are constructed with a prefabricated deck (TU Delft).

1.7 SCIENTIFIC, PRACTICAL AND SOCIAL RELEVANCE

Taking into consideration the identified problem and proposed solution, this section will discuss the scientific, practical and social relevance of this research.

1.7.1 Scientific relevance

The results of this research will extend the knowledge of research in engineering design science. Extensive research has already been conducted on standardisation, modularization, and product platform implementation. These studies are optimistic about the principles of mass customization, but it remains unclear if the principles of standardisation and modularization can be transferred to other industries. Little research has been conducted on the application of the principles of mass customization and development of a product platform in the infrastructural sector. This research focusses on this gap in the literature. Within this research, it is investigated whether or not the principles of standardisation and modularization are applicable, and will be beneficial, within the construction industry. It addresses the applicability of the application of the principles of standardisation and modularization in the infrastructural sector, for the infrastructural object: a viaduct.

1.7.2 Practical relevance

This research will provide BAM Infra with practical information for implementing a standardisation platform for a viaduct. It will provide insight into the current situation of the company, considering both the product and process. Some of the research results will potentially also be applicable for other infrastructural objects. A viaduct was proposed by BAM Infra as an object to investigate.

The output of this research is relevant to BAM Infra because it analyses the application of standardisation and modularization for a viaduct. The research will help BAM Infra assess whether or not they should implement the principles of standardisation and modularization, and it will provide insights if the development of a product platform is suitable.

1.7.3 Social relevance

The social relevance of this research is based on the strong need for a productive and innovative infrastructure. This has been argued by Eriksson et al. (2014). They argue that the need for a productive and innovative infrastructure arises from the monetary value and importance of such infrastructures in the development of a sustainable society (Eriksson, Olander, Szentes, & Widen, 2014). Application of the principles of standardisation and modularization can contribute to a productive and innovative infrastructure.

PHASE TWO

Literature review

2 LITERATURE REVIEW

What is already known in literature about the application of the principles of mass customization within the construction industry?

To get a thorough understanding of the research subject; application of the principles of standardisation and modularization in the infrastructural sector, with the focus on a viaduct, a literature study is conducted. The literature study enhances theoretical understanding and the practical implementations of industrialisation in the construction industry. Based on this literature study performed and insights obtained within BAM Infra research questions are formulated and a research framework has been developed. This chapter contains the literature review; the first questions presented in section 1.5.4 will be answered. First, an overview of the principles of standardisation and modularization are given and several opinions whether or not the principles of mass customization can be applied within the construction industry are discussed. Hereafter, the implementation of the principles of mass customization in the construction industry is discussed and the perceived advantages and disadvantages and the critical success factors are have been identified.

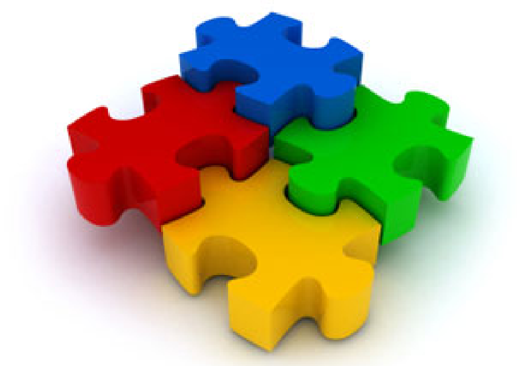
2.1 THEORETICAL BACKGROUND

Q1.1 - What is the theoretical background of a product platform, considering standardisation and modularization? And what are the main insights that can be derived from literature?

Firms are faced with the challenge of increasing demand for variety and higher specific customer demands within a dynamic market. To cope with these circumstances, firms are increasingly adopting mass customization techniques. These techniques can minimise the negative effect of increased product variety, by reducing complexity and the sharing of components. (Magnusson & Pasche, 2014). Although the principles of mass customization have been successful applied within diverse industries, it is not clear whether the principles are suitable for the infrastructural sector of the constructive industry. This research will focus on the application of the principles of standardisation and modularization in the infrastructural sector for a viaduct.

2.1.1 Mass customization

The theory describes mass customization as an intermediate between mass production systems, based on make-to-stock approaches of product realisation, and the engineer-to-order approach for the development of one-of-a-kind products. Blecker and Abdelkafi (2006) have argued that such an intermediate structure, the structure and composition of the product (the product architecture), must be designed and organised in a way that balances the contradiction between product variety and production volume (Blecker & Abdelkafi,2006). The construction industry is characterised by an "engineer-to-order" system. Benefiting of the repetition in large construction projects, mainly have potential for the design, production and assembly phase. Parts can be pre-engineered, but production only begins when the design for the order is finished. Because of various locational circumstances, requirements and demands require various scales and dimensions.



2—1 Development of a structure out of predefined building blocks based on a standardised interface: conceptual figure illustrates modularization

Thuesen and Jonsson (2009), argue that customization and low cost traditionally have been perceived as mutually exclusive (Thuesen & Jonsson, 2009). This implies that there are two options. Can either adopt a mass production strategy providing low cost, but this will be the cost of uniformity and value creation, or can adopt an individual customisation strategy creating high value, delivering unique projects but failing to control complexity and thereby failing to keep the cost down. They imply that mass customization tries to bridge these two strategies through delivering customised products while keeping cost down by controlling complexity.

Mass customization within all sectors relates to the design of products and product families. The basic principles have been listed by Piller and Stotko:
1) *Product architecture should be modularized.*
2) Production process should use product platforms and modularization.
3) Rules and constraints should reflect the need for stable processes.
4) There should be a clear division between standardised and customer specific parts within the product.
5) The specification process should use dedicated information systems. Piller and Stotko argue that mass customization involves both the product as the process. (Piller & Stotko, 2002)

Mass customization in construction is an intermediate system, the structure and composition of the product (product architecture), must be designed and organised in a way that balances the contradiction between product variety and production volume (Blecker & Abdelkafi, 2006). In literature there are multiple researchers who argue that implementation of mass customization does have potential for the construction industry, and emphasise that modularity can be essential (Erixon, 1998) (Gerth, 2013) (Malmgren, 2013) (Ballard & Howell, 1998)(Vrijhoef & Koskela, 2005) (Koskela, 2000) (Voordijk, Meijboom, & de Han, 2006) (O'Conner, O'Brien, & Choi, 2015).

Gibb (2001) argues that mass customization mean that mass production is combined with customization. Mass customization is also applicable to the construction industry, according to Gibb (2001). Gibb (2001) states: "*Where the benefits of mass production can creatively be combined with systems that offer greater choice for the individual customer, provide improved control of the total construction process, and flexibility of assembly options.*" (Gibb, 2001). The basic idea of mass customization is thus to improve the flexibility of the end product while maintaining standardisation and economies of scale (Tseng & Jiao, 2001).

2.1.2 Standardisation and Modularization

Standards exist principally to provide a reliable basis for which common expectations can be shared regarding specific characteristics of a product, service or process (British Standards Institution (BSI), 2011). For the construction industry, standardisation has been defined as: *Standardisation is the extensive use of components, methods or processes in which there is regularity, repetition and a background of successful practice and predictability* (O'Conner, O'Brien, & Choi, 2015). Another definition given is "*The extensive use of components, methods or processes in which there is regularity, repetition and a background of successful practice and predictability*" (O'Conner, O'Brien, & Choi, 2015). This definition implies that standardisation is a collection of components, methods and processes to assess repetitive activities**.** Implementation of standardisation efforts can potentially result in quality, organisational, time, cost, design, safety and information benefits.

Modularity is a general system concept: it is a continuum describing the degree to which a system can be separated and recombined, and it refers both to the tightness of coupling between elements and the degree to which the rules of the system enable the mixing and matching of components' capabilities (Shilling & Paparone, 2005). Shilling argues at the most abstract level modularity refers to the degree to which a system's components can be separated and recombined and the effect this has on the functionality of the system. All systems are characterised by some degree of coupling between their components, and very few systems have components that are completely inseparable and non-combinable, almost all systems are, to some degree modular. Systems have a high degree of modularity when their capabilities can be disaggregated and recombined into new configurations, possibly substituting new capabilities into the configuration, with little loss of functionality. Some of these systems will permit recombination of the separated modules and will still function. While other systems do not readily permit recombination of components (Schilling, 2000)

Langlois (2002) describes modularity as: *"a very general set of principles for managing complexity. By breaking up a complex system into discrete pieces, which then can communicate with one another only through standardised interfaces within a standardised architecture. One can eliminate what would otherwise be an unmanageable spaghetti tangle of systematic interconnections"* (Langlois, 2002). Baldwin & Clark (2000) considers modularity as a strategy for organising complex products and processes efficiently. The modular system is composed of modules that are designed independently, but function as an integrated whole (Baldwin & Clark, 2000). This implies that modularity has an effect on the complexity of the product design, but also has a significant effect on the processes related to the products. Sanchez and Mahoney have pointed this out as well. They state that a modular design allows for decoupling of components and systems and creates an information structure that can provide embedded coordination, thereby providing the company with increased strategic flexibility (Sanchez & Mahoney, 1996).

The principles of modularity come from the computer industry. The principles are:
- *Create nested, regular, hierarchical structures in a complex system.*
- *Define independent components within an integrated architecture.*
- *Establish and maintain rigorous partitions of design information into hidden and visible subsets.*
- *Invest in clean interfaces and "good" module tests*. (Baldwin & Clark, 2000)

These principles gave the designers a mean of coping with the constantly growing complexity in their market. Because complex problems could be divided into smaller sub-problems, which than could be resolved by different divisions in the company by employees with various backgrounds: *"the whole is greater than the sum of parts".* However, it may take extensive effort and experience before the architecture of the technological system is understood well enough to enable definition of design rules that facilitate the modularization. (Schilling, Toward a general modular systems theory and its application to interfirm product modularity, 2000)

2.1.3 *Product architecture: determine how products can be changed*

Ulrich states that the product architecture comprises out of three elements: (Ulrich, 1995):
1. The arrangement of functional elements
2. The mapping from functional elements to physical components.
3. The specifications of the interfaces among interacting physical components

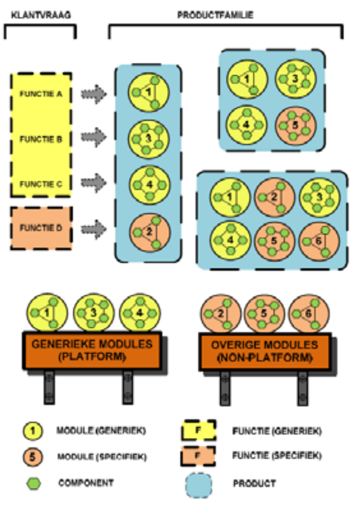
The architecture of a product determines how a product can be changed. When a component of the product is changed, it depends on the interface of the product whether other components need to be changed. Fully modular products could allow components to be changed without changing other elements. On the other hand, components of fully integral products can not be changed without the need to adapt other components.

Ulrich makes a distinction in various types of motives for those changes of a product: *upgrade,* add-*ons*, a*daptation*, *wear, consumption,* flexibility *in use*. Ulrich argues that in each of these cases, the changes to the product are easily accommodated through the modular architecture of the products. The modular architecture allows the required change, that is typically associated with the product's function, to be localised to the minimum possible number of components. Changes that can be made in a modular design are spanned by six modular operators (Baldwin & Clark, 2000). The modular operators can be applied to different points and diverse combinations, by applying the modular operators, all possible evolutionary paths can be generated. The six modular operators are listed as follows: 1) *Splitting a design (and it tasks) into modules*, 2) *Substituting one module design for another, 3) Augmenting – adding a new module to the system, 4)Excluding a module from the system, 5) Inverting to create new design rules, 6) Porting a module to another system*

Referring to a modular architecture, this means such architecture includes one-to-one mapping from functional elements in the functional elements structure to the physical components of the product and specifies decoupled interfaces between components (Ulrich, 1995). Baldwin and Clark (2000) states that: *"In a modular architecture, the components are interchangeable as long as the interfaces remain standardised. The interfaces are loosely coupled, providing possibilities for operations between the modules in the product architecture like substituting, augmenting or excluding"* (Baldwin & Clark, 2000). Note here that the modularity revolves around standardisation of how different components are coupled, this requires a standardised interface.

2.1.4 *Product platform*

A product platform is based on the concept of modularity. In a product platform it is clearly documented and standardised how the different components connect to each other, the interface is standardised. McGrath defined a product platform as: "set of subsystems and interfaces that form a common structure from which a stream of related products can be efficiently developed and produced" (McGrath, 1995). Platform thinking is the process of identifying and exploring commonalities among firm's offerings, target markets, and the processes for creating and delivering offerings. The leading principle behind the platform concept is to balance the commonality potential and differentiation needs within a product family. Therefore, a basic requirement is the decoupling of elements to achieve the separation of common (platform) elements from differentiating (non-platform) elements (Halman, Hofer, & van Vuuren, 2003). The basic idea of the platform is to constitute a robust core for a product family. Based on this core, new component technologies can be incorporated at a limited cost relatively to the investment of the platform. To enable a stable platform and variable product extension, the platform and external components are connected through well-defined interfaces so that external components can be easily plugged in. Here the concept of modularity has been applied within the platform illustrated in figure 2—2 (Meyer & Lehnerd, 1997). Based on the application of a platform, companies can create high-quality products at low cost, by systematically balancing an optimised solution between cost drivers and value proposition (Thuesen & Hvam, 2011).



2—2 Sharing of modules within a product platform, derived from Meyer & Lehnerd(1997)

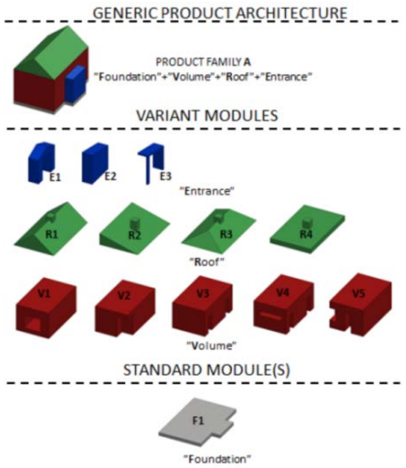
When a company wants to implement a product platform, first modular structure of the product and different products need to be identified. Modular product architecture is characterised by a high degree of independence between elements (modules) and their interface. Therefore, a basic requirement is the decoupling of elements to achieve the separation of common (platform) elements from differentiating (non-platform) elements (Baldwin & Clark, 2000). Baldwin and Clark (2000) identified three aspects of the underlying logic of a product platform: 1) *Its modular architecture, 2) The interfaces (the scheme by which the modules interact and communicate) and 3) the standards (the design rules that the modules conform to).* (Baldwin & Clark, 2000)

The main requirements for building a product family based on a product platform are, argued by Baldwin and Clark (2000):
a) *A certain degree of modularity to allow for the decoupling of elements*
b) The standardising of a part of the product architecture. (Baldwin & Clark, 2000)

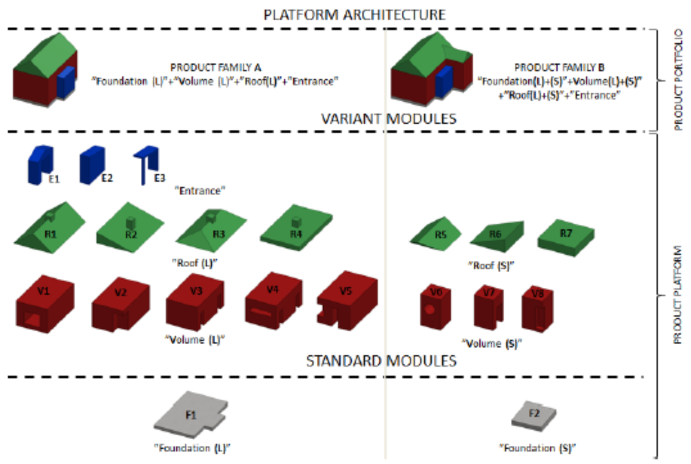
As explained before, there are gradations of modularity (Baldwin & Clark, 2000). Five features that are of importance to determine the degree of modularity can be distinguished (Wolters, 2011): a) *Distinctiveness/ autonomy of modules, b)Loose coupling between modules; tight coupling within modules, c)Clarity of mapping between functions and modules, d) Standardisation of interfaces, e)Low levels of coordination (self-organisation; coordination embedded in the architecture).*

Magnusson and Pasche (2014) argue that in diverse situations, various approaches for the use of standardisation and modularity are applicable. They distinguish three different approaches. First, if customers demand a high degree of customization, and the rate of change is high, firms may choose to adopt modular product architecture. Second, in the case customers favour cost-efficient functionality and the rate of change is low, firms should rather focus on the establishment of product platforms. Moreover, the third approach, in de case where there is a high demand for customization, in combination with a willingness to pay a premium for this, it may be the case that modularization and product platforms altogether constitute obstacles for achieving the required product flexibility. Which of the three approaches is suitable depends mainly on a firm's specific competitive environment. The firm has to balance the advantages of technology leverage and economies of scale against the ability of dynamically responding to various market demands (Magnusson & Pasche, 2014). The optimum platform can be determined through making trade-offs, to balance between commonality potential and differentiation needs. Halman et al. (2013) argue that key in the platform-driven approach is the sharing of components, modules and other assets across a family of products (Halman, Hofer, & van Vuuren, 2003). Based on the three platform related trade-offs, Hofer and Halman identified expected benefits of a product platform. These are, *1) Greater flexibility in product design, 2) Effectiveness in market positioning, and 3) Efficiency in product development and manufacturing.* (Hofer & Halman, 2005)

2.1.5 The essence of modularity



2—4 General product architecture, derived from Jensen (2014)



2—3 Creating a new product family from seven new modules and thirteen existing modules, derived from Jensen (2014)

The essence of modularization lays in the repetition that occurs. Jensen states based on literature study that, a decoupled modularized product architecture using interchangeable module interfaces provides the ability to combine the different module variants into streams of derivative products. (Jensen, 2014) An example of generic product architecture of a family house was given. The figure 2—4 shows a house that is decomposed into interchangeable modules.

By combining these 13 modules, 60 (1x5x4x3) different end products can be realised. This modular system reduces the number of products that must be developed, produced and maintained by 47, compared to a non-modular system. To continue, figure 2-4 indicates how easy it is to update, adapt or expand a modular house. The figure shows an expanded product family related to figure2—3. By developing two new modules with three variants each plus a new standard module for product family B, and combining these new modules with reused modules from product family A, a total of 540 unique derivative products in product family B can be generated.

2.1.6 Development of configurator

Eventually, firms can take the mass customization to a higher level by implementation of a configurator. A configurator is a design support system (Jiao, Simpson, & Siddique, 2007). Configuring a product is "putting together a product from well-defined building blocks (modules) according to a set of predefined rules and constraints (Hvam, Martensen, & Riis, 2008). Configurators exist to standardise and expedite the engineering design process by enabling the reuse of existing results and knowledge. The configuration of modular platform architectures also facilitates the effective use of information and its transfer between the different domains. (Jensen, 2014). Separate views of the same product and how they overlay each other can be visualised, a customer, engineering, production and assembly view are suggested. Also, information regarding rules and restraints can be transferred.

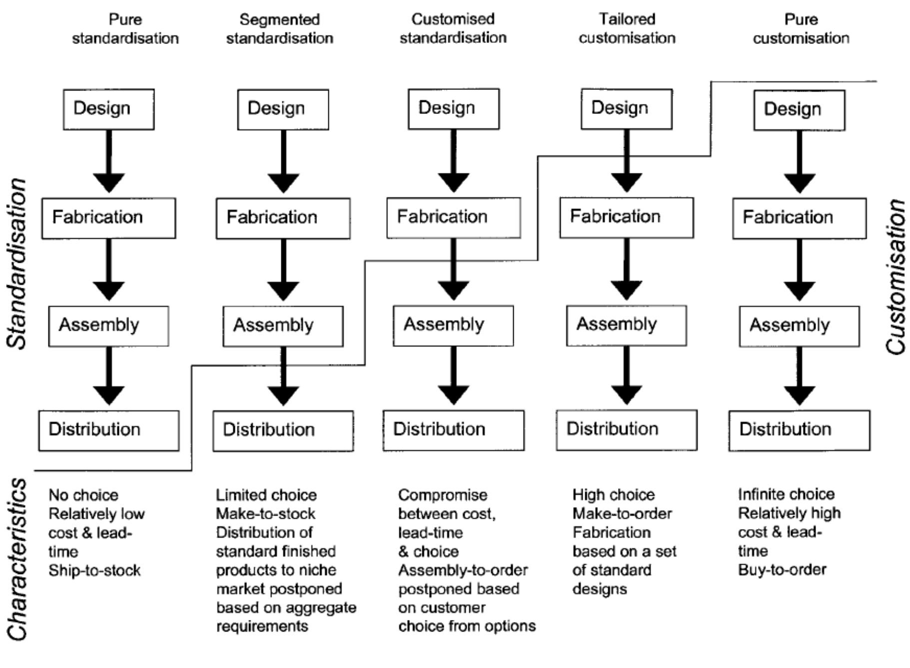
Haug et al. (2012) argue that the acquisition and representation of platform-related knowledge are essential for the design and development of platform configurators. They argue that two major challenges must be addressed in the development of configurators: a) their development needs to be synchronised with that of the platform itself, and b) the configurator needs to be accepted and adopted by the organisation that is using the platform (Haug, Hvam, & Mortensen, 2012). Two main kinds of configurators can be identified: sales configurators and engineering configurators. Sales configurators exist to guide customers through the product's specification process, highlighting relevant constraints and potential solutions. The Engineering configurators exist to standardise and expedite the engineering design process by enabling the reuse of existing results and knowledge (Hvam, Martensen, & Riis, 2008).

Although product configuration is described as an effective mean of structuring products and standardisation and could be very beneficial. Before a configurator can be developed, the following issues need to be resolved in the company. (Malmgern, Jensen, & Olofsson, 2010)

- *The range of products to be part of a configuration system need to be structured in some form of product structure. Often conflicting views exist in the company regarding rules, degree of detail, etc., these issues have to be resolved before any product modelling initiative is launched.*
- *Companies have to decide what parts of the product range should be included in a product configuration system. Probably, not all products are suitable for configuration.*
- *The information needed for the product configuration project has to be collected. This information often resides in documents, CAD files and different types of management systems such as enterprise resource planning, supply chain planning. It is also to be found as tacit knowledge of the product specialists within the company.*
- *How should product information be stored, updated and maintained? The product model will have to be constructed so that these parameters are effectively considered.*

2.1.7 Standardisation versus variation paradox

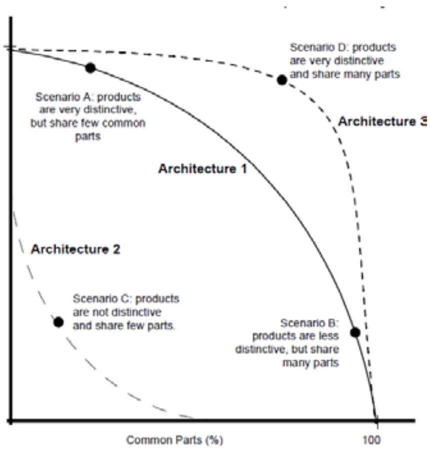
Companies within various industries continually have to consider the trade-offs between standardisation and variation. In the paper of Barlow et, al. (Barlow, et al., 2003) the different supply chain strategies used by companies in the Japanese housing industry have been investigated. They offer customised homes which are pre-assembled from standardised components. This way, the companies can offer mass customization for a reasonable price. However, there is no single model of mass customization; there are trade-offs between levels of customization, customer lead time and cost. By using standardised components, economies of scale can be obtained in the production process. Barlow et al. (2003) argue that companies must decide which level of pre-assembled and standardised components is most beneficial since a more efficient production processes result in a shrinking amount of variation possibilities.



2—6 Supply chain matrix: Customization versus standardisation, derived from Barlow et al

Barlow et al. (2003) state that mass customization can be supported by several generic supply-chain models. This is illustrated in figure 2—6. The models allow specific customer needs and market segments to be more effectively met, without the costs associated with full customization (Barlow, et al., 2003). The model of Barlow is based on the same ideas as Hvam et al. (2008) and can be considered more or less the same. The model of Barlow is based on the Japanese housing industry, were the model of Hvam et al. (2008) is based on the infrastructural sector of the construction industry; this will be discussed in section 2.3.1.

This 'standardisation versus variation paradox' can be explained by using the model of the supply chain matrix, of Barlow, given above. Within the figure, the line represents the customer order decoupling. From here, a product is linked to a specific order. When the CODP is situated at the retailer or end user, the supply chain is efficient and lead times are minimised. However, customization is hard to achieve here. When the CODP is situated at the raw material supplier or manufacturer, the level of standardisation decreased, but the supply chain offers a high degree of customization. A company has to find the optimal position of the CODP to provide mutual benefit for both the client and the company, making the trade-off between standardisation and variety.



2—7 Trade-off between distinctiveness and commonality between two products for a given product architecture, derived from Ulrich & Robertson (1998)

In the manufacturing industry, modularization and standardisation of semi-manufactured items have been ways to increase efficiency and lower costs in production, decreasing delivery times, and even increasing the flexibility and variety of products to satisfy customers' demands. However, currently, there is much attention to the question if the concepts of the manufacturing industry are also applicable in the construction industry. Koskela has already stated in 1992, that there are certain characteristics of construction, like one-of-a-kind products, temporary organisation and site production. These characteristics are preventing the attainment of flows as efficient as in the manufacturing industry (Segerstedt & Olofsson, 2010).

2.1.8 Opinions within literature

There are different opinions about whether or not the principles of the principles of standardisation and modularization are applicable in the construction industry and suitable for the development of a product platform. It can be noted that the opinions within literature are mainly positive. However, more research is needed. Some opinions have been listed below:

- *Bertelsen* - States that if the complexity of construction products can be divided into more easily manageable modules that each addresses a clear functional requirement, then the complexity of the construction process and products can be minimised. (Bertelsen, 2003)
- *Lennartsson* - States that modularization enabled better product control. (Lennartsson, 2012)
- *Veenstra, Halman, and Voordijk* - Conclude that the principles of standardisation and modularity are generally applicable and useful in the development of product platforms for construction. (Veenstra, Halman, & Voordijk, 2006)
- *Huang and Kusiak* - state that some benefits can be achieved by focusing modularization efforts exclusively on the internal interfaces between modules while allowing the use of unique external interfaces to meet the specific requirements of the project at hand. (Huang & Kusiak, 1998)
- *Ernst* - Argue that the use of modularity is limited by demanding coordination requirements and limitations to interface standardisation. Additionally, Ernst highlights that the existing theory appears to be overly enthusiastic about the benefits of modularity, pointing to the need to critically investigate when and how modularization can be purposefully applied, as well as the difficulties firms encounter when implementing a modular approach. (Ernst, 2005)
- *Gibb* – Gibb points out that a strategy to maintain flexibility within standardisation is by modularization. Gibb (2001)is of the opinion that industrialisation has major potential, also in the construction industry, but highlights that construction companies have always struggled to solve the conflict between uniformity and variation (Gibb, 2001).
- *Sawhney* - Sawhney (1998) states that it is possible to manage the conflict between high volume and high flexibility by allocating products to appropriate process platforms and reduce development risks by exploiting similarities between processes to use proven elements in multiple projects. Sawhney has argued that the use of product platforms is the key to cost-effective variety. (Sawhney, 1998)
- *Ballard and Howell* - Ballard and Howell emphasise that industrialisation can be beneficial and that product and process design can be standardised for standard products, while for non-standard products they consider it to be necessary to standardise procedures for planning and to manage the design and installation of unique facilities. They argue that in the situation standardisation of elements in certain products/objects will not be suitable or achievable the companies should still try to standardise their processes. By this, they can benefit of the repetition that occurs. The companies will get more experienced, and a learning curve is established, this facilitates the constant optimisation of product and processes. (Ballard & Howell, 1998)
- *Larsson, Eriksson, Olofsson & Simonsson* - Larsson et al. (2014) have investigated the key features of the principles of standardisation and modularization and barriers to implementation of these principles. To enhance theoretical understanding of industrialised construction in the infrastructural sector and its practical implementations. Larsson et al. (2014) have conducted a workshop for their research. Based on this workshop and other studies found in literature, they emphasise the need for flexibility to counter possible causes of reluctance to standardise. They point out they are not the only one who think the need for flexibility is the cause of the fact that standardisation is not applied broadly or not even applied at a small scale. (Larsson, Eriksson, Olofsson, & Simonsson, 2014)

2.2 PRINCIPLES OF MASS CUSTOMIZATION: OPPORTUNITIES AND RISKS FOR CONSTRUCTION

Q1.2 - What opportunities and risks for implementation of the principles of the mass customization industry are there for firms?

2.2.1 General reasons and drivers for adopting a modular architecture

Muffato and Rovenda (2000) argue that strategies based on product families sharing a common platform have proven to be a successful approach for many industries, e.g. electronics, software, automobile, domestic appliances (Muffato & Rovenda, 200). Halman, Hofer & van Vuuren (2003) emphasise that firms in many industries increasingly are considering platform-based approaches to reduce complexity and to better leverage investments in new product development, manufacturing, and marketing. (Halman, Hofer, & van Vuuren, 2003). This will make them able to cope with the pressure of shrinking product life cycles, increasing international competition, rapidly changing technologies, and customers demanding high variety option, by managing the complexity of offering greater product variety. In this approach the sharing of components, modules and other assets across a family of product is essential.

Ulrich (1995) considers the following points as the general reasons why firms adopt a modular architecture (Ulrich, 1995):

- *Increased commonality* - Allows more parts to be standardised, this provides opportunities to increase production volume and quality. It can be beneficial due to the learning curve that occurs and the economies of scale in production.
- *Shorter lead times in development and production* - In the design phase, re-use of the design of components takes place. A new design can be easily derived from already known products (proven technology), which are a combination of standard modules. This can be done by combining a set of these standard components. When innovation or more specific customization is wanted, (new) variable modules can be developed. The combination of standardised modules and variable modules will make the company able to deliver products with high differentiation while still make use of the repetition.

  Robertson and Ulrich discuss the combination of standard and variable modules; "Standard modules are included in all product variants within a product family and contribute to the product's commonality, while variant modules are available in different versions and are used to customize the end product and provide a distinctive solution for the customer" (Robertson & Ulrich, 1998). In addition, Erixon argues that different strategies can be utilised to ensure that the production of standard modules is matched to predicted demand, while variant module production and assembly are conducted on a made-to-order basis. This approach minimises the lead time while ensuring that production is tailored. It makes the company able of delivering tailored solutions for the specific on-site circumstances and various demands of the clients. (Erixon, 1998)
- *Testability (individually test components and modules, before assembly) - Because* the modules have fewer dependency relations than an integral design, and due to prefabrication, the modules can be tested before assembly. This can have a significant effect on quality and failure costs.
- *Opportunities for incremental product development.* - A modular product architecture can be optimised and innovate in a step-by-step manner. The different modules can be optimised individually, by considering constraints/borders of the product interface (Meyer & Lehnerd, 1997).

Although Ulrich is mainly positive about the opportunities modularization brings, he also argues that there are limitations in the application of modularization:

- *Modularization can also result in the standardisation of the end-products.*
- *A lower level of innovation* - A lower level of innovation is mainly due to the fixed design rules of the platform and here the limited freedom and space for change.
- *Can lead to more oversized designs* - Oversized designs occur when a product platform is used for products of different marked segments or various models. The functionality of the modules is greater for the high-end model than for the low-end model. Although due to the benefits of the use of repetition, the companies choose to also apply the functionality of the high-end model within the low-end model, resulting in an oversized design.

Although the general reasons for the implementation of modularisation have been put forward by Ulrich, the drivers for modularity differ between stakeholders. Scania was one of the first to implement a product platform with the principles of standardisation and modularity. In a study of the product development of Scania trucks twelve generic modules drivers are identified (Eriksson & Erixon, 2000). 1) Carry-over, 2) Technological evolution, 3) Planned design changes, 4) Technical specifications, 5) Styling, 6) Common unit, 7) Process and/or organisational re-use, 8) Separate testing, 9) Supplier available, 10) Service and maintenance, 11) Upgrading, 12) Recycling. These drivers can also be applicable for the construction industry.According to Gibb and Isack (2003) the main drivers for the implementation of for industrialisation in infrastructural projects are;

- *The increasing demands for cost and time reduction (higher demands of client)*
- *Increased competition, as the market is becoming more open (global market, competition from foreign contractors) and the recession in the economy.*
- *Improvement in quality*

- *Reduction of the complexity of on-site construction. (less complex on-site, become experienced/ optimisation of the assembly process)*
- *Increasing shortage of skilled workers in the construction industry.* (Gibb & Isack, 2003)

2.2.2 *Implementation of the principles of standardisation and modularization*

Implementing the principles of modularization and standardisation, by developing a product platform, has many benefits. Early studies that have been conducted and more recent studies identified that when these principles are properly used, it offers a great opportunity to improve project performance in the industrial projects. (Tatum, Vanegas, & Williams, 1987) (Song, Fagerlund, Haas, Tatum, & Vanegas, 2005) (Baldwin & Clark, 2000) (Sawhney, 1998) (Robertson & Ulrich, 1998).

Within literature, it has been argued that successful utilisation of a product platform make it possible to reduce process complexity, increases flexibility in product design, increases efficiency of product development and manufacturing, and optimises the effectiveness of market positioning. The limitations of a product platform are mainly considered to be created by the need for a strong initial platform, the continuous development and renewal of products, a long product development time, and high costs and complexity of the original platform. In addition, Halman et al. (2003) have highlighted that only by finding a balance between the commonality potential and the differentiation of needs a trade-off can be made and an optimum platform can be developed (Halman, Hofer, & van Vuuren, 2003).

To find out what modularity can bring the product the advantages and disadvantages should be reviewed. The main benefits are considered to be: lower capital costs, improved schedule performance, increased productivity, greater product quality, increased safety performance, reduced waste, and better environmental performance (O'Conner, O'Brien, & Choi, 2015). Eventually, this all comes down to the perceived main advantage of modularization, namely that the end product can vary in shape and have different functions while the design and production of components and modules within a product family can be shared. In an ideal situation, the design is replaced by selecting an appropriate set of module variants from the product family. The development of modularized systems incorporates the development of modules within the system, preserving the interface between them. (Jensen, Olofsson, & Johnsson, 2012)

According to Kamrani and Salhieh (2002), modularity in product development has some advantages. These advantages are mainly focussed on the production industry, and are summarised below:
- *Reduction in product development time:* De-coupling of the modules of the product reduces the complexity of the product and enables development of different components simultaneously.
- *Customization and upgrades:* Modular products accomplish customer requirements by integrating several functional components interacting in a specific manner.
- *Product variety:* Modular components are used in several product lines; combining components in different ways leads to high variety with the same amount of modules.
- *Quality:* Modularity allows production tasks to be performed simultaneously. Thus, independent components can be produced and tested separately before they are integrated.
- *Design standardisation:* Modular design facilitates design standardisation by identifying the component functions clearly and minimising the incidental interactions between a component and the rest of the product.
- *Reduction in order lead time:* Modular products can be made by combining standardised and customised components. This allows standard components to be inventoried, and then customization can be focused on the differentiating components.

(Kamrani & Salhieh, 2002)

However, there are also disadvantages considering the principles of standardisation and modularization. O'Conner et al. (2015) argue that the wider adoption of modularization is impeded due to different disadvantages perceived; financial, technical and logistical. The main impediments that occur are: 1) Higher initial costs, 2) Increased investment in engineering at an earlier stage of design, 3) Higher transportation costs, 4)Requires extensive coordination between disciplines, 5) Early design freeze, 6) Early procurement on lead items, 7) Complex logistics and 8) Lack of capable contractors that can handle the new approach of modularization.

2.2.3 Compare different viewpoints in literature

The advantages and disadvantages of the application of the principles of standardisation and modularization have been discussed. However, for this research, it is interesting to investigate the main opportunities, concerns and risks perceived more specifically for the construction industry. To give an overview of opportunities, concerns and risks perceived for the implementation of standardisation and modularization in the construction industry, that are present in literature, six articles are reviewed. In the Appendix A.4, the different articles are summarised. A table with the perceived opportunities and a table with the perceived concerns and risks are given in Appendix A.5 and A.6. By reviewing the articles, the main opportunities and main concerns and risks identified and listed below.

Opportunities

- *Increasing efficiency in product development (shorter development time, by design by reference, design only once and reuse existing designs, parallel design and use of standardisation)*
- *Improve schedule performance: Less time for the construction phase is needed. As many sequences can be optimised and are well understood and prefabricated modules are applied.*
- *Cost efficiency in the product development process (re-use of component design)*
- *More experience with the process and the product: increased efficiency and productivity*
- *Increased working conditions (in a factory and on-site), result in increased productivity.*
- *Higher product performance and fewer failure costs, due to constant process of optimisation (iterative process, accumulated learning)*
- *Increased safety performance (within a factory and assembly on-site)*
- *Efficient use of resources*
- *Common interface (platform) result in better cooperation and communication (within the companies and between companies)*

Main concerns and risks perceived

- *Product platform has limited lifetime*
- *Need to be managed and monitored*
- *Analysis of the future market (requires reliable forecast, need to understand the market needs for the coming years)*
- *High initial costs for the platform development (Investment)*
- *High development time for the initial implementation of a product platform*
- *Development processes become more complex*
- *Increased transportation logistics requirements (Limits to the scale of the modules, due to transport and assembly on site.)*
- *Sacrificed benefits from conventional customization*
- *Owners and contractors capabilities (Not sufficient work capital, for the transportation and lifting requirements, and limited number of providers of prefabricated elements)*

The main opportunities and concerns and risks that have been identified by this review are similar and coprime to the advantages and disadvantage that have been listed in outstanding literature. However, the literature has been reviewed with the aim to identified opportunities, concerns and risks that are not indicated in the general literature and are more focused on the construction industry specifically. These are identified and explained below

Opportunities

Based on the literature, it can be noted that the implementation of one interface will result in better communication and cooperation, both within the companies and between companies. By a common platform less communication is needed, and problems could be easier explained. It also opens the door for more long-term relationships between suppliers and contractors. In addition, as one interface facilitates the communication and knowledge sharing, it has been considered as a successful approach to optimise current practices, as accumulated learning occurs in all phases of the projects. These opportunities have also been highlighted in other industries, but the construction industry lacks behind and implementing a platform will have a significant impact. Reduced site based permits, efficient use of resources, less impact and hindrance on the surrounding area and less material storage on the site have also been mentioned, and fewer facilities on-site are needed when building modular in comparison to traditional construction. In addition, also specific for the construction industry, in the articles the advantages related to service and maintenance were mentioned.

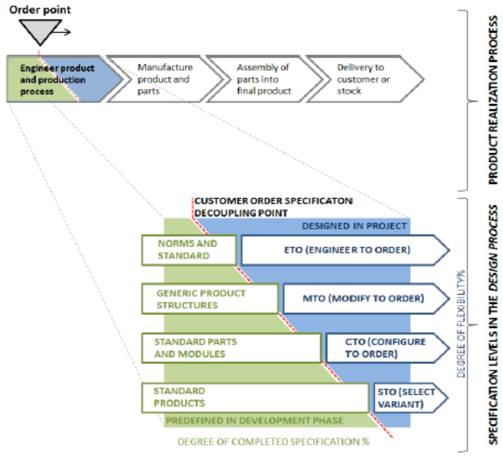
Concerns and risks perceived Most firms in the construction industry are redundant to implement a product platform. Appling the principles of mass customization within the construction industry is a new field. There is limited research conducted on successful strategies to manage the risks and problems related to platform development and implementation. Firms are not familiar with the process and do not want to sacrifice the benefits of the conventional customization that they apply currently. It is implied that a cultural shift is needed, from the perspective of different disciplines in the construction sector, as also from the perspective of the client. In the articles, it has been argued that no direct need for the implementation of a product platform is present. It has been argued that clients do not want standardise and/or modularized structures, they want unique structures. In addition, although the different actors in the construction industry due agree with the theory, they see too many barriers to the implementation. The perceived barriers are namely: a) Architect does not apply the principles of standardisation and modularization in their design process, however the other disciplines are dependent on the design made by the architect; b) Procurement barrier are also seen as an obstacle, functional specifications still not gives the desired freedom to make a product platform beneficial; c) The increasing regulation also results in limited freedom and limited incentives for innovation. Within the reviewed articles it has been questioned if the implementation is even possible, referring to the owners and contractors capabilities and the increased transportation logistics requirements. There are limits to the scale of the modules, considering transport and assembly on site. Moreover, there are limits to the capabilities of firms within the industry as well, referring to the transportation and lifting requirements, and a limited number of providers of prefabricated elements.

2.3 MASS CUSTOMIZATION IN THE CONSTRUCTION INDUSTRY

Q1.3 - Are the principles of mass customization also applicable for the construction industry, considering the characteristic of a civil infrastructure project, and how can these be implemented?

2.3.1 Infrastructural sector of the construction industry operates in the engineer-to-order supply chain

In the construction industry general four generic pre-engineering levels in the design process can be identified (Hvam, Martensen, & Riis, 2008) Namely, Engineer-to-order (ETO), Modify-to-order (MTO), Configure-to-Order (CTO), Select-variant-to-order (STO). Figure2—8 illustrates this.



2—8 Different specification levels in the design process of products realized through an "engineer-to-order" production process, derived from Hvam et al (2008)

Engineer-to-order specification level - ETO can be characterised by their on-off basis, and are mainly considered to be one-of-a-kind. The final product architecture is typically an integral design. The integral architecture makes it difficult to modularize and reuse technical solutions developed within the project.
Modify-to-order specification level - MTO starts with a pre-defined generic product structure that can be reused at a high level.
Configure-to-order specification level - CTO starts with a product architecture consisting of standardised parts and modules that can be configured to meet the customer's requirements.
Select-variant-to-order specification level - STO predefines products as a selection of final assemblies from which the customer may choose. (Jensen, 2014)

Within literature, the construction industry is mainly defined as an engineer-to-order industry. It is an industry that develops one-off projects that are realised by temporary teams of organisations. (Koskela, 2000). Vrijhoef and Koskela (2000) characterised the supply chain in construction as (Vrijhoef & Korkela, 2000)**:**

- Converging at the construction site where the object is assembled from incoming materials
- Temporary producing one-off construction projects through repeated reconfiguration of project organisations separated from the design.
- Typical engineer-to-order supply chain, with every project a new product or prototype is designed.

This has also been implied by Hofer and Halman (2005), they argue that: Project within the infrastructural construction sector can be identified as CoPS projects. These are engineered-to-order projects, which require project specific system design and engineering efforts and leads to high resource expenditures, time consumption, and project risk (Hofer & Halman, 2005).

2.3.2 Characteristics of the Construction Industry

In the construction industry, some characteristics can be identified at the project level. These characteristics are embedded in the industry and have its implications on the work methods and production methods during the project. These characteristics, mentioned above, explain the inefficiency and complexity that is experienced within construction projects, compared to mass production projects (Larsson, Eriksson, Olofsson, & Simonsson, 2013). However, in literature, it has been emphasised that the fragmented structure and the demand driven construction of the construction industry also highly contributes to the inefficiency and complexity. (Vrijhoef & Koskela, 2005). The most important characteristics that are identified can be clustered into five main categories, namely: one-of-a-kind projects, on-site production, temporary (ad-hoc) organisations/teams, demand driven construction process and the fragmentation within the current construction industry. All five main characteristics are elaborated below:

1. One-of-a-kind project
The construction industry has a one-of-a-kind nature. The various projects all have to deal with different circumstances, considering the different sites and surroundings and the diverse views of the designer on the best design solutions. The construction supply chain is a typical engineer-to-order supply chain, for every project a new product or prototype is developed. The difference between practices in the construction industry and business processes in mass production is mainly drawn by the routine and repetition. The routine and repetition within mass production stimulate innovation, provide opportunities for standardisation and sustained process improvement. (Gann & Shalter, 2000)
2. On-site production
Originally the construction industry was characterised by total on-site production. The current construction industry is still characterised by on-site production. Although it has to be pointed out that increasing prefabricated elements and modules are applied. Therefore, the actual construction on site refers mainly to assembly the different pre-fabricated components

Different features of on-site production are found in the literature. These can be categorised in three points:
- *The conditions of the site as an input* - The design should conform to the requirements of the surrounding (geology,

environment), like soil conditions, can have a significant impact on the construction project. Secondly, the interest of different stakeholders that are affected by the construction project needs to be considered. Thirdly, the weather conditions are of high influence since the production take place out in the open.
- *Dependency on local resources* - The dependency on local resources considers a) materials, as transportation has its boundaries and can be expensive. Moreover, b) the local labour that is available.
- *On-site productions* - The on-site production asks for a production infrastructure on-site for the project to be executed, and sufficient space is needed for construction. (Vrijhoef & Koskela, 2005)

Vrijhoef & Koskela (2005) argue that these features add to the uncertainty and complexity of construction, in comparison with factory production in the mass production industry. The construction supply chain is a converging supply chain; all the materials are transferred to the construction site where the object is assembled. The 'construction factory' is set up around the single product. In contrast to manufacturing systems where multiple products pass through the factory and are distributed too many customers (Vrijhoef & Korkela, 2000). However, as stated above, the construction industry is increasingly making use of prefabricated elements and modules, which implies more factory production and less construction work on-site, but the prefabricated elements and modules still require to be assembled on-site.

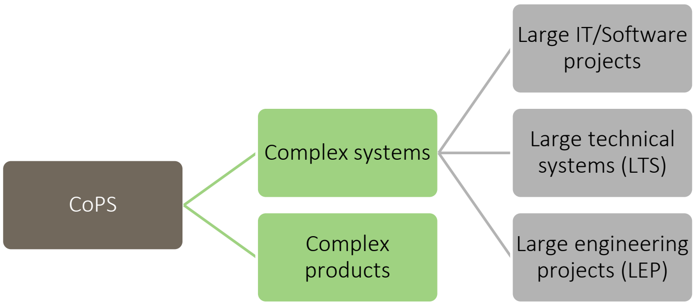
3. Temporary (ad-hoc) organisations/teams
A characteristic that follows from the project based industry and fragmented structure of construction are the temporary project teams. Construction projects are usually developed by a temporary organisation specifically formed for the purpose of the particular project. The nature of relationships is temporary, considering a short term. There are many actors and (sub) contractors working on the construction project on the side at the same time, all having a specific task. However, in current construction project limited cooperation and communication occurs. Communication and cooperation between the different parties can contribute to the construction project and is important for higher project performances (Choi, 2014). Due to the temporary nature learning and innovation within product development is limited. There is no incentive for continuously improvement, as the main goal of the project team is to deliver their current projects in an effective and efficient way (time, costs, quality). Therefore, the project team is focused on their current project and not concerned with implementing innovations that eventually can be beneficial in the long run for the whole organisation. These innovations can be applied, developed further and optimised in multiple projects. However, in the current situation, the innovations that occur are mostly only implemented on a project level, although these can also be beneficial for future projects. In addition, Additionally, it has to be pointed out that the employees are used to working in project teams that are formed for only several months. Therefore, they do not see the need to build up a relationship with the other parties involved. However, as stated more cooperation between the different parties will result in more innovation and product and processes will be optimised. (Lim, 2016)
4. Demand-driven construction process
The construction industry is characterised by a demand driven process. The first step in the project is the procurement of the project. The client specifies the functional requirements the object should deliver, within a predefined budget-range and time-scope. Different contractors can submit a proposal. The proposal should meet the proposed functional and non-functional requirements. The contract is awarded to the firm that has submitted the project with the lowest costs in relation to the quality. This is based on EMVI-criteria (Economic Most Valuable Investment). This is totally different from the mass customization and mass production industries where customers can choose from a catalogue between already designed and/or even produced products.

5. Fragmented construction industry
The construction industry is characterised by fragmentation. The relations between the different parties that contribute to the project are set up around the specific project. In most cases, the cooperation of firms and the cooperation between the different disciplines are for a temporary time-scope. The cooperation is as long as the duration of the project. Limited communication between the different parties occurs, as they all are focused on their own part and responsibilities. The construction industry can, therefore, be considered as fragmented and disintegrated. (BAM, 2016) (Sarhan & Fox, 2013)(Vrijhoef & Korkela, 2000) (Jensen, 2014). Abadi (2005) defines fragmentation within the construction industry as: "the division resulting from the increasing number of both professions (i.e. architect, engineer) and organisations involved in all processes of a building project. This has been caused by the growing demand for differentiation and specialisation, as building projects increase in both size and complexity" (Abadi, 2005).

The report "Re-inventing Construction" criticised the performance of the construction industry. The report identifies fragmentation and segregation of design and construction activities as the main barriers to improvement of investment and development. In addition, a conclusion has been drawn: To improve business and market conditions construction, the construction industry needs further integration and greater innovation effort. (Dulaimia, Linga, Oforia, & De Silvaa, 2006). This conclusion can be supported by the proposal by Lathan (Latham, 1994), which challenges the construction industry to work towards more collaboration and integrated delivery approaches. Moreover, it is also supported by the report of Egan (Egan, 1998). Egan suggests that process and team integration are key drivers of change necessary for the industry to become more successful.

2.3.3 Infrastructural projects are identified by Hobday as Complex Product Systems

The development of infrastructural objects can be defined as the creation and development of high cost, engineering-intensive sub-systems and constructs, also referred to as complex products and systems (CoPS). (Hobday, 1998). In figure 2—9, a schematisation of the hierarchy of complex products systems has been given. CoPS include complex products and complex systems. The complex systems can be split up in three different categories, namely: large IT/Software projects, large technical systems (LTS) and large engineering projects (LEP). A project or object within the infrastructural sector is a complex system in the category of large engineering projects.



2—9 Hierarchy of complex products and systems, derived from Hobday (1998)

Hobday (1998) has listed the characteristic of complex products and systems. The different elements of CoPS within infrastructural projects are and given in Appendix A.7 Hobday makes a clear distinguish between CoPS project organisations and mass production industries. In Appendix A.8, the differences in characteristics of CoPS project organisations versus mass production industries has been reviewed. (Hobday, 1998). By review of the table, it can be concluded that in project-based organisations are significantly different in comparison to mass production. Hereby, the approach to deal with the different characteristics will also be different.

In the article, Organisational capabilities and learning in complex product systems: towards repeatable solutions of Davies and Brady (2000), an organisational learning cycle model is developed, to show complex product systems firms can move from the first bid or projects of its kind in a new domain of business. The cycle makes them able to achieve “economies of repetition”. This by putting and placing organisational changes, routines and learning processes to provide a growing number of similar bids and projects more efficiently and effectively. (Davies & Brady, 2000)

There are three major differences between the nature of production in CoPS compared to high-volume production.

1. *Strategic and functional effectiveness is considered to be important in CoPS, as economies of scale and scope advantages are difficult to realise because production is limited to a unit or small tailored batches.*
   CoPS are designed and integrated by temporary project-based organisations to meet the requirements of individual business customer’s orders. In contrast to the volume production and mass marketing, functional capabilities essential in the supply standardised consumer goods, systems integration and project management are core capabilities in CoPS supply.
2. *User involvement is much higher in CoPS than in standardised consumer goods.*
   The sequence of functional activities in project-based production is the reverse of mass production. In high-volume production, product development is undertaken first, followed by production and marketing. In project-based production, by contrast, the product is developed after the order is secured and the design is modified during production (systems integration, assembly or construction), to meet customer requirements.
3. *Whereas the design and implementation of each individual CoPS involve systems integration, in high-volume production the emphasis is on ‘design for manufacture'.*
   Particular forms of organisation are appropriate for each system of production. Mass production systems tend to have mechanistic types of management structure. However, unit and small batch systems have organic structures. Functional specialisation is the most efficient way of producing large quantities of products and services, but project-based forms of organisation are ideally suited to low-volume CoPS production. Functional units in a typical mass production firm carry out the repetitive tasks required to maintain a continuous throughput of products or services but lack the flexibility and responsiveness necessary. To cope with unusually complex, new or rapidly changing project requirements. New and unfamiliar problems arising in CoPS supply often require the flexibility provided by organisations with adaptive and organic project management structures. (Davies & Brady, 2000)

The difference between mass production and complex projects (CoPS).

Difference mentioned in the article of Davies & Brady (2000), between product development projects and implementation projects are listed in the table below (Davies & Brady, 2000).

Product development projects: mass production	*Implementation projects (CoPS)*
Conducted in-house, with virtual client	*Procured by businesses or government organisations, rather than the final customer as in mass produced goods.*
Concerned with the integration of new technologies into a product.	*Mainly existing or known technologies that are configured to meet unique customer requirements.*
Economies of scale and scope	*Economies result in more from the repetition of new types of projects than from scale or scope. It is not so much the size of an organisation or the range of products provided, but rather the increases in the volume of projects executed that permits projects to be delivered at lower cost, on time and to the required specifications,*
The marketing department is responsible for articulating the needs of the target customer. The design is then frozen prior to market introduction and manufacture.	*The customer is deeply involved in modifying the design for the duration of product development and implementation projects.*

Davies & Brady (2000) argue that companies that are active in the market of complex product systems can also benefit from repetition like the mass-production industry does. They can improve their competitive position by learning from the initial project and developing the organisational capabilities to execute a greater number of similar projects. They argue that firms can achieve "economies of repetition", by putting in place organisational changes, routines and learning processes to execute a growing number of similar bids or projects at lower cost and more effectively. Firms can offer 'repeatable solutions' by recycling experience from one bid or project for others in the same line of business. The economies of repetition refer to the reduction in costs and improvements in project effectiveness gained by moving from the first-of-its-kind bid or project to the execution of many similar types of bids or projects within cost, schedule and the required specifications (Davies & Brady, 2000). This means that companies can improve their competitive position by learning from the initial project and developing the organisational capabilities to execute a greater number of similar projects. However, it must be noted that while a firm must be able to create and utilize a wide body of knowledge and experience to carry out the functional activities necessary to survive in an industry, it is the 'core'-capabilities which enable a firm to distinguish themselves and determine its ability to adapt, grow and achieve competitive advantages.

However, Hobday (1998) has argued that; "It is often recognised that there is less scope for routinized learning in CoPS because projects are inherently one-off or unique" (Hobday, 1998). The projects are usually one-off, with the focus on the requirements stated by the client. "While bids and projects may be similar and repeatable, and be assembled from increasingly standardised components and subsystems, the individual CoPS provided still has to be tailored to the unique requirements of each customer." Winch (2003) states that: "The greatest challenge is that maintaining capability represents is learning from project to project because there is a 'risk that learning will be dissipated and lost to future projects and the same mistakes will be repeated (Winch, 2003). Also, Davies and Brady (2000) emphasise that central to obtaining economies of repetition are the organisational capabilities, routines and processes. The growing stock of knowledge and experience need to becomes embodied in routines, procedures and IT tools of the organisation. These can improvement the organisation's ability to execute a growing volume of bids and projects more efficiently and effectively" (Davies & Brady, 2000).

Although in various industries product platforms are already applied and have multiple benefits, it cannot immediately be concluded that the implementation of product platforms for infrastructural construction works will be beneficial. Multiple studies have been conducted considering how the development of a product platform should look like. Conclusions that have been drawn are:

- The development of product platforms needs to be incremental and systematic, with a clear separation between the development of the platform and the production of the products. (Thuesen & Hvam, 2011)
- A generic product architecture (platform architecture) can be defined by using a top-down approach (Kudsk, Hvam, Thuesen, Gronvold, & Olsen, 2013)
- Describe a methodology for developing product platforms is based on the concept of identifying modules that are amenable to standardisation and distinguishing them from those that must accommodate customization. (Veenstra, Halman, & Voordijk, 2006)

No sufficient detailed step-by-step approach or framework for establishing a platform has been described. However, some initiatives have been taken to develop a framework. For example, the model of Veenstra (Veenstra, Halman, & Voordijk, 2006) , and the design-for-variety method developed by Martin and Ishii (Martin & Ishii, 2002). These models will be used as guidelines for this research, and are explained in Appendix A.14. To benefit from a product platform, transfer of the predefined technical solutions from project to project is needed. This requires the formalisation of the relevant knowledge. This knowledge has to be effectively shared in one database: a product platform. Certain aspects of the product are fixed, however other aspects can be changed. It is still important to adapt the product to the individual requirements and to deal with particular site conditions.

Unique constructions can be developed by combining predefined solutions from a product platform, with unique design features that can be built into a particular product instance (Jansson, 2013)*.*

2.3.4 Apply the principles of mass customization within construction industry

It has been argued by several experts that the principles of mass customization can also be applied in the construction industry. (Gerth, 2013) (Malmgren, 2013) (Jensen, 2014). According to Jensen (2014), this can be beneficial, within his thesis he highlights some examples in literature that show that construction industry currently does not work optimal, and could be improved by adopting certain aspects of the mass production industry. The following opinions have been derived from literature in the thesis of Jensen. (Jensen, 2014):
- The procurement is mainly done on lowest price, where different companies only work together for this specific project, this means the interaction and dependencies relations between each other are short-term.
- The client is already involved in the early phases of the project. Based on the requirements of the client a concept is drawn. The client specifies what they want and then the project team starts designing, this is seen as a bottom-up process. For every new project, a design from scratch is made, to be able to meet the demanded requirements of the client.
- The current circumstances provide little incentive to develop practices, methods and design solutions that can be reused between disciplines, partners and projects. - Separation of disciplines within the design process also creates operational islands, impeding the capacity to design for constructability, within the engineer-to-order realisation process.
- Due to fragmentation and the loose connections between the different disciplines involved in the design process, confusion relating to drawings and production instructions is a major cause of construction defects.

Implementation of a product platform, considering standardisation and modularization, will result in the incremental industrialisation of all the parts of the production process. The current engineer-to-order specification level will then become a modify-to-order specification level. Moreover, when the mass customization is further applied, it will become a configure-to-order specification level and eventually can become a select-variant-to-order (Jensen, 2014). In theory, it is all possible, but there are limitations. Ulrich, hereby, argues that predefined solutions can only be used to address specific functional requirements if the platform architecture is based on a modular design. (Ulrich, 1995)

2.3.5 Why are the principles of mass customization: standardisation and modularity, not yet implemented?

Standardisation of products is not a new concept, despite its slow implementation. It has long been recognised as essential for maximising predictability and efficiency in construction projects (Gibb, 2001). Although, the benefits and constraints are well documented by researchers, standardised and pre-assembled products and their benefits are poorly understood by many practitioners, leading to a widespread reluctance to use them (Pasquire and Gibb, 2002). The main drivers of the implementation of industrialisation in the construction industry have been mentioned before and can be summarised: the increasing demands for cost and time reduction, increased competition, improvement in quality, reduction of the complexity due to the production of modules off-site and more straightforward process of assembly of the construction on-site. In addition, the driver of increasing shortage of skilled workers was also mentioned in different countries. (Gibb & Isack, 2003) Larsson et al. (2014) point out that*: "Standardisation is regarded as a major component of an industrialisation strategy since it facilitates implementation of many of the other core elements, such as prefabrication, experience feedback and continuous improvement of products and processes".* Many of the identified core elements of industrialisation are related to long-term processes, rather than short-term projects.
The question here is why these principles are not applied in the construction industry, as it appears to have only benefits.

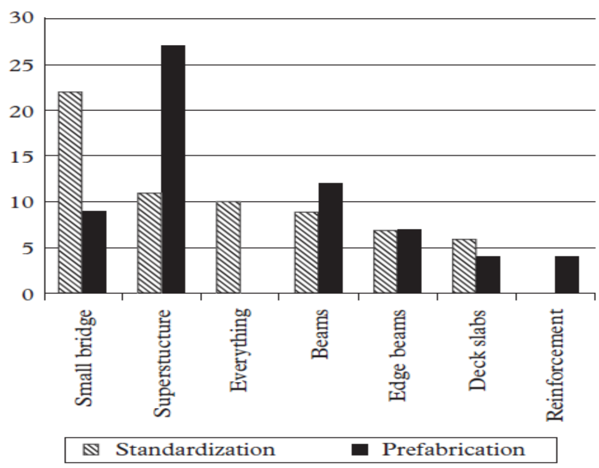
The implementation of industrialisation, referring to the implementation of product and process innovations, Cortney and Winch (2003) argue that this also requires cultural and attitudinal changes. In addition, they found that some constraints are more strongly related to organisational and behavioural obstacles than to technological obstacles (Courtney & Winch, 2003). Here it is essential that a mind-shift occurs, as identifying similarities among projects instead of merely their uniqueness is the first step towards increased industrialisation.

The book of Liker (2008): The Toyota way, 14 Management Principles from the World's, argues that cultural and attitudinal changes are needed (Liker, 2008). Liker (2008) states that the right process will give the right result. In addition, consistently changing the root problem drives organisational learning. However, the mindset of the employees is essential for the successful implementation of the 14 management principles. The principles are categorised by the 4P's that are the core of the Toyota Production System. It is vital for an organisation to consider these principles when they want to implement a product platform. It is important that the employees understand and adopt these principles. However, implementing the 14 principles will be a challenge on itself. According to Vrijhoef and Kosekela (2000) and Voordijk et al. (2006), the principles are also suitable to be applied in project-based organisations (Vrijhoef & Koskela, 2005) (Koskela, 2000) (Voordijk, Meijboom, & de Han, 2006)

Larsson et al. (2014) argue that the way business is organised can significantly hamper innovation. A link occurs between the innovation and the three peculiarities of construction identified by Koskela (Koskela, 2000). There is a focus on on-site production and the one-off production of the "unique" design. These construction projects are mostly undertaken by temporary teams that are formed for the specific project. The peculiarities of construction do not support the long-term thinking and the knowledge transfer from an improvement perspective, no optimisation due to repetition is established. In addition, the institutionalisation of the construction industry increases the need for coordination and communication in the complex project organisations. Institutionalisation refers to the cultural rules that provide foundations for the way people think and act. According to Kadefors (1995), this explains why innovations in individual projects seldom bring about long-term changes. The current policies, way of working, and opinion of the employees are not adapted or changed easily. (Kadefors, 1995)

Gibb (2001) states that in 1998 Gray (Gray, 1998) commented that a "*wholesale switch to standardised components is unlikely to occur unless there are some major changes in design policy and these will only occur if there is a major constraint on cost or construction resources in a period of boom*". Gray (1998) has also argued that stability of demand which would suit maximum standardisation is only possible by limiting choice, which the UK has so much of and is unlikely to give up. Or increasing demand, which is closely linked to the overall economy. This probably is not a viable strategy. Gibb (2001) argues that the contrary to common perception, the modernist architects of the first half of the 20th century did not argue for complete standardisation and prefabrication, largely due to their desire for flexibility: "*It is the nature of the part to provide standardisation and uniformity. It is the nature of the whole to provide unique, specific combinations, that is, variation*" (Herbert, 1959). However, modularizations result in flexibility. Combining standardisation and modularization is, therefore, a perfect fit. For components that do not change significantly, both time as locational circumstances, the principle of standardisation can be applied. For components that do change and client demand variety, the principles of modularization can be applied. By combining the two approaches, a company can benefit of both the advantages of standardisation as well as the advantages of modularization.

In the research conducted by Larsson et al. (2014), it has been investigated which objects are considered to be suitable for industrialisation, considering standardisation and prefabrication (Larsson, Eriksson, Olofsson, & Simonsson, 2014). The conservative industry culture and the mind-shift that is needed have also already pointed out by several researchers. A survey was conducted, to identify what their viewpoints and opinions of the participants within the infrastructural sector are, and identified what holds them back from using the approach on their infrastructural projects. By this particular survey Larsson et al. (2014) have analysed if the different participants within the infrastructural sector consider standardisation and prefabrication to be applicable and beneficial for their firm.



2—10 Graph of the number of participators (of a total of 52) that felt that the indicated parts of concrete bridge can be standardised and prefabricated, derive from Larsson et al (2014)

The figure 2—10, indicates that different practitioners within the infrastructural sector of the construction industry are of the opinion that industrialisation is applicable within the industry, by applying standardisation and prefabrication. One of the outcomes of this research was that 94% of the respondents thought it was possible to standardise concrete bridges or at least some parts of the concrete bridge. Also, 42% were of the opinion that the bridges could be standardised. They conclude that the various parts of the superstructure (beams, edge beams and deck slabs) are suitable for standardisation. Based on the conducted surveys, the conclusions was drawn that similar infrastructural structures are seen as suitable for both standardisation and prefabrication. Although, the participators are of the opinion that industrialisation can be implemented within the infrastructural sector. The concept is almost never applied within the infrastructural sector. In the research of Larsson et al. (2014), two reasons for the reluctance to standardise (industrialise) bridges were frequently mentioned by the respondents: 1) Architects want to put their unique mark on each bridge, and because they enter early in the project they set constraints on production. 2) Clients are often conservative, i.e. reluctant to use new product options, as proved solutions decrease risks of failure. These factors are hindering the implementation of more predefined specifications, and more time efficient production methods. However, it is argued that these specifications could all be incorporated into the design process in infrastructure construction, since the client entered the value chain in the specification phase of the project.

Some researchers argue that industrialisation within the construction of house-building have proven to be successful, this approach should then also be successful for other sectors of the construction industry. Although the industrialisation of the housing industry has been successful, Winch (2003) argues that increased industrialisation has been difficult to achieve in other construction sectors, such as infrastructure and complex industrial buildings. The infrastructural projects are significantly different from projects within the housing sector. The number of houses build is significantly higher than a number of infrastructural objects that are constructed. Although the housing sector is part of the construction industry, they cannot be compared directly with each other, as they have significantly different characteristics (Winch, 2003).

2.3.6 Building a product family based on a layout platform

Although the concept of a product platform has been applied in various industries of mass customization goods, the approach cannot be directly copied for complex products and systems. CoPS are a distinct area of innovation research for products and systems. It has been argued that complete decoupling of subsystems is almost not feasible. Hobday argues that as CoPS are highly customised, the dynamics of innovation in CoPS are likely to differ from mass-produced commodity goods. This can cause high levels of uncertainty and risk in system design, production, and integration. (Hobday, 1998).

CoPS projects are a complex project, were a lot of architectural choices will have to be made, within each project individually. We can state that CoPS are more one-off than mass-produced commodity goods. This makes it harder to establish a product platform. These products are developed and manufactured in single projects or small lot sizes. This makes the identification and realisation of re-use potential difficult and challenging. However, we must note that within CoPS also many possibilities for reuse of components occur, as the repetition that occurs could benefit from as well. The typical characteristics of complex products and systems are their hierarchic product architecture and the freedom in architectural choices. The result is that considerable complexity and risk in design, engineering and manufacturing occur. CoPS are considered as a one-off, and are engineered-to-order. This requires for every project specific system design and engineering effort and will lead to high resources expenditures, mainly considering due to long design periods and costs. The way engineer-to-order products are developed is time-consuming and results in high project risks. The high risks that occur in these projects are mainly caused by the complexity, and the uncertainties of the appliance of not already established components because most parts are developed specially for that product.

In general, it can be stated that the more customised a product is, the higher the degree of complexity will be in the realisation of products and systems. On the component level, variation usually results in limited changes to the overall system, as the components still have to conform to the architectural interface. The components can be changed, without other components need to be changed to function, as they are designed to be compatible. On the architectural level, variation is harder to establish. The changing of a system layout constitutes an architectural innovation and causes potentially higher complexity in the product architecture. Although substantial risks occur and trade-offs will have to be made in the development and managing of platform-based product families. Hofer and Halman (2005) argue that the deliberate restriction of architectural choices, through a layout platform, is a powerful mean to reducing engineering complexity and risk (Hofer & Halman, 2005). The basic idea to apply the platform concept was to search for commonality potential across all market segments with the goal to increase the re-usability of concepts.

A product platform and a layout platform differ. A product platform is considered to be an efficient and effective tool for mass customised goods. A layout platform is considered to be a successful approach for CoPS to benefit from the concept of a product platform, while still being able to reduce engineering complexity and risks. By this, it has been concluded that building a product family based on a layout platform is a powerful strategy for reaching mass customization in the case of complex product systems (Hofer & Halman, 2005).

The implementation of a platform is mainly driven by the time-efficiency and cost-efficiency that a platform can bring. To organise business processes in a time-efficient and cost-efficient manner is the key to staying competitive. The traditional platform approach, namely product platform, focusses on the component level. Moreover, hereby mainly affects direct material and labour cost through economies of scale. However, complexity along the value chain is not substantially reduced by this platform approach. The effects are not sufficient to support a product range for multiple market segments. In the article of Hofer and Halman (2005), multiple case studies have been conducted, to answer the question of whether new platform potential can be found in other layers of the product architecture, other than on the component level. The case-studies have been conducted with companies that have tried to apply a combination of one of their current product platform within other segments. The idea of a segmented approach is that a product range is created with segment-specific levels of complexity through the alignment of market segments with product range and processes. This is perceived as important, for example, Sanchez and Mahoney argue that: "*In a situation with a broad product range (high variety), and increasing adaptation time and costs, the value of flexibility in the use of resources becomes increasingly important*" (Sanchez & Mahoney, 1996). The task of market and product range segmentation is the realisation of the chosen competitive strategy and the effective segment specific market positioning and differentiation of the product range and processes (Hofer & Halman, 2005).

The new concept is based on the commonality potential, on the assembly, and on the layout level. The platforms of product family are in this case: 1) The standardised assemblies: product platform, and 2) The standard arrangement of these assemblies: layout platform. A layout platform is, just as the product platform, applied with the goal of efficient use of resources and time through increased reusability. These findings of the case-study imply that the layout platform supports the effective positioning of the product family in the market. The product family design is limited by the layout platform. The platform forms a stable basis for the development and realisation of new products. The platform limits the innovation capability. It is, therefore, vital to define the boundaries and restrictions to have as little influence as possible on the rest of the product architecture. Hofer and Halman (2005) argue that the most essential requirement for the definition of a layout platform is the robustness. It should have sufficient possibility for its decoupling within the product architecture to achieve independence from changes within the product family. Referring to application of the platform principles in CoPS, a product platform is considered to be too complex, and appliance does not always establish the desired results. The appliance of this approach was unsuccessful in the case studies due to difficulties in realising concept or design reuse potential. However, Hofer and Halman (2005) have presented the layout platform as a powerful instrument in managing CoPS. The standardisation of the system layout seems to be an efficient and effective way to reducing system complexity and engineering risk in systems, by 1)Multiple hierarchic layers of their product architecture, 2) Wide architectural choices in design, and 3) Strong influences of system layout variety on product and process complexity. (Hofer & Halman, 2005)

The main effects of layout platforms were argued by Hofer and Halman (2005): a layout platform enables market segmentation, imposes a dominant design, and increases reconfigurability (Hofer & Halman, 2005). In the case of infrastructural projects, this lays in the same scope. A wider variety of infrastructural objects can be realised by building a product family on a common layout. The non-standard elements can be rapidly adapted to variable needs and the different local circumstances. These adaptions will be made within the boundaries of the standardised layout and the product family. This will result in fast development of a design and will save design costs, because the standard design only requires some adaptations. In addition, learning takes place. The product architecture limitations and options can be used as a framework for the development of new designs, improvements and innovation. It can be concluded that the layout platform can be an effective tool to make a step from highly customised engineered-to-order processes, which have much architectural freedom, to a more mass customization approach as modify-to-order, which has a standardised system layout. The article of Hofer and Halman (2005), imply that a platform can also be beneficial to complex product systems. Moreover, it can, therefore, be concluded that it can be a suitable approach for infrastructural projects; these are also complex product systems which contain a certain amount of repetition.

2.4 Perceived barriers

Q1.4: *Which perceived barriers make the implementation the principles of standardisation and modularization hard to accomplish in infrastructural projects in the construction industry?*

2.4.1 Barriers

In the article of Sarhan & Fox (2013), different barriers for the implementation of standardisation are identified. These barriers are considered to be applicable as barriers for the implementation of a product platform as well, because here also the interface and components need to be standardised. The identified barriers originate from the characteristics of the construction industry and lead to a higher level of complexity in projects. The barriers identified are summed up as follows (Sarhan & Fox, 2013):

- *Fragmentation and subcontracting.*
- *Procurement method and contract restrictions.*
- *Culture and human attitudinal issues with resistance to change.*
- *Adherence to traditional management concepts due to time and commercial pressure.*
- *Financial issues.*
- *Lack of top management commitment and support.*
- *Design and construction dichotomy.*
- *Lack of adequate awareness and understanding of standardisation method.*
- *Lack of customer focused and process-based performance measurement systems*

The viewpoint of participants in the construction industry about the barrier they experience have been identified in the research of Larsson et al. (2014). Different practitioners were asked about the barriers they feel to implementation of industrialisation. The barriers are listed below, based on their importance on a scale from 0 to 5.

1) *Conservative industry culture (3.5)*
2) *Design-bid-build contracts (3.5)*
3) *Strong focus on lowest bid price (3.5)*
4) *Norms and rules of governmental organisations (STA, RWS) (3.1)*
5) *General governmental rules regarding plans (3.1)*
6) *Lack of large-scale and repetition possibilities (3.0)*
7) *Impaired aesthetics and monotonous architecture(2.2)*
8) *New solutions and methods increase risks (1.5)*
9) *Severe environmental impact due to long transportation distances (1.3)*

When the score op the considered barrier is 3, 0 or higher, the assumption can be made that these have a significant effect on the implementation of increasing industrialisation within the infrastructural sector. Therefore, the identified barriers 7, 8 and 9, are not taken in considered as core barriers. Within the six core barriers, these are mainly elements that cannot be changed by the construction firms. Four out of six core barriers consider regulation and barriers due to contracts and how these are awarded.

For the industrialisation in the construction industry, two strategies can be distinguished. Standardisation of products involves producing many required components in a factory for assembly at the construction site. Moreover, standardisation of processes involves developing of processes to address unique aspects of specific products in specific locations. Both product and process are underpinned by continuous improvements. However, the standardisation of the product and the process has proven to be difficult to achieve in the project-orientated infrastructural sector. Although there are supporters for the implementation of industrialisation in the construction industry, it has not been adopted yet, as the implementation of industrialisation has many constraints. Blismas et al (2005) identified three major categories of constraints for industrialized production, namely (Blismas, Pendelbury, Gibb, & Pasquire, 2005): 1)*Processes related to early design decisions, 2) Prioritization of lowest bid prices rather than best value, 3) Supply chain issues including long lead times and scarcity of suppliers.*

2.5 CORE ELEMENTS AND CRITICAL SUCCESS FACTORS

Q1.5: What factors are considered to be essential for successful implementation of the principles of standardisation and modularization, referring to a product platform?

2.5.1 Essential for implementation of industrialisation within the infrastructural sector of the construction industry

It has been indicated that increasing industrialised construction is an appropriate approach to improve productivity and reduce both costs and time. (Larsson, Eriksson, Olofsson, & Simonsson, 2014). Larsson et al. (2014) considered different factors to be essential for the implementation of industrialisation within the infrastructural sector. The identified factors are summarised below:

- *Flexibility is needed* - Flexibility is needed, to counter possible causes of reluctance to standardisation. The flexibility can be maintained within standardisation, is by the appliance of modularization (Gibb, 2001).
- *Early involvement and more openness for innovation* - Early involvement of contractors and being more open for innovations are considered to be important for the client to permit the development of these innovations.
- *Identify similarities* - Identifying similarities among projects instead of merely their uniqueness has been pointed out as the first step towards increased industrialisation.
- *Identify modules* - Since every infrastructural object is seen as on-off (unique), it is important to identify modules and subsequently components of the modules that can be standardised.

The development of standardised products, subsystems and components in the infrastructure sector should exploit recent advances in product platforms, modularization and configuration strategies for building systems (Hvam et al., 2008; Jensen et al., 2012).

In the article of Larsson et al (2014): Industrialised construction in the Swedish Infrastructure sector: core elements and barriers (Larsson, Eriksson, Olofsson, & Simonsson, 2014). Eight core elements of industrialisation have been identified, based on the results of surveys and interviews conducted. Six of the core elements have been graded by the survey and interviews on a scale from 0 to 5. The components are listed from high to lower importance below.

1) *Planning for efficient production (4.5)* - Planning for efficient production means using available planning tools to create a continuous flow through the whole process, to minimise all kinds of waste.
2) *Experience Feedback (4.2)* - Considers to be an important tool for continuous improvement. Here cooperation and clear communication channels between the actors are essential for increased industrialisation. Within the survey, the participants highlighted that when standardisation has to be applied within a "unique" problem, as the characteristics differ early involvement of the contractor is advised. The technical and architectural issues related to the specific location and structures that to be constructed, can be managed more easily and earlier in the project by better cooperation.
3) *Cooperation: Integrated design and production (4.2)* - Within an infrastructural project the integration of the design and production are problematic elements. There has to be sufficient and clear communication between the different actors, already in the design phase, this becomes essential. Clear communication is essential in all phases of the project, as knowledge has to be exchanged to facilitate the design, development and construction.
4) *Repetition and standardisation (4.1)* - Standardisation is a major requirement for industrialisation within the infrastructure, and here standardised processes are required to make and use the standardised products in an efficient way. By recognising similarities among projects and analysing, important possibilities that are suitable for repetitive use can be identified.
5) *Automation (3.9)* - The automation of processes, mainly for production, is considered as a core element. The reference can be made with the application of the principles of mass production, that also uses automation to be able to deliver products with high quality at relatively low price.
6) *Prefabrication (3.8)* - Prefabrication of elements is essential to apply industrialisation within the infrastructural sector. Prefabricated elements can be produced in off-side, transferred to the site, and finally can be assembled on-site.
7) *Process (not graded)*
8) *Continues improvement (not graded)*

The core elements process and continues improvement were not graded within the workshops because overlap occurs with many of the other core elements of industrialisation. The overall opinion of standardisation of work tasks, referring to the core element process, is that it can be beneficial. When there are sufficient standardised product and processes, these can be combined to develop a new product. The standardised products and processes can then be continuously improved.

2.5.2 Standardised interface facilitates communication

Although the opinions about the development of a product platform with using the principles of mass customization differ. Almost all literature implies that sufficient and effective communication between parties is essential, referring to direct and indirect communication (Larsson, Eriksson, Olofsson, & Simonsson, 2014) (Jansson, 2013) (Jensen, 2014) (Schilling, Toward a general modular systems theory and its application to interfirm product modularity, 2000). Direct refers to the sufficient cooperation and timely dialogue between the different parties. Moreover, indirect communications mean that the platform provides clear constraints for the different parties. By this less direct communication will be required, which result in more efficient communication and increase quality.

Shilling argues that modularity within companies does not only enable economies in product design, but can also greatly simplify coordination. An integral design requires that the different individual involved have sufficient close contact. However, a modular design can enable the design and production process to be decentralised. The standardise interface provides clear boundaries, by this, it will still be assured that the components will interact effectively (Schilling, Toward a general modular systems theory and its application to interfirm product modularity, 2000). In addition, the standard interface facilitates effective information exchange (Jansson, 2013). In the research of Jensen (2014), it has been concluded that the flow of information and constraints between different domains (customer, engineer, production, etc.) is important for the successful implementation of a product platform (Jensen, 2014). This is again a confirmation that had already been put forward by Jiao et al. (2007) that the transformation of information across domains is fundamental for the interpretation and implementation of product families (Jiao, Simpson, & Siddique, 2007). When the platform is implemented, this has to be managed and monitored, and updated if needed. Additionally, optimisation of the platform should be established, and new product development must be pursued on a continuous basis. Here communication is an essential factor. However, the communication within the current industry is not optimal and needs to be improved. Building Information Modelling is considered to be a good tool that should be used to improve communication (Choi, 2014) (Jensen, Olofsson, & Lessing, 2015). The implementation of standardisation and modularization, by the development of a product platform with a standardised interface, facilitates the indirect communication between different parties.

2.5.3 Critical Success factors to raise modularization to an optimum level

Modularization's Critical Success Factors to raise modularization to an optimum level within the construction industry, have been identified by the Construction Industry Institute (CII). Twenty-one CSF have been assessed, as they are considered to be essential to create an optimum environment for a broader and more effective use of modularization. The Critical Success Factors are summarised in Appendix 10.10.

The CII has identified 21 factors that are critical for the successful implementation of modularizations. Based on these critical success factors, various enablers are identified to provide project organisations and teams with additional guidance on how the listed factors can be achieved. (O'Conner, O'Brien, & Choi, 2014). The main findings of the research by CII can be concluded as:

- *Project teams should pay particular attention to module envelope limitations, team alignment, on project drivers, adequate owner planning resources and processes, timely freeze of scoping and design, and due recognition of possible early completion from modularization. As these are perceived to be the most important CSFs.*
- *More industry effort is needed to accomplish the critical success factors. This mainly refers to factors that are currently not sufficiently reached in most projects, these are the occasional, rare, and very rare CSFs, as illustrated in the figure A-9in Appendix A.9.*
- *The establishment of most critical success factors requires leadership and implementation by project owners (client). To successfully implement modularization, early involvement of the client is needed. The clients need to change their current practices.*
- *The assessment and selection phases are vital for reaching the CSF and hereby establish successful implementation of modularization, with regard to timing.*

By analysing old practices and current practices within the construction industry Gibb (2001) identified essential factors to fully benefit of standardisation. These have been listed below.

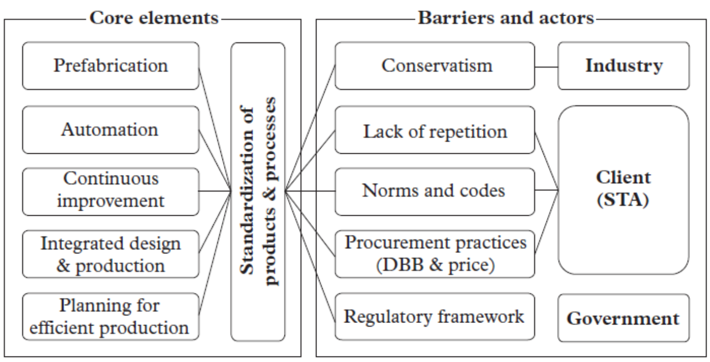
- <u>Better management</u> - As standardisation and pre-assembly facilitates better management, it also requires better management
- <u>Mind shift</u>- The understanding and commitment by all parties is considered to be vital
- <u>Early design decisions and sharing of critical information</u> - Design decisions need to be made earlier than for conventional construction, and critical information had to be established at the earliest stage possible
- <u>The project team needs to ensure</u> - Increased design choice, facilitated controlled innovation and ensured work of quality, aesthetic appeal and distinction.
- <u>Management needs to be trained</u> - Management needs to be trained to control a manufacturing process, as that is considerably different to the on-site, often ad-hoc management of conventional construction.
- <u>Customised solutions</u> - While the parts can be standardised, the whole must provide variation: customised solutions from standardised components.

Choi (2014) has also identified factors that have a significant influence on the increase of modularization. These factors are considered to be essential to establish a higher level of modularization in the construction industry (Choi, 2014). The seven factors are summarised as follows:

- *Early Consideration* - Ideally the modularization strategy should be incorporated from the start of the project. Systematic analyses and making decisions at an early stage, based on the specific factors of the project.
- *Alignment on drivers* - The implementation of modularization could be facilitated by the unrestrained involvement of construction with the design. When all parties are aligned, they all are informed about the benefits. As parties will be more aware of what modularization can bring, they all will be motivated to contribute to the goals of implementing modularization in a certain project
- *New technology* - Technologic development have a significant impact on the implementation of modularization. These new construction technics, new possibilities for the production of parts, atomization of processes. However, also IT-developments, as the increasing use of and advances in 3D-technology and Building Information Modelling (BIM).
- *Design freeze* - to make designs more applicable to modularization, Erixon (1998) has highlighted that designers should reduce interdependency between elements. (Erixon, 1998)
- *Standardisation* - By the standardisation of modules, cost benefits can be obtained through resulting economies of scale.
- *Fabrication infrastructure* - to fully be able to benefit from the standardisation, modularization and preassembly of components, there need to be sufficient fabrication facilities to develop the modules.
- *Improvement in logistics* - A limiting factor for modularization is considered to be a logistic problem. As the modules need to be transported to the side, and mostly need to be lifted. Therefore, the availability of large cranes and other heavy lifting excipient will be essential for increased use of modularity.

2.5.4 Relationship – core elements, barriers, critical success factors.

Core elements, barriers and critical success factors are all interrelated. Removal of the six identified barriers perceived to be essential for the implementation of the core elements of industrialised construction (Larsson, Eriksson, Olofsson, & Simonsson, 2014). In figure 2—11, the five main perceived barriers are presented in a schematic drawing. Three of the barriers are caused by the client and the industry, and government are only responsible for one barrier. It implies that to implement and benefit of industrialisation in the infrastructural sector first the client needs to adjust their approach. This has been confirmed in the research: Modularization's Critical Success Factors to raise modularization to an optimum level within the construction industry, conducted by the Construction Industry Institute (CII). As they state that most of the critical success factors can only be established if the client changes their way of working. (O'Conner, O'Brien, & Choi, 2014).



2—11 Main perceived barriers (process and product) to increased industrialization of infrastructure construction, their relationship to the core elements and the actors that have influence on these elements, derived from Larsson et al (2014)

2.6 CONCLUSION OF THE LITERATURE REVIEW

Within literature, various researchers argue that implementation of mass customization does have potential for the construction industry, and emphasise that modularity can be essential. The basic idea of mass customization is to improve the flexibility of the end product, while maintaining standardisation and economies of scale. The main benefits of the implementation of standardisation and modularization are considered to be: lower capital costs, improved schedule performance, increased productivity, greater product quality, increased safety performance, reduced waste, and better environmental performance. This all comes down to the perceived main advantage of standardisation and modularization; the end product can vary in shape and have different functions while the design and production of components and modules within a product family can be shared. In addition, the implementation of standardisation and modularization, by the development of a product platform with a standardised interface, facilitates the indirect communication between different parties. One of the most important core element is that flexibility is needed, to counter possible causes of reluctance to standardisation. The flexibility can be maintained within standardisation by the application of modularization.

Project within the infrastructural construction sector can be identified as CoPS projects. These are engineered-to-order complex project, where a lot of architectural choices will have to be made, within each project individually. CoPS are more one-off than mass-produced commodity goods. This makes it harder to establish a product platform. The various characteristics of the construction industry hamper the implementation of the principles of standardisation and modularization. In addition, other barriers for the implementation have been identified, the main barriers considered are: conservative industry culture, design-bid-build contracts, strong focus on lowest bid price, norms and rules of governmental organisations, general governmental rules regarding plans and lack of large-scale and repetition possibilities. It is interesting to note that technical aspects are not perceived as a major barrier. The implementation of the principles of standardisation and modularization are considered to be technically feasible.

Based on the literature review it can be stated that core elements, barriers and critical success factors are all interrelated. Removal of barriers is perceived to be essential for the implementation of the core elements of industrialised construction. However, the main barriers are caused by the client. This implies that to implement and benefit of industrialisation in the infrastructural sector, first, the client needs to adjust their approach. In addition, the implementation of industrialisation also requires cultural and attitudinal changes. It is essential that a mind-shift occurs; identifying similarities among projects instead of merely their uniqueness is the first step towards increased industrialisation. The understanding and commitment by all parties is considered to be vital for successful implementation. The parties in the construction industry have to cooperate to establish the implementation of the principles of mass customization.

PHASE THREE

Analysis

3 EMPIRICAL RESEARCH: ANALYSIS

3.1 POTENTIAL IN INFRASTRUCTURAL SECTOR, CONSIDERING THE MAIN CHARACTERISTICS OF INFRASTRUCTURAL PROJECTS

Q2.1. Is there potential for the implementation of the principles of mass customization in the current market of the infrastructural sector of the construction industry, considering the main characteristics of infrastructural projects?

Before it is investigated if a viaduct is suitable for the implementation of the principles of standardisation and modularization, first an analysis considering the current construction industry and the company BAM Infra is needed to identify whether or not there is potential for the implementation of mass customization within the industry and BAM Infra. Based on several characteristics of infrastructural projects that have been identified by Hobday (Hobday, 1998), and are discussed in Appendix A.8, other opinions that are discussed in the literature review, and insights gained during interviews and discussions with experts of BAM Infra, it is analysed if the viewpoint and situation sketched within literature is applicable to the current situation in the construction industry and more specific for BAM Infra. The most important aspects that have been used by Hobday to compare industrial practices are elaborated on below.

1. *Unit costs/financial scale of project*
   In comparison to the manufacturing industry, the unit cost for an infrastructure object is relatively high. The objects are mostly one-off and therefore no economies of scale are achieved. When the concept of an object can be applied in a repetitive way, the unit costs will decrease. The development cost of one concept can be recouped over multiple projects. In addition, product and processes can be optimised, as learning takes place. Hereby, companies can benefit from the "economics of repetition", considering the repetition that occurs in both process and product.
2. *Product volume* (reuse of design in various projects)
   Within the current situation of the infrastructural sector, product volumes are low, due to the one-off nature of the construction projects. Every project has to deal with different circumstances and requirements, they are considered to be unique. However, the implementation of a product platform using standardisation and modularization can result in object concepts that can be applied in a repetitive way. A design can be reused within different situations. When this reuse is applied, the production of a certain design will increase. Then the construction industry will be able to benefit from the principles of mass customization. Reuse of design of components and/or modules can be beneficial due to efficiency and effectiveness, considering time, costs and quality.
3. *Degree of components customization*
   Infrastructural structures are mostly designed from scratch, as every project as considered as unique. The constructions are hereby highly customised to meet the specific on-site circumstances and requirements. By the implementation of a product platform, the degree of customization of components will decrease, as the design has to comply with the interface of the product platform. However, some degree of customization is needed. Hence the reference object can be obtained and adapted to the specific situation in multiple settings. In addition, it is important to note that a product platform can also result in higher customization, as new components can be easily developed based on the common interface. However, this requires careful management, as stated by Emes, Smith and Marjanovic-Halburd: *"Although the technologies used may be well known, the architectural vision or context for each project will be unique." Therefore each project will have his own challenges, which are often difficult to anticipate and without careful management can lead to significant cost and time increases* (Emes, Smith, & Marjanovic-Halburd, 2012).
4. *Complexity and choice of system architectures*
   An infrastructural object is not considered as highly complex in a technical manner. However, the locational circumstances and many stakeholders present in an infrastructural project creates a complex project as a whole. To cope with this complexity, it is essential that at the beginning of a project, a clear choice for a system architecture is made. The implementation of a product platform can significantly reduce the complexity, considering both process and product.
5. *Feedback loops from later to earlier stages*
   Feedback loops are essential for every organisation or product platform to be effective. It is important that the system is constantly optimised and updated to the changing circumstances. Feedback-loops are desired in all phases of the construction project. However, more attention should be given to the application of feedback loops in earlier stages, because adjustments are easier and less costly to make in earlier stages. Feedback in later stages is important to learn from a certain project and take these learning points into consideration when establishing a new construction project.

6. *Intensity of user involvement*
   The user involvement in current construction projects is limited. The client, in the Dutch infrastructural industry mainly RWS, sets up functional requirements that the project outcome has to meet. In this process only limited to no involvement or feedback from the public, the actual users of the infrastructure, occurs. More involvement of the public is desirable to create designs that meet client(mostly RWS) requirements and result in higher user satisfaction.

7. *Uncertainty/change in user requirements*
   In current infrastructural projects, it is not always clear what the client means by the listed (functional) requirements. Therefore, it is suggested to increase the collaboration between client and the structural engineer company; this will result in less uncertainty within the user requirements. In the current situation, the uncertainty is high and could decrease when the client will be involved more in the total process.

The most important aspects that have been used by Hobday to compare industrial practices are elaborated on above. Based on these aspects a table has been developed. The Table 3—1 below gives insight into the current situation in the infrastructural sector. The current statuses of the CoPS elements of Hobaday are mapped, and based on the literature review and discussions with experts, the potential of where infrastructural projects can move to has been identified. Based on this table, it can be concluded that there is still a lot of unused potential and space for improvement by implementing the principles of mass customization within the construction industry.

Therefore, it is interesting to investigate if the principles of standardisation and modularization can be implemented within the infrastructural sector of the construction industry.

CoPS elements (Hobday)	*Very high*	*High*	*Average*	*Low*	*Very low*
Unit cost/financial scale of project					
Product volume (reuse in design in various projects)					
Degree of customization of components					
Complexity and choice of system architectures					
Feedback loops from later to earlier stages					
Intensity of user involvement					
Uncertainty/change in user requirements					

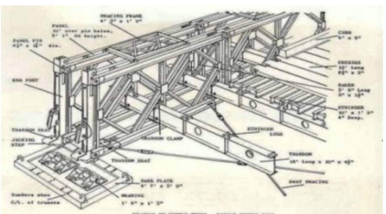
Table 3—1 Current situation in the construction industry: CoPS elements and potential movement for improvement for infrastructure objects

Legend	
	Current situation
	Potential movement for improvement
----- >	*Unused potential*

Table 3—2 Legend: current situation in the construction industry

3.1.1 Application of principles of standardisation and modularization for complex systems

Although a viaduct is a complex structure, this does not mean that it is not possible to apply standardisation and/or modularization. In the Appendix A.11, two examples are given from highly complex products were some form of standardisation and modularization has been applied: Bailey bridge and Shipyard Damen. The examples prove that it is possible and beneficial to standardise and modularize complex systems.



3—1 Example of the application of standardisation and modularization for complex systems: Bailey bridge and product platform Damen

3.2 Components of a viaduct – suitable for standardisation and/or modularization.

3.2.1 General design

Q2.2 - What is a general design of a viaduct? (Considering main practices in the Netherlands)

For this research report, it is vital to understand the standard structural layout of a viaduct. In section 1.3.6, it has already been explained that this research will focus on the development of viaducts from prefabricated elements. This is the main practices within the Netherlands currently, and since a product platform requires the application of prefabricated components. However, in this analysis also types of viaducts are analysed to get a thorough understanding of the structure. A viaduct can be divided into four main parts: the superstructure, the substructure, and bearings and joints. The decomposition of the different components are listed below.

<u>Viaduct: structural components</u>

- **Foundation** **(Fundering)**
- Foundation pad (Funderings sloof tussensteunpunt(en))
- Foundation piles (Funderingspalen)

- **Substructure** **(Onderbouw)**

The substructure can be split up into the following components:

- Intermediate wall/columns (if present) (Pijlers van tussensteunpunt(en))
- Abutment or bank seat (Landhoofd, laag of hoog gefundeerd)
- Capping beam(if present) (Onderslagbalk tussensteunpunt(en))
- Wing Walls (Vleugelwanden van de landhoofden)

- **Superstructure** **(Bovenbouw)**

The superstructure can be split up into the following sections:

<u>*Core elements*</u>

- Deck: Prefabricated beams (Dek: prefab liggers)
- Edge beam (prefabricated) (Randligger: Prefab randligger)

<u>*Extensions*</u>

- Pavement: asphalt (Wegverharding: asfalt)
- Edge element (finishing) (Rand element, esthetisch)
- Parapets (pedestrian + traffic) (Leuningen voor wandelaars + verkeer)
- Upstand (Schampkanten)
- Safety guards (Geleiderails)

- **Bearings, expansion joints and transition slab** **(Opleggingen, voegen en stootplaat)**

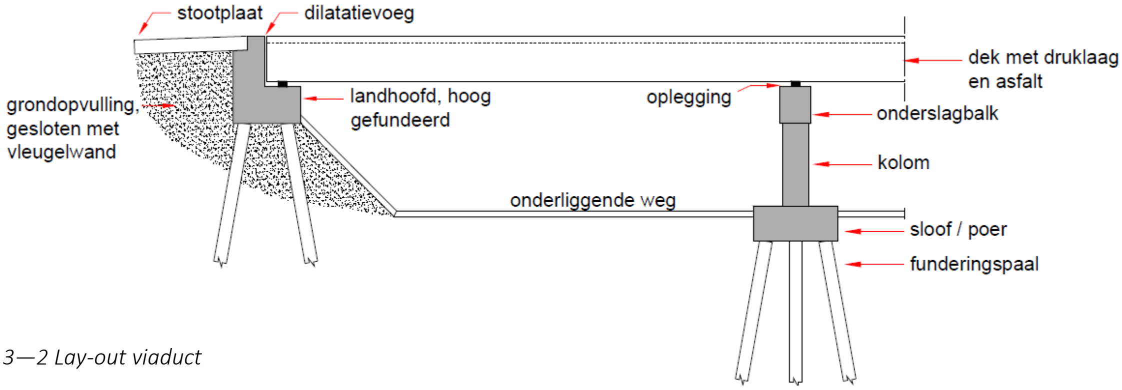
Between the superstructure and the substructure, a bearing is needed to transfer the loads. These transitions consist of bearings and expansion joints.

A viaduct has to provide a smooth passage of a split level of different roads. Key elements for this function are the bearing, expansion joints and transition slab. The transition slab provides a smooth transition from the embankment on the abutment. The expansion joint accommodates this from abutment to the deck and anticipates for the elongation/shortening of the deck due to temperature fluctuations. An expansion joint is needed for a smooth transition from the bridge to the adjacent areas. Moreover, bearings are needed to transfer the loads from the super- to the substructure.

- Bearings (Opleggingen)
- Expansion joints (between abutment/bank seat and beams) (Dilatatievoegen) (tussen landhoofd en liggers)
- Connection between approach slab and abutment/bank seat (Verbinding tussen stootplaat en landhoofd)
- Approach slab (Stootplaat)

<u>Viaduct: non- structural components – Installations + Road</u>

- Traffic signs (Bebording)
- Lighting (Verlichting)
- Cables (electricity etc.) (Kabels)
- Water drainage (Water afvoer)
- Camera's and sensoren (Camera's en sensoren)



3—2 Lay-out viaduct

3.2.2 Type of viaducts

Two types of viaducts can be distinguished: In-situ and pre-fabricated viaducts. As explained in section 1.6.3, this research will focus on the development of viaducts from prefabricated elements, since a product platform requires the application of prefabricated components. Several advantages and disadvantages of the application of prefabricated concrete components are identified and listed below.

Advantages of the appliance of prefabricated concrete components (pretension concrete)

1. *Shorter building time on the construction site*
2. *No moulds are needed to realise the deck (labour-intensive, cause hindrance for the traffic)*
3. *Minimal impact on traffic: lost vehicle hours*
4. *Higher quality of the concrete. The components are produced within the optimal working environment in the concrete factory.*
5. *Relative large spans and slender structures possible*
6. *Various shapes can be developed, that cannot be realised by an in-situ process on site. (In lengths with a limited radius).*
7. *Less expensive regarding the number of beams*
8. *When an integral viaduct is developed, no joints are applied. (Joints are sensitive elements of the construction and require regular maintenance or replacement)*

Disadvantages of the appliance of prefabricated concrete components (precast concrete)

1. *Under each prefabricated beam, a bearing needs to be placed.*
2. *A capping beam and/or an abutment are needed, to support the prefab elements. This has an effect on the architecture of the viaduct. These elements are mainly cast on site.*
3. *It is necessary to arrange for special equipment for transportation, lifting and moving of the prefabricated concrete components.*
4. *Deck is thicker when the deck is realised of an in-situ process with pre-tensioning. The consequence is a significant impact on the total structure, for instance, a higher embankment is required.*
5. *Compared to in-situ viaduct, more expansion joints are needed between concrete elements. Expansion joints can cause damage to the bearings, due to leakage and icing salt. Therefore, bearings of high quality need to be applied.*
6. *Constraints in length and weight of the elements. Due to the transport of the components from factory to the site. Moreover, the components should remain manageable for the construction team.*

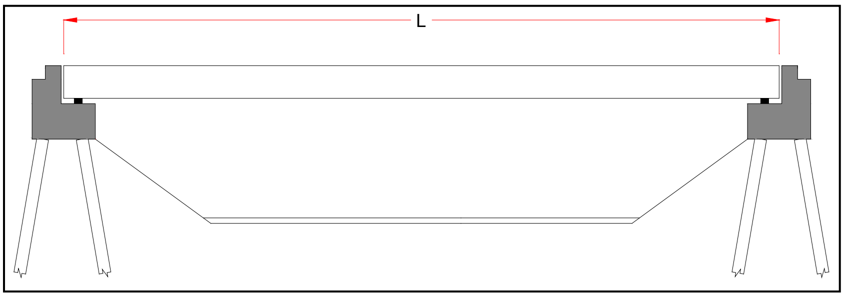
3.2.3 Components of a viaduct

3.2.3.1 Foundation

For the foundation of a viaduct, two main methods can be distinguished: pad foundation and foundation on piles. A pad foundation is well-known as spread foundation (fundering op staal). It makes use of a spread footing of concrete. A spread foundation requires a stable soil; the soil (top and underlying layers) should have sufficient bearing capacity. The other method is the foundation on piles. This foundation is applied in situations where the soil has not sufficient bearing capacity to support the structure. Piles are then drilled or driven into the ground until a depth is reached where the soil has sufficient bearing capacity. The piles are 'vertically' drilled or driven into the soil, with a slope of 5:1 or 1:8. The foundation piles than form a sufficient support structure, the different forces (horizontal and vertical) that are on a viaduct can be distributed to the ground. In the western parts of the Netherlands, the ground does not have sufficient bearing capacity to apply pad foundation. Viaducts are mostly constructed with foundation on piles.

3.2.3.2 Intermediate support (wall or columns)

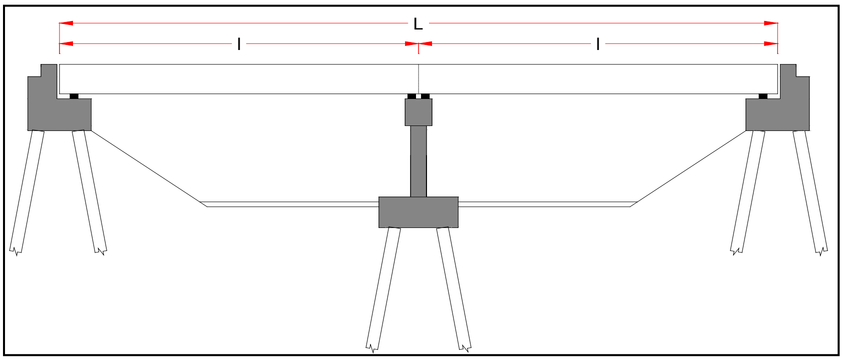
A viaduct can be constructed out of one or multiple spans. If the distance that needs to be spanned by the deck is relatively small, the viaduct can be constructed out of one span. This is the situation as visualised in figure 3—3.



3—3 Conceptual drawing of viaduct with one span

If the distance that needs to be bridged is relatively large, it could be necessary or economically more attractive to divide the distances and apply two or more spans. An intermediate support will need to be constructed. For the intermediate support, mostly columns are applied. However, a wall can also be constructed. This depends on the wishes of the client and architect. In most cases columns are chosen, these give a more open and transparent construction. In addition, it is argued that applying columns is safer for the traffic than applying a wall. The dimensions of the columns are dependent on the forces from the superstructure, collision vehicles and geometry of the adjacent elements.

The columns can be created by an in-situ process or be prefabricated. In general, columns are constructed by in-situ process on-site. Applying prefabricated columns has significant restrictions for the dimensions and weight of the components. The components cannot be too large or too heavy; it still has to be possible transported, handled and assembly the components on-site. However, currently more and more prefabricated columns are applied. For example in the project of the N261, this will be analysed later on in this report. The main advantage of prefabrication perceived is the faster building time. In addition, it is easier to construct columns with different dimension and shapes (aesthetic appearance) can be realised.



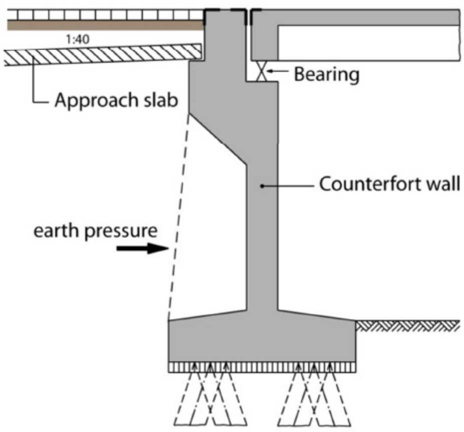
3—4 Conceptual drawing of viaduct with two spans

3.2.3.3 Abutment or bank seat

Within a viaduct, an abutment or a bank seat can be constructed.

<u>Abutment</u>

In figure3—5, a conceptual design of an abutment is visualised. An abutment is a foundation that lays on a certain height from the ground-level. The underlying road that crosses viaduct is located on this ground-level. The abutment forms the connection between the superstructure and substructure of a viaduct. The abutment can be founded on piles, or a pad foundation can be applied. The abutment is a low founded structure. This means the structure is located on the ground-level of the underlying road. This provides the viaduct of a good load distribution from the substructure to the foundation. To prevent that the soil, that is needed for the raising of the ground, will slip away. The wing walls will assure that the soil stays in position.



3—5 Abutment

Several advantages and disadvantages compared to a bank seat are the following:
Advantages:

- The structure is relatively slender. An abutment will be suitable in situation were not a limited space is available

Disadvantages

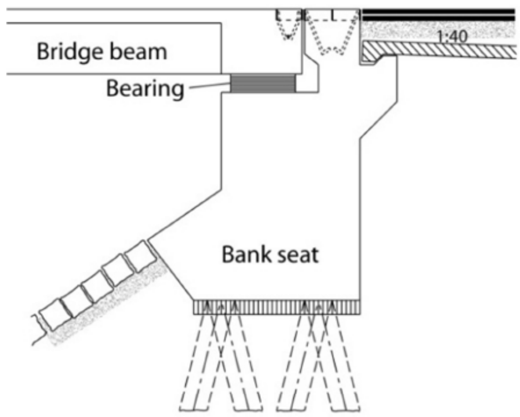
- A relatively high amount of concrete is needed. As the structure has to reach from the foundation located on the ground level to the height of the deck.
- A high horizontal earth pressure from the embankment to the abutment occurs. The counterfort wall needs to be of sufficient strength to be able to bear these forces. The counterfort wall needs to be dimensioned relatively large.
- The foundation (piles) also carries the weight of the soil on top.
- People driving on the road underneath the viaduct experience the abutment in a negative way. It is seen as a narrow passage. When the wall is directly next to the road, drivers are often afraid that they will hit the wall. In reaction to this, the drivers will slow down and will stir away from the construction.

<u>Bank seat</u>
A bank seat is a foundation that lies on top of an embankment. The bank seat has the same functions as an abutment. It forms the connection between the superstructure of a viaduct and the road construction. The bank seat can be founded on piles or on a pad foundation. The bank seat is high founded, an embankment exists with a certain slope. This slope is subjected to different regulations and depends on the specific locational circumstances.

- The slope of the embankment provides more light under the viaduct and gives the drivers on the road better sight of the situation behind the viaduct.
- The bank seat is high founded; this means limited earth pressure is on the bank seat compared to an abutment.

Disadvantages:

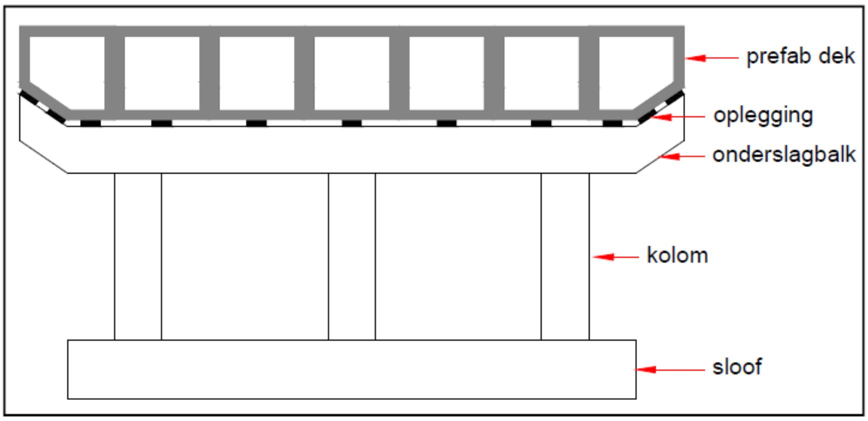
- The disadvantage of a bank seat is an increased span of the viaduct. This result in higher deck beams, increasing costs of the deck and more space needs to be available in comparison to and abutment.



3—6 Bank-seat

3.2.3.4 Capping beam

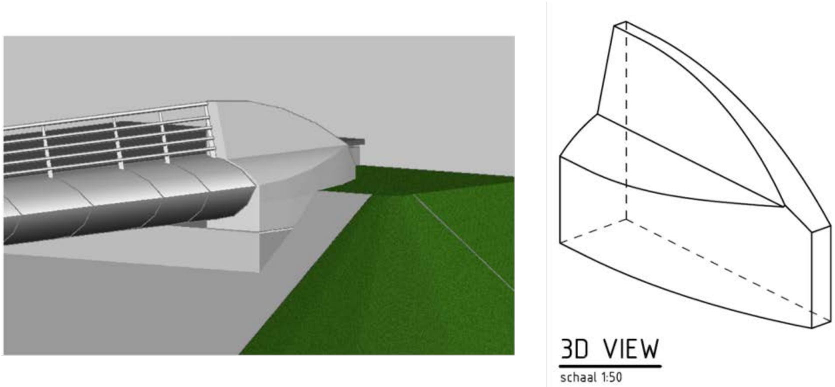
A capping beam is typical for a viaduct that is constructed out of prefabricated parts. The function of the capping beam is to bear and redistribute the forces from the pre-fabricated deck to the intermediate support columns. Within an in-situ viaduct, the beams and the columns are poured on site. This results in a stiff and fixed structure. However, within a pre-fabricated viaduct, this connection is hard to realise. For the intermediate support columns, basic rules are applied. The dimensions of the columns are dependent on the amount of columns that need to be constructed and the distance between these columns. A basic rule that is applicable here is width/height ratio of 2/3. In general, a capping beam is not preferred for a viaduct from an architectonic point of view. The capping beam has a significant impact on the design and on how people experience the viaduct. A viaduct with a capping beam is perceived as less open.



3—7 Capping beam

3.2.3.5 Wing walls

The definition of a wing wall is: “A wall attached to the abutments of bridges or box culverts retaining the backfill of the roadway. The sloping retaining walls are located on each side of a bridge abutment.” The wing walls provide lateral resistance to the forces that are on the structure.



3—8 Wing wall

These forces are caused by the horizontal earth pressure or other material in the backfill of the roadway. The wing walls keep the earth or other material in place, so that the backfill and approach slab will remain in their place. In addition, wing walls minimise settlement of the carriageway by retaining the backfill. Wing walls can have different dimensions and designs, in figure 3—8 a 3D-view of a wing wall of the N261 is given which were prefabricated due to architectural requirements. More common is in-situ wing walls.

3.2.3.6 Deck: Prefabricated beams

Three different types of prefabricated beams

Three different types of viaducts with prefabricated elements in the Dutch infrastructural market can be distinguished. The three different types differ in the type of deck applied. However all three types are pre-stressed. Three main types of prefabricated decks have been listed below and will be analysed in further detail in the following sections.

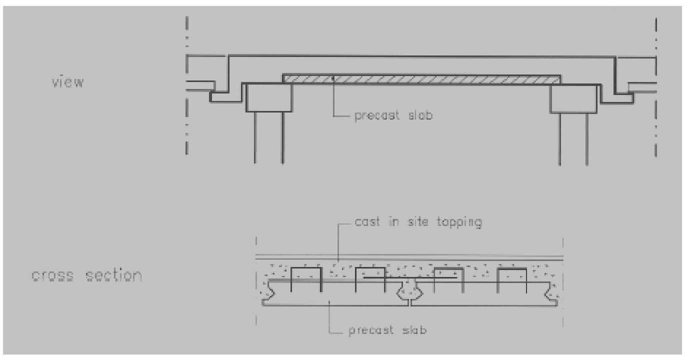
1. *Solid deck beam bridge (for example Volstortliggers)*
   Ratio length/height: 20-25*
   Length of span possible: 6 till 16 meters
2. *T-beam bridge and Inverted T-beam bridge (Railbalken)*
   Ratio length/height: 22*
   Length of span possible: 15 till 45 meters
3. *Box beams bridge (Kokerliggers)*
   Ratio length/height: 30*
   Length of span possible: 15 till 60 m

**The higher the ratio of length/height (slankheidsratio), the lower the height of the beams of the deck will be. A thinner deck is mostly preferred.*

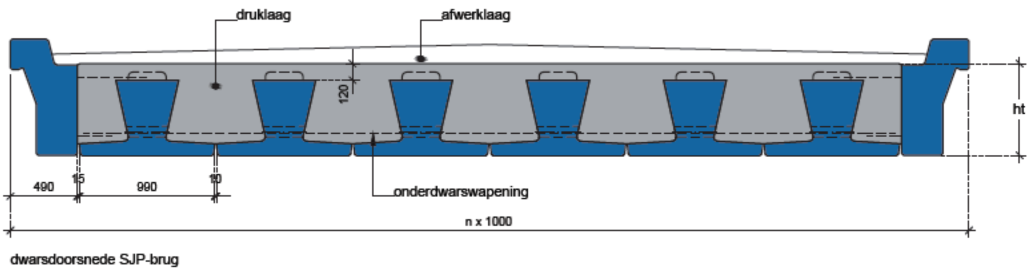
3.2.3.7 Solid deck beams bridge

The solid deck beam bridge is suitable for relatively small spans of around six till 16 meters. The solid deck are constructed out of prefabricated components and a cast (constructed on-site) in-situ topping. The prefabricated components and the in-situ topping together form the deck structure. The prefabricated slabs are pre-stressed, and protruding bars at the top of the slabs ensure a good connection with the concrete topping.For this type of viaducts only prefabricated slabs can be applied. However, the in-situ pouring of concrete completes the deck structure. (Concrete, 2004)

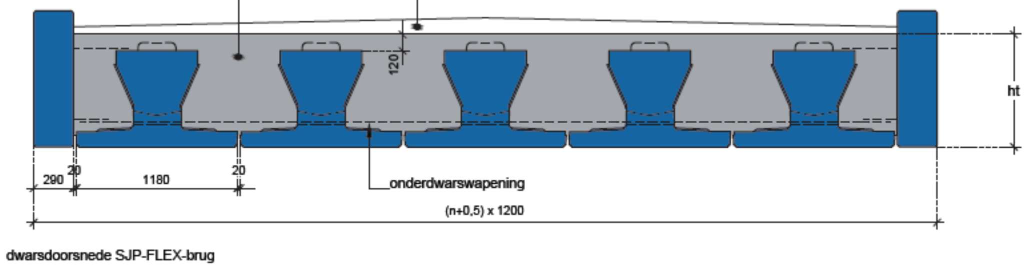
The solid deck beam bridge can be composed out of I-shaped, inverted T-profiles or double T-units. These are placed side by side and are connected to each other by applying an in-situ top layer and filled with in-situ concrete. These deck beams can span a length of approximately six till 20 meters.



3—9 Solid deck beam



3—10 Inverted T-profiles



3—11 Inverted T-profiles

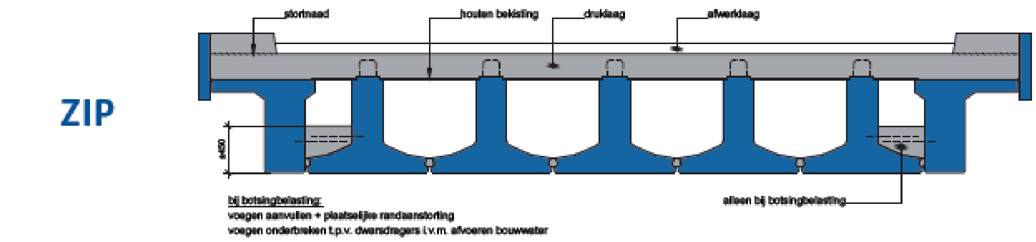
Advantages

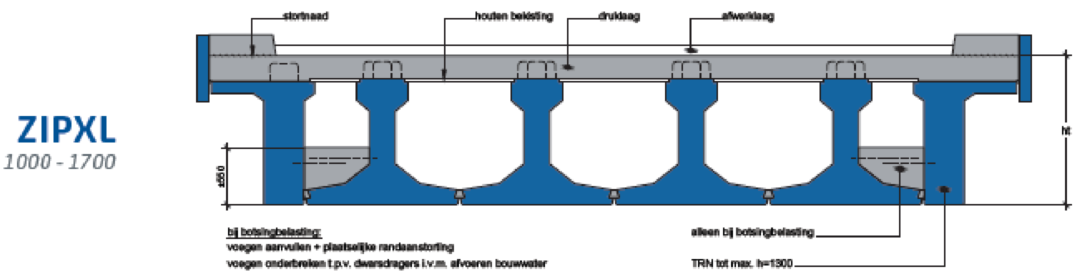
1. Bigger lever in transversal direction. (Hefboom)
2. Can better cope with vibrations, in comparison to a grinder or box beam bridge.
3. The structures constructed with a solid deck are robust and durable (will stand the test of time)

Disadvantages

1. The viaduct is completely constructed out of concrete with reinforcement steel. The space between the I-shaped, inverted T-profiles or double T-units will need to be filled completely with concrete. This results in a massive and heavy structure. The structure requires much material, and the foundation of the viaduct has to be dimensioned to the larger loads.
2. Bearings under the prefabricated beams are needed

3.2.3.8 Girder bridge: Inverted T-shaped or I-shaped beams





3—12 Inverted T-shaped beams

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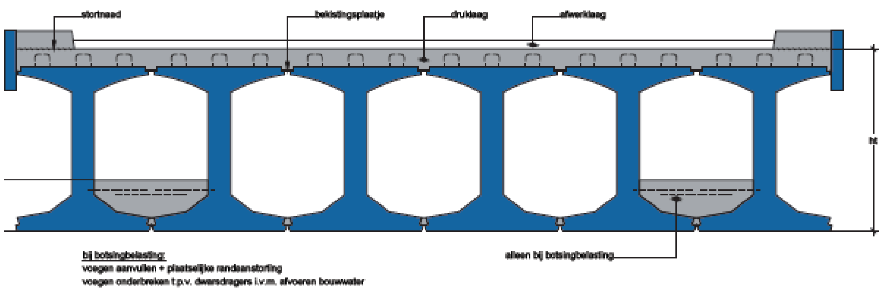


3—13 Inverted I-shape beams

The deck of a girder bridge is composed out of multiple inverted T-shaped or I- shaped beams. A deck composed out of inverted T-beam is suitable for span lengths between 15 till 45 meters. A deck composed out of I-shaped beams is suitable for a span length of 15 till 55 meters. The beams are connected by a transversal diaphragm beam at each support. This diaphragm beam increases the torsional stiffness of the viaduct. From the prefabricated beams, stirrups (steel brackets) arise which are applied to the shear forces and the connection between the prefabricated beam and in-situ top layer. The stirrups make sure that a strong connection of the beams with the structural-topping is established. Compared to a solid deck beam bridge, much material is saved and is economically more attractive.

Advantages

1. Large span till 55 meters can be realised
2. Less concrete is needed in comparison to a solid deck which results in a smaller foundation
3. The beams are connected by a transversal diaphragm beam at each support; a good stiffness of the deck is established.

Disadvantages

1. Special edge-element needs to be constructed. This edge element is only esthetical and will not bear loads.
2. Bearings under the prefabricated beams are needed which require maintenance (every ten till 15years the bearings need to be replaced).

3.2.3.9 Box beam bridge

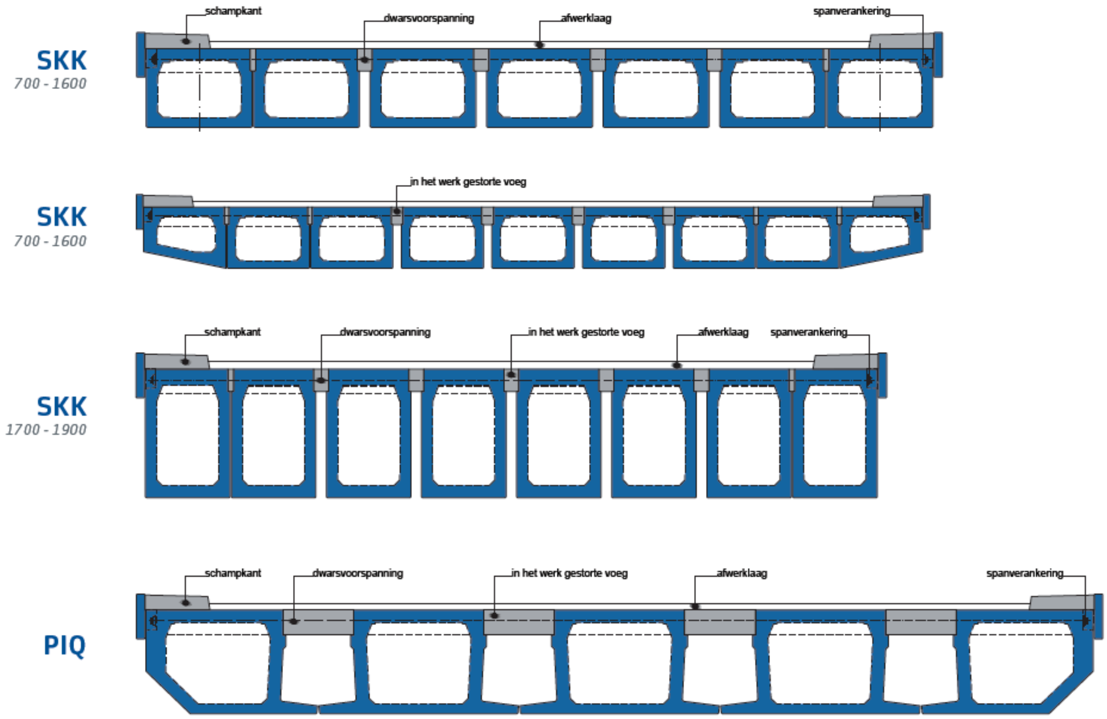
A box beam bridge is a type of viaduct that has a deck composed out of box beams. A box beam has the shape of a box and is hollow. The beam is prefabricated and pre-stressed. These beams are considered to be beneficial if a thin deck is required combined with a relatively large span. For this type of deck, no structural top layer is required. The asphalt layer can be applied directly on the box beams. This is an advantage compared to the T-shaped, I-shaped or solid deck beams. It saves time in the construction process, but also saves time because no curing of the concrete topping is needed. A box- beam bridge is constructed by the installation of the box beams next to each other, side by side. When the box beams are placed, they are connected to each other by transversal post stressing. This post stressing in transversal direction result in a better dispersion of the forces, compared to the inverted T-beams. The post stressing and the pouring concrete in-situ on the longitudinal joints, together result in a stable bridge construction. On top of the box beams the asphalt layer can be constructed directly on the box beams. Because the deck is fully prefabricated, the construction height will be significantly lower compared to other types of beams. In addition, by applying the box beam, horizontally curved bridges can be constructed, this is not possible for a solid deck or an inverted-T beam deck.

Advantages

1. Large span till 60 meters can be realised
2. Lower construction height, compared to the construction of a deck by application of inverted T-shape, I-shaped beams or a solid deck. The lower construction height has an impact on the distance of the ramp needed. A smaller distance of the ramp results in a reduction of the required backfill.
3. Fastest execution method compared to solid decks and girder bridge. After one week the road on the viaduct will be ready, and traffic can cross this road.
4. These edge beams of a box beam deck are not only applied for esthetical reasons, the edge beams can also bear almost the same amount of the traffic forces. They only have another shape, as can be seen in figure 3—14.
5. Large stiffness (torsion), due to the closed profile of the box beam.
6. With box beams, it is possible to make horizontal curved beams.

Disadvantages

1. In general, a box beam bridge is more expensive. This results from the fact that every 1,2-meter post stressing in longitudinal direction has to be applied.
2. Bearings under the prefabricated beams are needed. (maintenance)

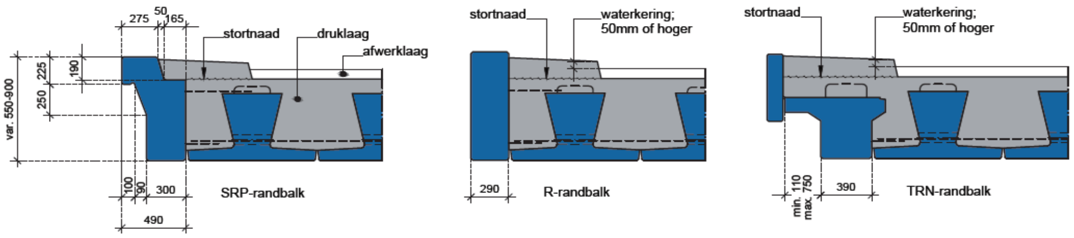


3—14 Box beams

In research conducted by Avinash Gangaram-Panday (2012), it has been concluded that for viaducts with a single span greater than 18m precast concrete box beams is economically the best solution. Spans between 15 - 60m with box beams can be realised. It, therefore, can be concluded that a deck composed out of box beams is suitable for the various situation and in comparison to the other types of prefabricated beams the applicable spans are significantly larger.

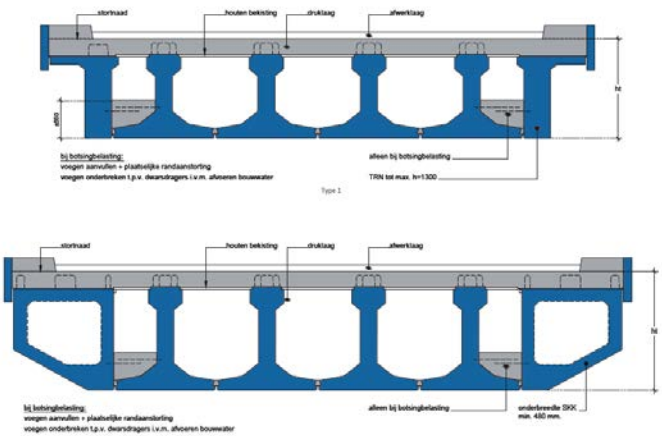
3.2.3.10 Edge beam

In figure 3—15 different options for edge beams are presented (examples from Spanbeton). The prefabricated components are blue, and the concrete that is added by pouring concrete on site are grey.



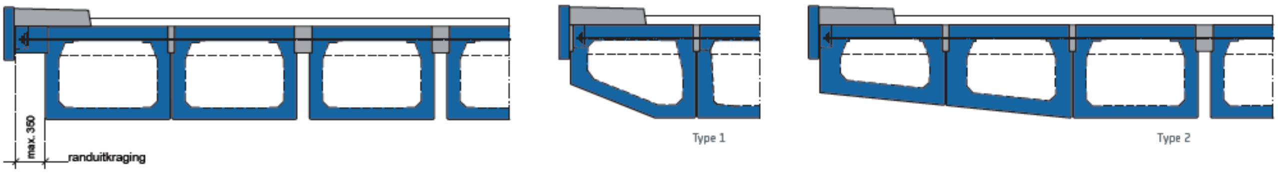
3—15 Options for edge beams for inverted T-profile beams

In figure 3—16 the options for the edge beams of the inverted T-shape beams of Spanbeton (ZIP-Beams) are illustrated.

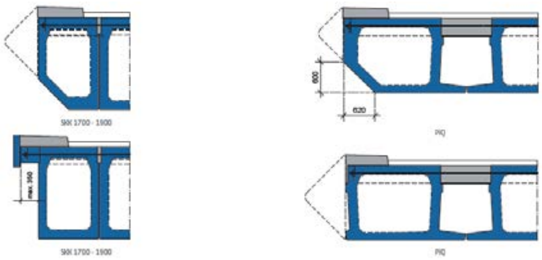


3—16 Options for the edge beam when inverted T-shaped beams are applied

In figure 3—17, below various types of options for the edge beam of the SKK-beam deck are illustrated. In the first illustration, the edge of a box beam deck is illustrated. The edge beam does not differ significantly from the other beams in the deck. The edge beam only has a small extension, and the finishing edge element and upstand are connected to the edge beam. Although, this is a robust and simple way to build a viaduct and the edge beam has the same characteristics as the other beams. For viaduct that is constructed in the Netherlands this it is not applied often. This has to do with the preferred architectonic design of the viaduct. For aesthetic reasons it is preferred that the deck looks thin. The traffic on the road located underneath the viaduct will experience a more open view when an edge beam with a more triangular shape is applied. The angle of the more triangular shape of the edge beam is chosen by the architect. The more triangular shaped edge beams do not have the same strength as the box beams, they will not be able to bear the same forces as the regular box beams in the deck. This needs to be considered during the design phase.



3—17 Various options for edge beams for deck out of box beams



3—18 Various options for edge beams for a deck out of box beams, including the location of edge element.

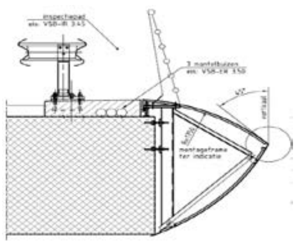
In figure 3—18, several options for an edge element for SKK-beam deck are illustrated. The dotted line here shows how an edge element, for the finishing of the structure, can be situated.

3.2.3.11 Pavement

All the three different deck types require a finishing layer. Mostly, asphalt is applied. When an inverted T-shaped, I-shaped beams or solid deck beams are applied. An in-situ concrete topping (pressure layer) needs to be constructed before a finishing layer (mostly asphalt) can be applied. The concrete topping is applied by an in-situ process. The concrete topping makes the beams of the deck one robust structure: one stiff and stable whole. The main reasons to apply this concrete topping is because it results in a deck with higher strength, greater rigidity, while it can handle bigger transverse forces and spread the forces equally over the entire deck. In addition, the pavement is important for the water drainage. The asphalt is put on the in-situ top layer with different thinness's, to provide a small slope for the water drainage. Although mainly in relatively large viaduct the slope is also established by deviations between the height of the columns, the pavement applied contributes to the slope that is required. Another function of the asphalt is that it reduces that amount of noises caused by the traffic.

3.2.3.12 Edge element (finishing)

An edge element is a component of a viaduct which is applied for esthetical reasons. The edge elements are mainly for architectural purposes. The drivers of the vehicles on the underlying road will experience a better view than when they only see the structural elements of the viaduct. The edge element is connected to the edge beam. The edge elements are often constructed out of light weighted and durable materials. Currently, fibre reinforced polymers and aluminium are often applied

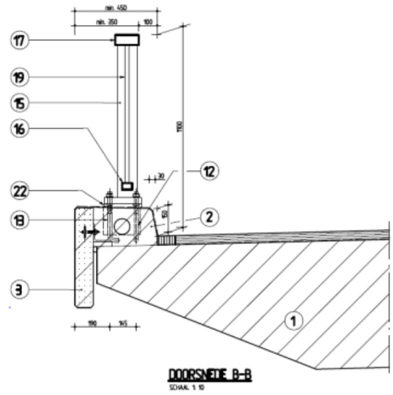


3—20 Edge element N261

3—19 Picture of realised viaduct N261

3.2.3.13 Parapets (pedestrian and traffic)

Parapets are located at the outside of the deck and/or between the different roads and pedestrians. The parapets are placed for safety reasons. They are not designed to handle the forces of a vehicle that hit these parapets because that is the function of the guardrail. The parapets prevent that people will fall off the viaduct.



3—21 Parapets (standard detail RWS)

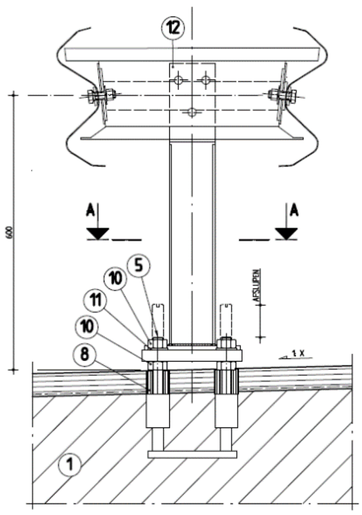
3.2.3.14 Upstand

In Dutch, an upstand is translated as a “schampkant”. This component makes sure that a vehicle (car or truck) will remain in his lane, and by this prevents it from falling off the structure. When a driver of a vehicle does not follow the road properly, the vehicle can hit the upstand. The upstand than assures that the vehicle will not lose track of the road and the driver is warned want the vehicle hits the upstand. An upstand is mainly made out of concrete. The upstand can be effectively made by application of an in-situ construction method, but also by the assembly of prefabricated elements on the building site. However, still many viaducts have in-situ upstands, this is a relatively effective method. The prefabricated elements need to be poured to make a stiff connection to the deck and to make sure it will be able to handle the forces of a driving vehicle. In comparison with an in-situ upstand, this requires more work, but the deck can be ready earlier.

3—22 Upstand on the site and middle of the deck (N261)

3.2.3.15 Safety guards

In Dutch, a safety guard is translated as a “geleidderail”. The public mostly knows this component as “vangrail”. However, this is not the correct technical term. The safety guards are located at the both sides per the road direction. These are recurring for the vehicle. The safety guards are designed so that they can handle the forces of a riding vehicle considering a specified velocity and angle. When the safety guards are hit by a vehicle, they still need to keep functioning.



3—23 Safety guard (standard detail RWS)

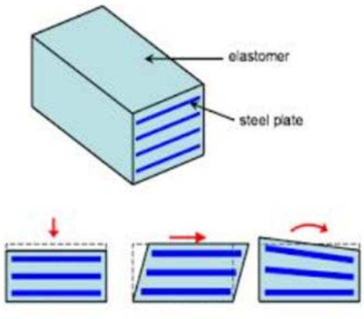
3—24Assembly of safety guards

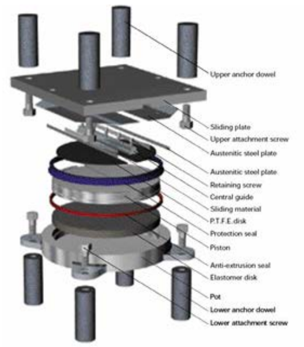
3.2.3.16 Bearings

Bearings are 'blocks' between the deck beams and the abutment/bank seat or an intermediate support wall/column. The bearings transfer the forces of the superstructure to the substructure. The blocks have to be able to bear the forces that are on the deck. The blocks have to be able to bear the forces that are on the deck, the weight of the deck and the dead loads like asphalt. The blocks have to be able to bear the forces, and divide them evenly over the bank seat and/or capping beam.

There are a lot of different types of bearings. However, in the Netherlands, two types are mostly applied within a prefabricated viaduct: elastomeric bearings and pot bearings. An elastomeric bearing is applied the most in the Netherlands. It is a relatively simple component. It is a rubber block with or without steel plate reinforcement within the rubber (not on the outside). An elastomeric bearing can be unanchored or anchored, depending on what is needed in the different situations. A port bearing is more complex and is only applied for viaducts that have a large span.

Both the elastomeric bearings and the pot bearings are placed parallel with the longitudinal axis of the deck beams. This is needed to provide a good transferal of the forces from deck towards the substructure. The bearings need maintenance, every three till five years, depending on the type of bearing and the quality of the material. In addition, the bearings will need to be replaced every ten years. However, this depends on the type, quality, site conditions and the intensity of the traffic crossing the viaduct.





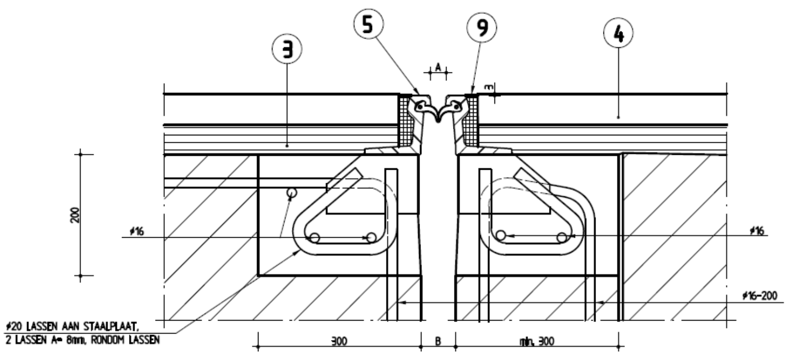
3—25 Elastomeric bearing and pot bearing

3.2.3.17 Expansion joints

The expansion joints provide a smooth transition between the abutment or bank-seat and the deck beams, or between to separated deck beams. The main objective of an expansion joint is to let the superstructure be able to move a little in horizontal direction, without damaging the construction. The expansion joints are flexible and can move with the structure during extension and contraction. They take up the deformation, occurring due to the temperature variations, breaking forces from the traffic and shrinkage of concrete. The main requirements of an expansion joint are:

- Enable the horizontal movement of the different components in the viaduct.
- Reduce the noise when a vehicle crosses over different beams
- Guarantee safety and comfort for the traffic
- Handle the forces of a static and dynamic loads on the viaduct
- Guarantee water tightness, to prevent leakage of salt containing water on the bank seat or capping beam

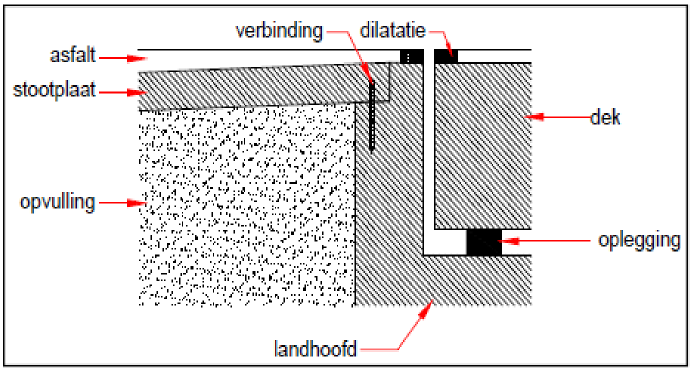
During the design of a viaduct, a rule of thumb for the different components is considered. The components are not allowed to expand or shrink more than one millimetre per metre (mm/m). The longer the deck beams are, the longer the expansion joints will need to be.



3—26 Expansion joint (Standard detail of RWS)

Transition slab (also known as approach slab)

For a viaduct with an abutment or bank-seat a transition slab is required: also named an approach slab. This component creates a smooth transition between the abutment or bank seat which are strongly founded structures with limited settlement to the road structure (before and after the viaduct) which is susceptible to settlement., A relatively small difference between the road and the deck will functionally be not a problem. However, when the difference between the road and the deck becomes too large, the traffic will bump onto the beams of the deck. The approach slab provides sufficient affiliation for the functioning of the viaduct. The approach slab also has a "luxury" purpose, as it provides a smooth transition between the road and the deck. The approach slab combined with an expansion joint together makes sure the road user, that cross over the viaduct, do not experiences a bump due to an unequal surface.



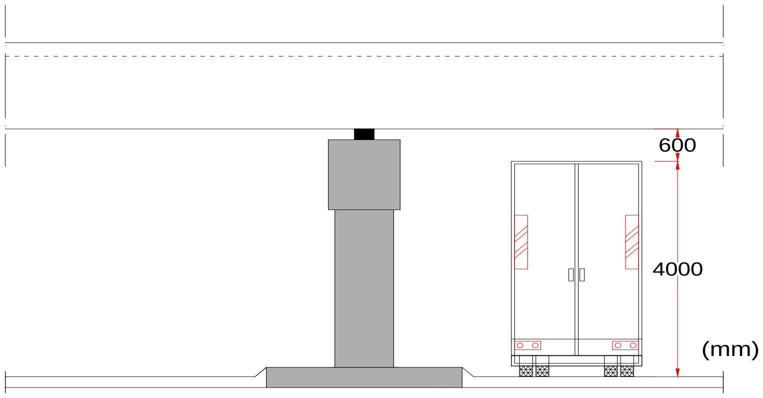
3—27 Transition slab

Each approach slab is joint by application of flexible connection (hinge) and has to be able to settle and/or rotate on the connection point. The approach slab has a length between 2 and 12 meters, and is around 200 to 650 millimetres thick depending on the length of the slab required.

3.2.4 **Additional design aspects**

In this section, additional design aspects that need to be considered in the design of a viaduct are discussed.

3.2.4.1 Free space needed: Profile for required open space.

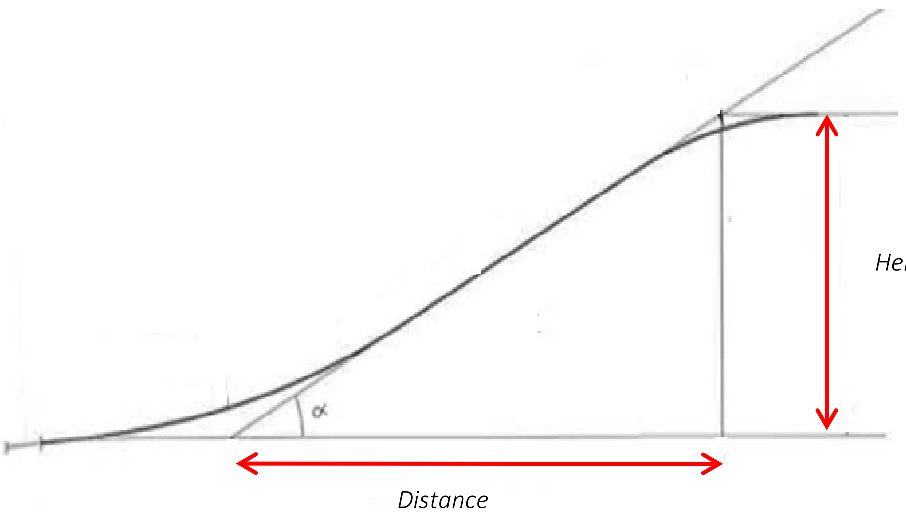


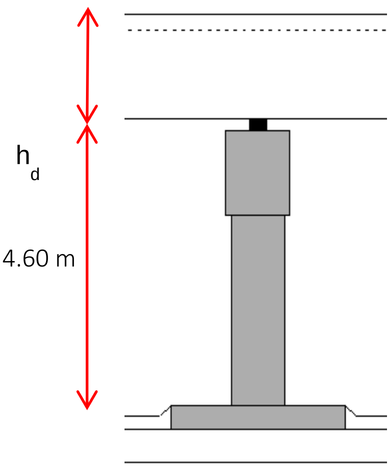
3—28 Profile for required open space

In figure 3—28 the profile for required open space is given. The height of 4,6 meter is based on four factors: height of the normative vehicle (4,0 meters), vertical movement when driving (0,25 meters), minimal vertical distance between vehicle and the deck (0,25 meters) and a reservation (0,1 metres) for in case the structure will sag during the construction life and for overlaying of the asphalt layer. In addition, during the design, it has to be taken into account that the viaduct will have an influence on the view of the driver. Sufficient distance from the different components of the viaduct will need to be provided to mitigate the risks of accidents.

3.2.4.2 Safe slope

The length of the viaduct is determinative for the height of the viaduct. The length of the slope is adapted to the length and height present. The gradient cannot be too large because of safety reasons, and the minimal height and maximal gradient are documented in legislation. The preferred and maximal gradient is based on the allowed maximum speed. For a road where the maximum speed is 100 km/h, a safe slope of 4% is preferred and a safe slope can be 5% at most.





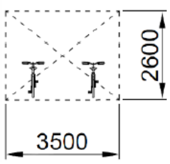
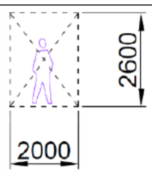
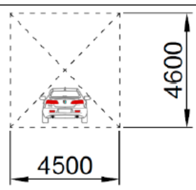
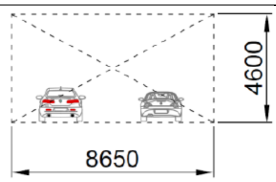
	Bicycles	*Pedestrians*	*Traffic - Auto, one direction*	*Traffic - Auto, two directions*
Visualisation				
Free space height (mm)	2600	2600	4600	4600
Free space width (mm)	3500	2000	4500	8650

Table 3—3 Amount of space required

3.2.5 Morphological table

In this section, a morphological table of a general viaduct, considering the main practices in the Netherlands, is presented.

The components and their various most general options are listed in order of their component number, the same order in which the components are explained before in section 3.2. However is should be noted that a viaduct is designed by a top-down approach. The length of the deck required is the first parameter where the design is based on.

The general options for the components of a viaduct are given. The design team generally makes a choice between these presented options. The morphological table is given below.

Morphological table					
	Component number	**Options the design team can choose from**	**Options processes applied**	**Options materials applied**	**Different dimensions and/or different designs**
Foundation					
Foundation pad	1	General construction by in-situ process	In-situ	Combination of concrete with steel rebar.	Different dimensions
		Prefabricated: divide design in different parts, assembly on site	Prefabricated	Combination of concrete with steel rebar	
		Prefabricated: apply prefabricated moulds that become part of the structure, filling the moulds by pouring of concrete on site.*(suggestion for development)*	Prefabricated	Combination of concrete with steel rebar	
Foundation piles *(Foundation pad is constructed on the foundation piles.)*	2	Spread foundation: no foundation piles are applied. Only a foundation pad. Requires stable soil (soil needs to have sufficient bearings-capacity)	In-situ or prefabricated foundation pad.	Combination of concrete with steel rebar	Different dimensions (standardise dimensions). Only two shapes for the foundation piles can be chosen: round and square.
		Foundation piles screwed into the ground (Schroefpalen).	in-situ	Steel, or combination of concrete with steel rebar	
		Foundation piles drilled into the ground (Boorpalen)	in-situ	Steel, or combination of concrete with steel rebar	
		Foundation piles hammered into the grout (Prefab palen)	Prefab	Pre-stressed and reinforced steel plus concrete	

Substructure					
Intermediate wall/column(s)	3	General construction by in-situ process (pouring of concrete in moulds)	In-situ	Combination of concrete with steel rebar.	Different dimensions and different designs
		Prefabricated columns, assembly and connection on site (connection by pouring of concrete)	Prefabricated	Combination of concrete with steel rebar.	
Abutment or bank seat	4	Abutment: In-situ process (pouring of concrete in moulds)	In-situ	Combination of concrete with steel rebar.	Different dimensions and different designs (choose abutment or bank seat). Although, the design of an abutment are relatively the same, this is also the situation for a bank seat. (General design)
		Bank seat: In-situ process (pouring of concrete in moulds)	In- situ	Combination of concrete with steel rebar.	
		Abutment or bank seat prefabricated: Apply prefabricated moulds that become part of the structure, filling the moulds by pouring of concrete on site. *(suggestion for development)*	Combination prefabricated elements and in-situ process.	Combination of concrete with steel rebar.	
Capping beam	5	General construction In-situ (pouring of concrete in moulds)	In-situ	Combination of concrete with steel rebar.	Different dimensions and different designs. The dimensions depend mainly on the length of the span, deck type and applicable load models. The design can be different because different shapes are designed by the architect
		Prefabricated: out of one part, assembly on site.	Prefabricated	Combination of concrete with steel rebar.	
Wing walls	6	In-situ (pouring of concrete in moulds)	In-situ	Combination of concrete with steel rebar.	Different designs and different dimensions
		Prefabricated	Prefabricated	Combination of concrete with steel rebar.	
		Prefabricated: apply prefabricated moulds that become part of the structure, filling the moulds by pouring of concrete on site.	Combination prefabricated elements and in-situ process.	Combination of concrete with steel rebar.	
Superstructure					
Deck: In-situ	7	General construction by in-situ process	In-situ: braid (construct) rebar on-site. Apply false and formwork and filled with concrete.	Combination of concrete with steel rebar	Different dimensions, but the same type is applied.
Deck: prefabricated beams		Solid deck beams	Prefabricated components with an in-situ topping	Combination of concrete with pre-stressing and rebar steel.	Different dimensions are offered by suppliers.

		Inverted T-shaped or I-shaped beams	Prefabricated components: inverted T-shaped or I-shape beams	Combination of concrete with pre-stressing and rebar steel	Different dimensions are offered by suppliers.
		Box beams	Prefabricated components	Combination of concrete with pre-stressing and rebar steel rebar. Lateral post tensioning on site.	Different dimensions are offered by suppliers.
Edge beam: In-situ	8	Not required. The shape of the edge of the deck is already realised by the shape of the moulds.	-	-	-
Edge beam: prefabricated beams		Edge beam for solid deck	Prefabricated components	Combination of concrete with steel rebar	Different dimensions are offered by suppliers.
		T-shaped beam	Prefabricated components	Combination of concrete with steel rebar	Different dimensions are offered by suppliers.
		Triangular or square shaped box beam	Prefabricated component	Combination of concrete with steel rebar and steel pre-stressing	Different dimensions are offered by suppliers. Dimension depends mainly on the height of the box beams applied in the deck. Different shapes can be chosen.
Pavement: Asphalt	9	Asphalt: finishing layer For solid deck beam and inverted T-shaped or I-shaped beams before the finishing layer (asphalt) is applied. First a pressure layer has to be applied. For box beam bridges no pressure layer has to be applied.	In-situ process	Different asphalt mixtures	Different types can be applied. (this is not future investigated because does not lay in the scope of this research)
Edge element (finishing)	10	Designed for the specific structure. Several options for how the elements are connected to the deck.	Prefabricated components	Light weighted and durable materials: aluminium, composite	Different dimensions and different designs are applied. Depends on the dimensions of the deck and the design of the architect
Parapets (pedestrians+ traffic)	11	Designed for the specific structure: a vision of the architect. However, the design should meet requirements of RWS, see 'standard detail RWS'.(or from other clients, for example, ProRail, provinces and municipalities)	Prefabricated components	Steel, aluminium, composite	Different dimensions and designs. Design depends on the design of the architect. Dimensions have to meet the requirements of RWS.
Upstand (schampkant)	12	In-situ (Prefabricated would be possible, but is not applied, it is not beneficial)	In-situ process	Concrete	Designs are more or less the same, dimensions can defer.
Safety guards	13	Prefabricated: Standard detail of RWS	Prefabricated	Aluminium, steel	Different dimensions: depends on the maximum speed allowed on the road of the viaduct. Design is standard, provided by RWS

		Integrated: Safety guards can be combined with other elements. (example the safety guards for on viaduct within the A12 have been combined with the parapets).	Prefabricated	Combination of concrete and steel rebar	Different designs: designed for the specific situation
Bearings, expansion joints and transition slab					
Bearings	14	Elastomeric bearing	Prefabricated	Rubber block, with or without steel reinforcement plates.	Different dimensions. Depends on the dimensions of the beams and the abutment/bank seat. Different types: basic principles are the same, but differ within the amount of steel reinforcement plates applied Elastomeric bearings are generally applied. Pot bearings are more complex and only applied for viaducts that need to have a large carrying capacity.
		Pot bearing	Prefabricated	Rubber block, with or without steel reinforcement plates.	
Expansion joints	15	Different expansion joints can be applied. However, these options are provided by RWS in the RTD document. In the RTD document guidelines formulated. RWS has made these guidelines based on their experiences with expansion joints.	Combination prefabricated elements and in-situ process.	Concrete, steel, rubber	Different dimensions: depends on the length of the span. Different designs are provided by RWS
Connection between	16	Standard process (not a component)	In-situ	Concrete	Always standard process
Approach slab	17	On basic design is applied: rectangular concrete plate. For each approach slab, a flexible connection (hinge) is applied (the approach slab can by these move with the structure, it can settle or rotate on the connection point)	In-situ	Concrete, with steel rebar	Different dimensions. However, the same basic design.
			Prefabricated	Concrete, with steel rebar	Different dimensions are offered by suppliers. Have to make a choice out of the standard dimensions.

Table 3—4Morphological table

3.3 Projects where a form of standardisation and/or modularization has been applied

Q2.3 - What practices, related to standardisation and modularisation, in viaduct development, have been recently established by BAM Infra

Five projects were a form of standardisation and/or modularization for a viaduct has been applied, are analysed. The choice for these five projects is based on the interviews conducted. The projects that are analysed are the N33, A12, N261, in-house research of a reference viaduct, and the tender of the N18.

3.3.1 Analysing the different projects individually – N33 Assen - Zuidbroek

Year of the starting of the project (Tender phase): 2012
Procurement: BAM got awarded the contract. The N33 has been build.
Type of contract: DBFM-contract

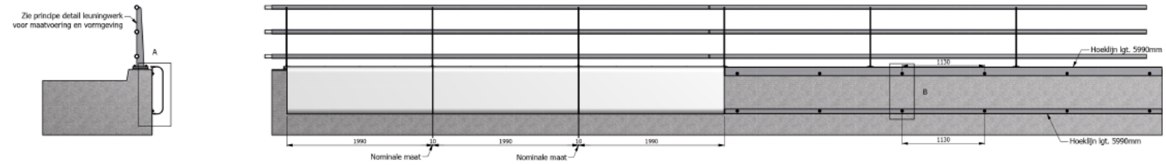
3—29 N33-Assen

The project of the N33 has been put forward by different employees of BAM Infra, as one of the first projects where some form of standardisation of a viaduct has been considered and applied. However, different members of the project team of the N33-Assen, argue that the project team did not apply standardisation and or modularization in the design of the viaducts. At the beginning of the project there was a vision to apply standardisation. However, during the development phase, it became clear that the structures that needed to be designed were significantly different. The application of a standard would not be beneficial.

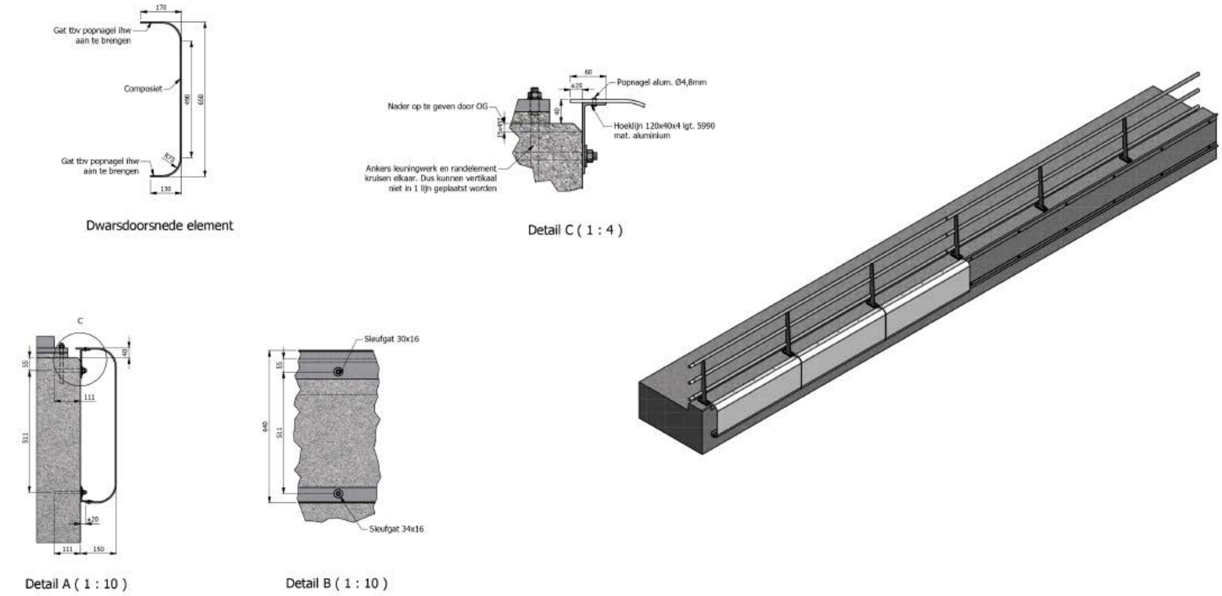
The contract of the N33-Assen is a DBFM-contract, the requirements are specified functional. This means the requirements are not very specific. The requirements mainly subscribe that design has to be developed and constructed for a viaduct to come from point A to point B. The width (amount of roads) needed, and the type of traffic that has to go over the viaduct are specified. In addition to these functional requirements, the project team also has to deal with the design document. This contains the aesthetic requirements, and this document is considered as leading. Another leading document that is of influence is the ROK (Richtlijnen ontwerp kunstwerken). The ROK presents guidelines for the new object. These guidelines (and standard examples for solutions given) are binding. The new design should conform to these guidelines. A result of these binding documents is, there is limited freedom in design, and by this not much freedom to apply standardisation and/or modularization.

Within the N33 the possibility to apply standardisation has been investigated, but there was not sufficient freedom in design to apply standardisation. In addition, if there would have been sufficient freedom in design, applying standardisation would not be suitable. Within the N33-Assen, various viaducts needed to be developed. The viaducts that had to be designed were significantly different. These were of various shapes and dimensions (width, height, etc.), had to fit within the local restriction of the surrounding area, were designed for a different division of the roads and their functions, and even in some cases, artwork had to be realised next to the structure. Because of the limited freedom in design and the fact that all the objects that needed to be constructed were significantly different, standardisation cloud not be applied. The only thing that has been standardised is the edge elements (finishing) of the viaduct. The edge-elements have been standardised to give all the structures of that part of the N33 the same aesthetic appearance; this was preferred by the client. Because for the structures the same finishing (edge elements) has been applied, it gives the impression that the viaducts have been standardised. However, this is not the case.

Although no standardisation and/or modularization were applied within this project, it is still a project with around 25 different viaducts. All the structures were designed by the same project team, and all the components (in-situ and prefabricated) were made on site by the same project team, or are prefabricated by the same supplier. Because of this, there will be a certain amount of repetition in the different structures, but in this case that does not mean that the structures are standardised and/or modularized. Because different members in the project team are of the opinion that no standardisation and/or modularization have been applied, this project is not analysed in more detail. The drawings of the finishing of the viaducts are given in figure 3—30 and 3—31.



3—30 N33- finishing edge element and parapets



3—31 N33- finishing edge element and parapets

In Table A.12.1, given in Appendix A.12, it is explained for which components a form of standardisations is applied, and why it was possible or chosen to apply standardisation. In Table 3—5 an overview is given for which components a form of standardisation is applied. The table shows that some form of standardisation is applied within the N33. However, the standardisations applied are on a small scale and very limited; there is still a lot to be gained.

Standardisation within the N33	Some form of standardisation applied	Prefabrication or In-situ process	Type	Dimensions	Aesthetic appearance	RWS standard detail	Suppliers - catalogues
Components of a viaduct							
Foundation							
Foundation pad	-	In-situ	X				
Foundation piles	-	Prefab					X
Substructure							
Intermediate wall/column(s)	-	Prefab	X		X		
Abutment or bank seat	-	In-situ					
Capping beam	-	Prefab	X				
Wing walls	X	Prefab	X	X			X
Superstructure							
Deck: prefabricated beams	X	Prefab	X				X
Edge beam: prefabricated beams	X	Prefab	X				X
Pavement: Asphalt	-	In-situ	X				
Edge element (finishing)	X	Prefab	X	X	X		
Parapets (pedestrians+ traffic)	X	Prefab	X	X	X		
Upstand (schampkant)	-	In-situ	X				
Safety guards	X	Prefab	X			X	X
Bearings, expansion joints and transition slab							
Bearings	-	Prefab					
Expansion joints	X	In-situ	X			X	
Connection between	-	In-situ					
Approach slab	X	Prefab	X	X			X

Table 3—5 Standardisation applied within N33

Conclusion N33

The project of the N33 has been one of the first projects that investigated if the application of the principles of standardisation was possible and if this would be beneficial. However, there was only limited design freedom, and because of the diverse locational circumstances application of standardisation was not suitable. The client required that the total highway had the same aesthetical appearance. The project team, therefore, designed a standard finishing element (edge element). It has to be noted that this element was designed because it was required by the client, and for this specific aspect sufficient design freedom was given. Although, members of the project team have argued that standardisation was not suitable and has not been applied within the N33. Still, there is some amount of repetition present. The various structures (25) all had different circumstances, but also many similarities were present. The N33 is a clear example of a project where the project team thought regarding the differences, but should have focused more on the similarities.

Four conclusions can be drawn:

- *The client should specify standardisation.*
  If the client does not specify that the want to apply some form of repetition, this will not be designed by the project team. The project team will choose a solution that is the most optimal fit for that specific situation.
- *Contractors only have limited freedom in design.*
  The limited design freedom makes it very complex, and in most cases not beneficial or possible, to apply some form of standardisation.
- *When contractors are given sufficient design freedom, application of some form of standardisation can be beneficial.*
- *People are not always aware of the repetition present.*
  Within projects always some amount of repetition is present. However, the different members of the project team are not always aware of the repetition present. They perceive every structure as unique.

3.3.2 Analysing the different projects individually – A12 Poort van Bunnik

The project of the A12 – Poort van Bunnik is situated between Ede and Veenendaal. In this project, some viaducts had to be adapted, and totally new viaducts had to be constructed.

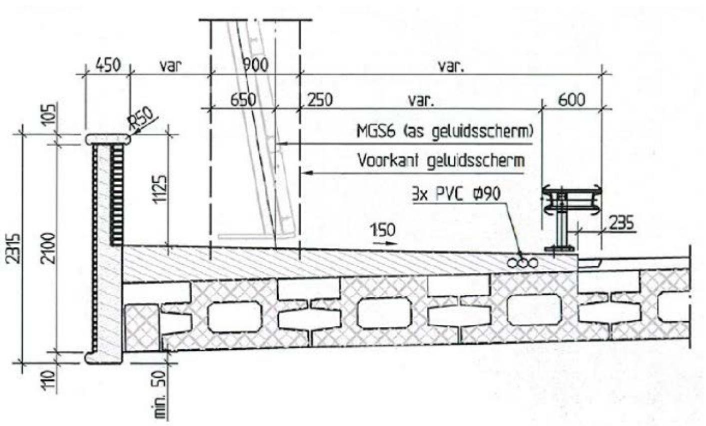
Introduction – A12

Year of the starting of the project (Tender phase): 2014
Procurement: BAM got awarded the contract.
Type of contract: DBFM-contract

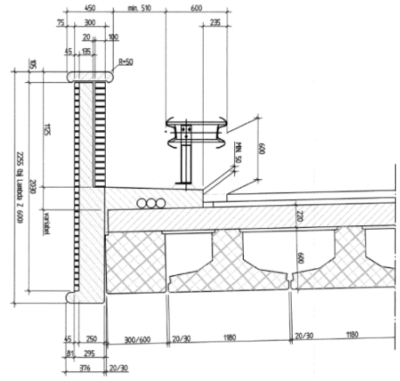
The project of the A12 – Poort van Bunnick is located between Ede and Veenendaal. In this project, some viaducts had to be adapted, and totally new viaducts had to be constructed. The project of the A12 is one of the first large projects for BAM Infra in which a new contract form was applied; a DBFM-contract. In this contract, BAM Infra is responsible for the design, the construction, the finance and the maintenance of road and structures for 20 years. This asked for a new design approach. The decisions that had to be made where not only focused on the initial costs but on the total life-cycle costs. To keep the maintenance cost low, BAM Infra decided to apply a specific type of construction for the structures in the project: Integral viaducts (Integraal viaduct) have been applied. An integral viaduct requires significantly less maintenance, compared to a general viaduct. In general viaducts the expansion joints, connections between and bearings need maintenance every 2 to 5 years, and every five till ten years these components need to be replaced. These are costly and time-consuming processes, and cause hindrance for the traffic because during maintenance closure of the road is needed (lost vehicle hours).

The project of the A12 was a very large project and has been clustered in three phases. Because it was such a large project, it was possible to test certain ideas, the risks of applying an innovation could be spread over the three phases. When a new approach appeared to be effective, this could also be considered for the structures that still needed to be built. The concept could be optimised, and a learning curve was established. However, mainly due to contractual agreements between BAM Infra and the client, application of innovation was not possible in most cases.

Within the project of the A12 one general design of the structures was demanded by the client. The viaducts that needed to be adapted and the new to build viaduct all had to have the same appearance. Therefore, the edge elements of all the different structures were the same for all the viaducts, see figure 3—32 and figure 3—33.



3—32 Edge element always the same



3—33Edge element has the same dimensions

Because the A12 was a very large project, it was very interesting for BAM Infra to apply some form of standardisation. The company could benefit of the repetition that occurred within the project. In Table 3—6 Standardisation applied in A12 an overview is given of the standardisation applied within the A12. In Appendix A.12, the Table A.12.2 explains why certain decisions are made and how the different components of a viaduct are designed.

Standardisation within the A12	Some form of standardisation applied	Prefabrication or In-situ process	Type	Dimensions	Aesthetic appearance	RWS standard detail	Suppliers - catalogues
Components of a viaduct							
Foundation							
Foundation pad	X	In-situ	X	X	X		
Foundation piles	X	Prefab	X	X			
Substructure							
Intermediate wall/column(s)	-	In-situ	X		X		
Abutment or bank seat	-	In-situ					
Capping beam	-	In-situ	X				
Wing walls	-	In-situ	X		X		
Superstructure							
Deck: prefabricated beams	X	Prefab	X	X			
Edge beam: prefabricated beams	X	Prefab	X	X			
Pavement: Asphalt	-	In-situ	X				
Edge element (finishing)	X	Prefab	X	X	X		
Parapets (pedestrians+ traffic)	X	Prefab	X	X	X		
Upstand (schampkant)	X	In-situ	X	X			
Safety guards	X	In-situ	X	X			
Bearings, expansion joints and transition slab							
Bearings	X	Prefab					
Expansion joints	-	-					
Connection between	X	In-situ	X			X	
Approach slab	X	In-situ	X	X			

Table 3—6 Standardisation applied in A12

Based on the Table A.12.2 conclusions can be drawing, these are listed below.

<u>*Conclusion A12*</u>

- *At the beginning of the project the project team needs to investigate if prefabrication of components and application of some form of standardisation is appropriate. It is essential that the project team makes trade-offs and decide on which approach should be applied. The design can then be made with the limitations in mind.*
  Within the A12, in later phases, it became clear that the construction time could be decreased significantly by application of prefabricated foundation pads for three structures. However, during the first design phases, prefabricated foundation pads were not considered. Moreover, by this, the constraints for the transportation of the prefabricated elements were not

considered. The design of the foundation pads had to be adapted, without causing any change in the other components of the viaduct. This resulted in a complex, time-consuming and expensive process.

- *There are limits to the size, shape and weight of prefabricated components, due to transportation and manageability on site.* When prefabrication of the components is the best option, but the components are too big or weight too much for transportation and manageability on site the components can be realised by combining various prefabricated parts. However, although the application of prefabricated parts has many benefits it is not always the optimal solution: 1) Combine prefabricated parts by pouring concrete on-site is more expensive than when the components are made by an in-situ process. 2) It does not always result in a decrease of the time required for the construction, 3) The components need to be dimensioned larger, their size and weight can have a significant impact on the structure.
- *A DBFM- contract provides more freedom in design for the construction company.* Within the project of the A12, there was sufficient freedom in design. It became possible to apply some form of standardisation.
- *Different functions can be combined in one component.* Within the A12 the edge element and the parapets are combined. This is one of the steps Vanessa Veenstra has put forward as possible strategies to reduce the impact of the non-controllable changes; this is further discussed in Appendix A.14.
- *Involving suppliers early and together innovate can be very beneficial.*
- *Collaboration between the architect and the project team is essential. They can together analyse and make the decision to apply some form of standardisation.* Within the A12, the architect, the project leader and other members of the project team together have analysed how one standard dimension that would be applicable for all structures could be established.
- *When a construction company is also responsible for the maintenance of the structures, it can be interesting to apply a technique or material that required less maintenance.* In general this means that the initial cost will be higher. However the maintenance cost will be reduced. Choosing the most optimal design considering a long time period and not only base the decision on lowest initial cost, can result in lower overall costs on the long-term.

3.3.3 Analysing the different projects individually – N261 – Eftelingweg

The project of the N261 is an example of a project where BAM Infra applied standardisation. The project has been very successful and is currently still reviewed by the employees of BAM Infra to learn from the project for new projects.

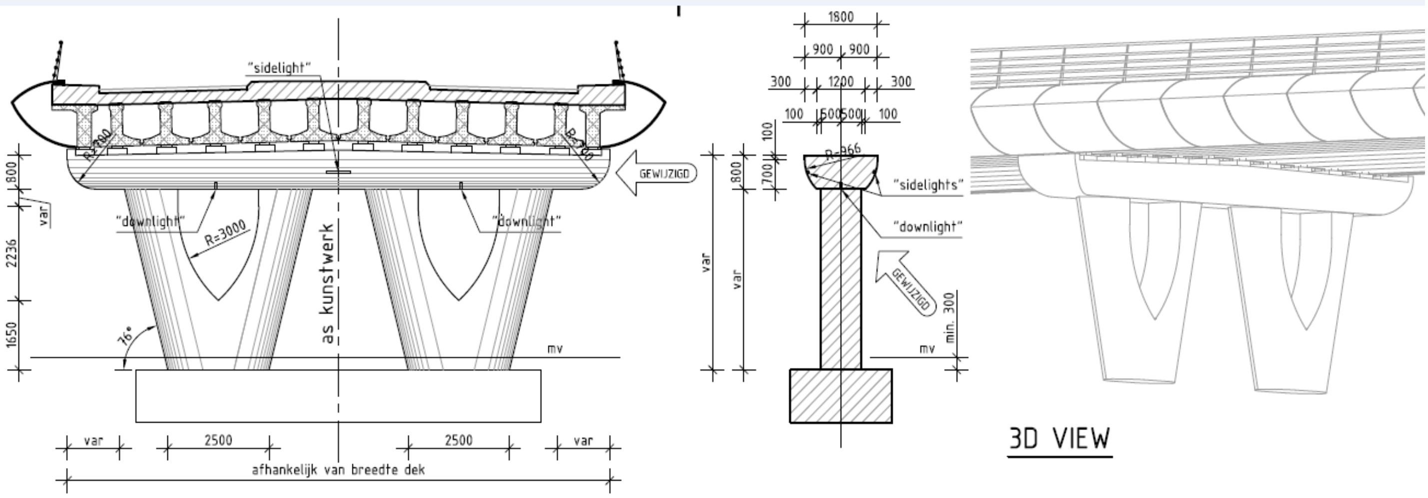
Year of the starting of the project (Tender phase): 2012
Procurement: BAM got awarded the contract. The N33 has been build.
Type of contract: DBFM-contract

BAM Infra got awarded the contract, mainly based on lowest price. However, this price was very low, and not realistic for how BAM Infra worked at that moment. Therefore, innovation of the current practices was needed. A need to innovate occurred. Different steps have been taken to be able to deliver the project of high quality and with sufficient profit margin:

- *BAM Infra chose to apply standardisation, to benefit from the repetition that occurred within the project.*
- *Already at an early stage, the different stakeholders were involved in the design process.*
- *A innovation on product level has been developed and implemented.* This new technique has been accepted by RWS. The proposed technique was not according to the requirements, but BAM Infra could convince RWS that the technique was an effective solution. This new technique gave a new way of working for the “hydrofoberen” of the deck of a viaduct. By “hydrofoberen” the deck is made waterproof, so the water does not negatively affect the structure, for example, it should not be negatively affected by salty drainage water. Before, the process of “hydrofoberen” was applied when the concrete had sufficiently hardened, the concrete then has sufficient strength to apply “hydrofoberen”. This process has to be repeated two times. However, it takes a few days before the concrete is stiff enough. The new technique is based on the application of a small layer of special material that is placed on the concrete deck. This layer can be applied relatively fast after the deck has been assembled, and only one layer is needed. The result of this innovation can save much time, in comparison to the old approach. In the interview conducted with Chris van der Zwaard, he points out that he thinks this has to become the new standard.

These applications of standardisation, involving stakeholders in early stage and the new development of a new technique all have greatly contributed to the success of the project and the project planning. With the result that the project was delivered on time, within the budget and sufficient profit was established.

In figure3—34 below, the concept that has been applied, considering almost all structures, is given.



3—34 Concept applied in (almost) all structures

In Table 3—7 and overview of which components have been standardised is given. The N261 is perceived as the best practices of BAM Infra considering the application of standardisation.

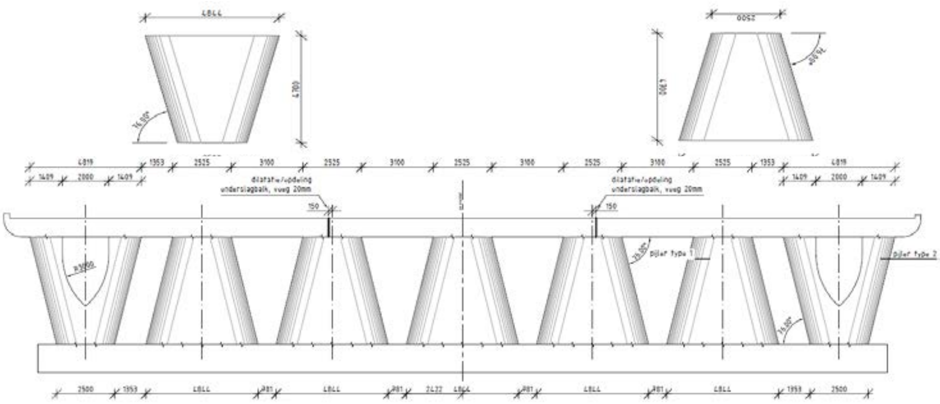
Standardisation within N261	Some form of standardisation applied	Prefabrication or In-situ process	Type	Dimensions	Aesthetic appearance	RWS standard detail	Suppliers - catalogues
Components of a viaduct							
Foundation							
Foundation pad	X	In-situ	X	X	X		
Foundation piles	X	Prefab	X	X			
Substructure							
Intermediate wall/column(s)	X	Prefab	X	X	X		
Abutment or bank seat	X	In-situ	X	X			
Capping beam	X	Prefab	X	X	X		
Wing walls	X	Prefab	X		X		
Superstructure							
Deck: prefabricated beams	X	Prefab	X	X			
Edge beam: prefabricated beams	-	-	X	X			
Pavement: Asphalt	X	In-situ	X				
Edge element (finishing)	X	Prefab	X	X	X		
Parapets (pedestrians+ traffic)	X	Prefab	X	X	X		
Upstand (schampkant)	X	In-situ	X	X			
Safety guards	X	Prefab	X	X		X	X
Bearings, expansion joints and transition slab							
Bearings	X	Prefab					
Expansion joints	X	Combination	X			X	
Connection between	X	In-situ	X			X	
Approach slab	X	Prefab	X	X			X

Table 3—7 Standardisation applied within the N261

Table A.12.3, given in Appendix A.12 discussed why certain decisions are made, and how the different components of a viaduct are developed, an explanation is given. In Appendix A.13, various drawing of the N261 are given, and the standardisation is made clear. To get through understanding of why certain parts are or are not standardise it is advised read Table A.12.3 and to analyse the drawing provided in this paragraph and in Appendix A.13 when reading the text.

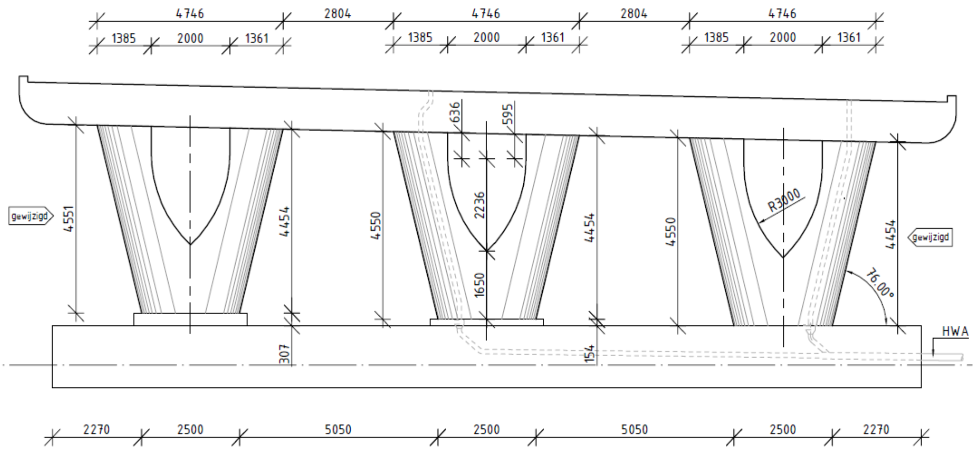
Conclusion N261

- *Application of different forms of standardisation has resulted in efficiency and effectiveness in the design and construction phase*
  In Appendix A.13 an overview is given of the repetition in the different structures. The cost and time for construction were decreased by standardisation of processes and techniques, and by the use of repetitive nature of the project.
- *The project proofs that it is possible to realise unique solutions out of standardised components.*
  Diverse structures have been realised. The structures were developed with a standardise column, which have been prefabricated by application of only one mould. The prefabricated columns could be realised as V-shape or A-shaped. However, the mould for these columns was the same; the V-shape could be turned upside down. The result is an A-shaped column, see figure 3—35 below.



3—35 V-shape turned upside down, into A-shape

In addition, when columns with a lower height needed to be constructed, the same moulds could be applied, see figure K3 in Appendix A13. Only the first part of the moulds was filled with concrete, to prefabricate these smaller columns. However, these smaller columns were more an exception to the rule. Mainly one standardised dimension for the columns has been taken as a starting point. Considering the water drainage of the road on the viaduct, it is required that the deck has a slope. However, this affects the height of the columns. Within the N261 this was solved by constructing small concrete plates with different thickness, see figure 3—36 below. By this still, one main height of the columns could be applied.



3—36 Columns all have the same height, but still slope could be established

- *A new technique/innovation*
  - *Combining prefabricated components on site*
    The prefabricated components were lifted and place on the steel rebar of the other component, see figure 3—37. In comparison to the traditional approach, the assembly process was very fast, and less pouring of concrete was required, the result was that the structure was ready to be used earlier.
  - *Capping beams were prefabricated as U-shaped moulds.*

- Due to limitations in transportation and the assembly process, it was not possible to fully prefabricate the capping beams. Therefore, the capping beams were realised by putting prefabricated U-shape moulds in place and fill these with concrete. The mould became part of the structure. The application of these prefabricated moulds had the advantage that it speeded up the assembly process. In addition, it made it possible to realise the specific shape of the capping beams that was designed by the architect. This could not be have been realised by application of the conventional method of an in-situ process.

3—37 Assembly of prefabricated components on site

- *The highway was finished earlier than required.*
  The highway could be constructed relatively fast, mainly because:
  - *Application of standardisation*
  - *Different stakeholders were involved in an early stage.*
  - *The innovation developed and applied.*
  - *Application of standard prefabricated components for elements that are usually not prefabricate, because of limitation in transportation (size and weight) and the manageability for the assembly on-site.*
- *Freedom in design and cooperation with the client: highly contribute to the success of the project.*
  The way the project has been realised would not have been possible if there was only limited freedom in design. Moreover, dialogues with the client were held to propose certain solutions and to make trade-offs together.
- *The unique design could not have been realised by a conventional in-situ process on-site.*
  The unique design could not have been realised by a conventional in-situ process on-site.
  The prefabrication of the columns and capping beams made it possible to realise the specific shapes the architect had designed.

3.3.4 Analysing the different projects individually – In-house research: Reference viaduct

Year of the starting of the project (Tender phase): 2012, and has been proceeded in 2014.
Current status: The research has not been finished. The research stopped due to the reorganisation within BAM.

As already mentioned, an in-house research for the development of a reference design for a viaduct has been conducted at BAM Infra. The idea behind the development of a standard reference viaduct was that the design could be applied and reused within different projects. The objective of this research was to develop a reference viaduct that could be used as a starting point for the design of viaducts within infrastructural projects. By the application of a standard reference, the project team wanted to the benefit of the repetition that is present within the different projects. The main perceived benefits identified within the research were; decreased project lead times, reduced risk, and a decrease in failure costs. A learning curve could be established, and the product(s), and the processes could be optimised. Although the report has been a good first start for the development of a standard reference viaduct, the report has not been finished, due to reorganisation practices within the Royal BAM Group.

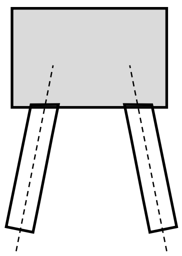
Within the research the most important requirements for the design of the reference viaduct have been identified:
a*) Low costs (mainly considering the initial costs)*
b) Short building time
c) Safety
d) Proven 'state of the art' technology (innovation on technical aspects is not needed, only established practices are analysed)
e) Flexibility: the reference design should be sufficiently flexible, to meet various requirements and different circumstances occurring.

The main positive effect identified by the project team of the research are:

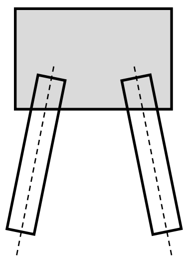
- *Speed-up the tender and design process, and by this will lower the tender and design costs*
- *Increasing the scoring chance – Working from a reference will save time; this time can be invested in other more project-specific aspects/designs.*
- *Increasing the quality of tender, design, realisation and utility phases – The quality can increase due to the learning curve that occurs.*
- *Reduce failure costs and risks, and by this increase the margins in the realisation phase.*

Different technical choices for a standard reference viaduct have been made. Different aspects have been analysed, investigated, discussed within the research team and trade-off tables have been filled in. A small summary of the conclusions that were drawn from this research are listed below:

- *Application of a bank seat (hooggelegen landhoofd) should be the standard for the reference viaduct.*
  An abutment and bank seat have been compared. Trade-off matrices have been filled in and discussions about the tables and their outcome took place. A bank seat was found to be the most suitable for the various circumstances in the Netherlands. This conclusion was confirmed. Currently, a bank seat is applied more often than an abutment within the infrastructure in the Netherlands.
- *Foundation piles*
  The foundation piles need to be "snellen" instead of "boucharderen.

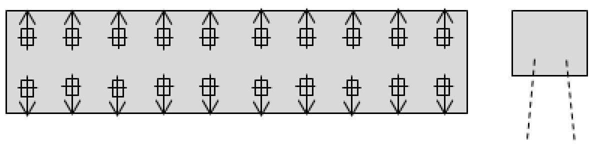


Snellen

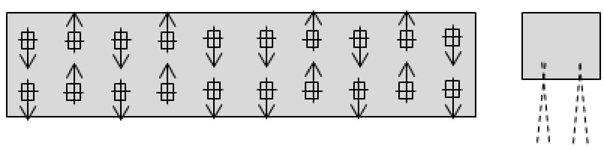


Boucharderen

  Trade-off tables were filled in, and the outcome of the tables have been discussed. "Snellen" was found to be the most optimal. Snellen is more efficient for the steel reinforcement within the foundation pad, and with this method, small deviations that will occur during construction can be handled more easily.
- *Pile configuration of the abutment or bank seat*
  The foundation piles that are located under and connected to the abutment or bank seat should be constructed under an angle of 5:1. The most optimal approach is to apply spread footing (pile configuration – spreidstand), with two piles.

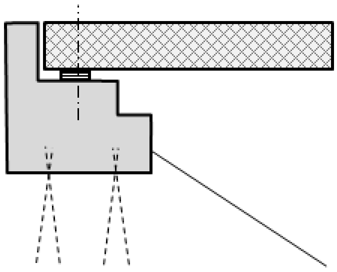


Pile configuration - "Spreidstand."

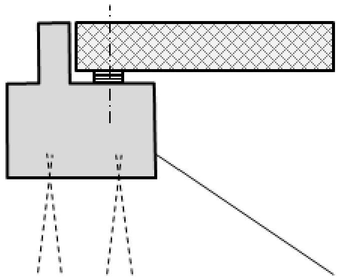


Pile configuration - "Juk stand."

- *Location of the bearing point of the beams of the deck on the abutment or bank seat.*
  The location of the bearings between the beams of the deck and the abutment or bank seat can be placed centric or eccentric, see figures below. Based on discussion and the trade-off tables filled in, the most optimal approach identified is the eccentric placement of the bearings.



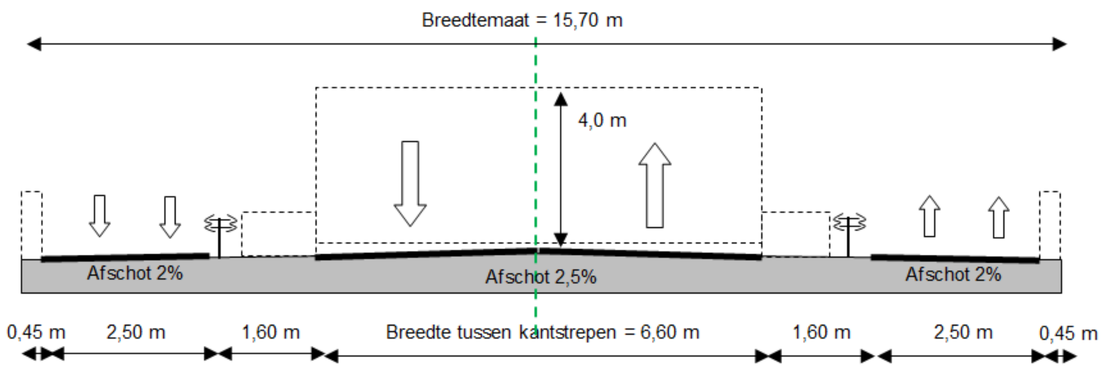
Centric



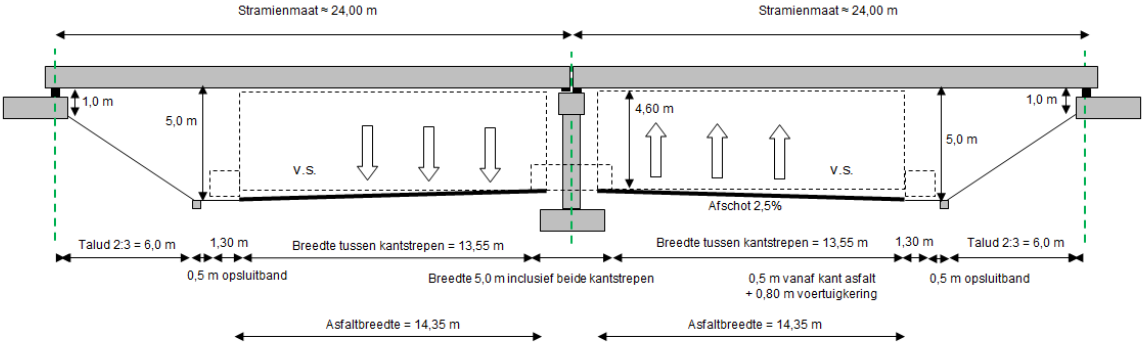
Eccentric

- *Intermediate wall/column(s)*
  For the intermediate wall/column(s) steel rebar (reinforcement steel) should be applied, that are continued from the foundation pad to the prefabricated capping beam. The steel rebar has to be spread over the entire length of the columns.
- *Expansions joints*
  A flexible expansion joint should be applied. For the reference viaduct, the RENO profile is chosen.
- *Connection of the edge element(finishing)*
  The research team has taken the way the edge elements were connected to the deck in the N33 as a reference. To connect the edge element, special measures need to be taken so that a steal connection can be made. The steal where the edge element should be connected to have to be incorporated in the upstand.
- *Prefabricated beams should be applied*
  The deck should be constructed out of box beams with straight edge beams. This conclusion has been drawn based on the research of Avinash Gangaram-Panday. Within the various studies, different type of decks have been analysed, and trade-offs have been made. The outcome of the research was a flow diagram. The flow diagram can be applied within different projects, the most optimal solution for a specific situation can be determined.
- *Standard details Rijkswaterstaat (RWS)*
  RWS provides standard detail for some components of a viaduct; these are the upstand, safety guards, expansion joints and the approach slab. The design of these components needs to be conforming to the standard detail provided. These details have not been investigated within the in-house research. Within the different project, the standard details provide by RWS need to be applied.

Layout of the reference viaduct



3—38 Layout on the road on the viaduct – transverse direction



3—39 General layout of the total structure – longitudinal direction

In Table 3—8, it can be reviewed that the research team had the intention to apply some form of standardisation for all components. In Appendix A.12, table A.12.4 discussed how the different components of a viaduct are designed within the research for the design of a reference viaduct.

Standardisation within the reference viaduct:	Some form of standardisation applied	Prefabrication or In-situ process	Type	Dimensions	Aesthetic appearance	RWS standard detail	Suppliers - catalogues
Components of a viaduct							
Foundation							
Foundation pad	X	In-situ	X	X			
Foundation piles	X	Prefab	X	X			
Substructure							
Intermediate wall/column(s)	X	Prefab	X	X	X		
Abutment or bank seat	X	In-situ	X	X			
Capping beam	X	Prefab	X	X	X		
Wing walls	X	Prefab	X				X
Superstructure							
Deck: prefabricated beams	X	Prefab	X	X			
Edge beam: prefabricated beams	X	Prefab	X	X			
Pavement: Asphalt	X	In-situ	X				
Edge element (finishing)	X	Prefab	X	X	X		
Parapets (pedestrians+ traffic)	X	Prefab	X	X	X		
Upstand (schampkant)	X	In-situ	X	X			
Safety guards	X	Prefab	X			X	X
Bearings, expansion joints and transition slab							
Bearings	X	Prefab					
Expansion joints	X	Combination	X			X	
Connection between	X	In-situ	X			X	
Approach slab	X	Prefab	X			X	

Table 3—8 Standardisation applied within the reference viaduct

<u>*Conclusion reference design*</u>

The in-house research for the development of a reference viaduct provides inside in the different trade-offs that needed to made when designing a viaduct. The initial driver for the research was to develop a reference design that could be applied and reused within different projects. The reference design should be a starting point for the project team, and the design should be adapted to fit the specific situation. The main positive effect identified within the research are: speed-up tender and design process, increase the scoring chance, increase the quality of all phases, reduce failure costs and risks. However, the research was ended abruptly due to the reorganisation within BAM Infra (before BAM Civil).

The research was a great start and should be continued. The insights gained have to be shared within the organisation. However, developing one reference design that should fit in the most situation occurring will not be possible. It is advised to continue the research by making flowcharts of the decisions that need to be taken. When a viaduct needs to be designed, the flowcharts should be used and the trade-off tables provided in the flowchart need to be analysed. The outcome of the flowcharts should be applied for their current project. People need to become aware that application of the flowcharts will result in a more effective and efficient process. They need to trust the outcome of the research and not “to reinvent the wheel” again for every general viaduct that needs to be designed. However, support of the employees of BAM Infra is needed. Implementing a new approach will not be easy. This will be further elaborated on in the synthesis of this research, in chapter five.

3.3.5 Analysing the different projects individually – Tender N18

Year of the starting of the project (Tender phase): 2016
Procurement: BAM Infra did not get awarded the contract
Type of contract: DBFM-contract

The tender of the N18 is a recent example of a project where BAM Infra applied standardisation and by this benefit from the repetition that occurs within the project. The tender team needed to develop a project design and project plan that could be constructed for a relatively low price within a limited timeframe. Time and quality were the most important factors. The A12 and N261 have been reviewed by the tender team, to learn from these projects and analyse if some aspects could be applied in the tender as well.

Points that can be noted about the design process of the tender of N18:

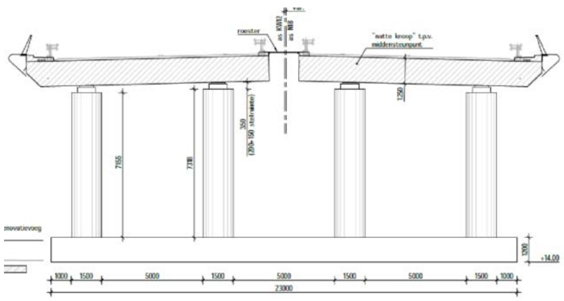
- Already in an early stage, the tender team cooperated with suppliers of prefabricated elements. This concerned the general components that are usually prefabricated. For instance, the beams of the deck or the column(s). In addition, the tender team investigated together with a supplier if it was possible and if it would be beneficial to apply prefabricated foundation pads and prefabricated abutments/ bank seats. BAM Infra had good experience with RomijnBeton as a supplier in the previous project of the N261 and therefore had asked them for the tender of the N18. As elaborated on in section XXX, the application of standardising prefabricated concrete components for almost all components has been very successful.
- During the development of design, the tender team was steered by their design and project leaders to combine already established/applied methods and designs. The tender team was not triggered to be innovative by thinking ‘out of the box’ and fully design a new concept, but to be innovative by combining already established design and practices. This means the project team was encouraged to copy and learn from already established projects. Within the interview conducted with Leon Hendriks. Leon Hendriks has argued that we can develop a standard, the difference between certain designs are only marginal. He has pointed out that there were many similarities between the objects that needed to be designed. In the design, the project team tried to the benefit of these similarities. The tender team was pushed to combine already established methods and designs that could be suitable for different circumstances. No innovation was established, only already established techniques were applied. The different options were analysed, and trade-off tables were made.
- For the standardisation of the different structures of the N18 the project team mainly focused on: dimensions of the beams, the end beams, the upstand, the parapets, the elements for the finishing of the design and other architectonic details. This with the goal of developing one detail that could be applied to all the different objects within the project. The standard detail had to apply to the various circumstances, to benefit of the repetition present. Within the interview, Leon Hendriks has argued: *“Only if you had really good and specific arguments, you could differ from the standard details, but this is not desirable”.*
- During the design phase, the project team was triggered to be creative. Brainstorm challenges have been organised. The project team was challenged to think of other ways of making different structures less expensive, and to optimise the products and processes. The tender managers gave the project team a more open description of the listed requirements. By this, there was still room for innovation and some great ideas came out of the sessions. After the session, the ideas were translated into the real requirements listed.
- For the planning of the N18, the planning of the N261 has been reviewed. The same planner that was responsible for the planning of the N261 was responsible for the planning of the N18. The planning of the N261 was used as a reference. Different aspects could be reuse and lessons learned could be considered.

In Table 3—9, given below, it can be seen that, for all the components a form of standardisation has been applied. In Table A.12.5, given in Appendix A.12 explains the design and why certain decisions are made within the tender.

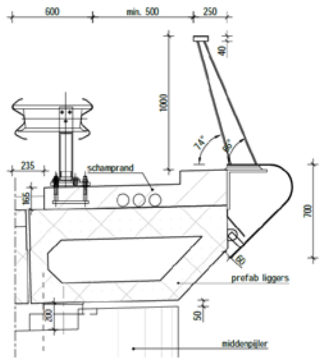
Standardisation within the tender of the N18	Some form of standardisation applied	Prefabrication or In-situ process	Type	Dimensions	Aesthetic appearance	RWS standard detail	Suppliers - catalogues
Components of a viaduct							
Foundation							
Foundation pad	X	In-situ (investigate prefab)	X	X	X		
Foundation piles	X	Prefab	X	X			
Substructure							
Intermediate wall/column(s)	X	In-situ (investigate prefab)	X	X	X		
Abutment or bank seat	X	In-situ (investigate prefab)	X				
Capping beam	X	In-situ (investigate prefab)					
Wing walls	X	In-situ (investigate prefab)	X		X		
Superstructure							
Deck: prefabricated beams	X	Prefab	X	X			
Edge beam: prefabricated beams	X	Prefab	X	X			
Pavement: Asphalt	X	In-situ	X				
Edge element (finishing)	X	Prefab	X	X	X		
Parapets (pedestrians+ traffic)	X	Prefab	X	X	X		
Upstand (schampkant)	X	Prefab	X	X			
Safety guards	X	Prefab	X	X		X	
Bearings, expansion joints and transition slab							
Bearings	X	Prefab	X	X			
Expansion joints	X	Prefab	X	X			
Connection between	X	In-situ	X	X			
Approach slab	X	Prefab	X	X			

Table 3—9 Standardisation applied within the tender of the N18

In figure 3—41 a detail of the N18 is presented, this edge details is reused within the design repeatedly. In figure 3—41, a conceptual section profile is given from a viaduct.



3—41 Section profile viaduct N18



3—40 Detail of tender of the N18 - Edge-element

<u>*Conclusion Tender of the N18*</u>

Within the tender, there was a clear focus on the repetition that occurred and how to benefit of this repetition. The project leader challenged the project team to make a design that could be developed in an efficient and effective way. Although a great design had been developed, BAM Infra did not get awarded the contract. The plan ended up at the second place. Both Kitting Lee, the tender manager and Leon Hendriks the project leader, have highlighted in the interviews conducted that they would no change anything if they had to do the tender again. A summary of aspects that contributed to the development of an effective and efficient design, are listed below.

- *Sessions with the project where hold: Team was challenged*
  Sessions with the project team were held. The project team was challenged to think of other ways of making different structures less expensive and optimise the product and process. Some great ideas can forward out of these sessions.

- *No innovations were developed.*
  Only already established/applied methods and designs are combined and applied. Current practices were optimised.
- *Only one detail for every type of component was applied*
  The vision was to develop only one detail for every component that could be applied to all the different objects that needed to be realised. This detail became the standard and should always be applied. Only when there were extensive reasons another detail could be applied.
- *Trade- off tables were made*
  For every situation, trade-off tables were applied to be able to choose the most optimal solution.
    - In an early phase, the project team looked for similarities and repetition. Spreadsheets have been made, based on these sheets the most optimal standardised dimensions for the various components were identified. For example, the lengths of the deck are divided into five standard dimensions and three different deck heights are applied. The standardisation of the dimensions of the deck made it possible to standardise the dimensions and shape of the edge beams and de edge elements.
- *Over-dimensioning of design*
  Standardising the dimensions of elements resulted in over dimensioned designs. However, this eventually was less expensive, due to the repetition. (considering the design, the production and the actual construction on site).
- *Other projects have been analysed*
  Projects of the A12 and N261 have been analysed by the project team: get insights and ideas, and analyse the lessons learned.

3.3.6 **Comparison N33, A12, N261, reference viaduct and tender N18**

The analysis of the standardisation in the N33, A12, N261, the reference viaduct and the tender of the N18 shows that BAM Infra currently already tries to benefit from the repetition that occurs within projects. BAM Infra already applies some amount of standardisation within their projects. The projects have been discussed in the order of the year when BAM Infra started to work on the project. Taking this in consideration and analysing the general Table 3—10 Application of some form of standardization, application of standardisation given on the next page, it can be concluded that the application of standardisation within projects of BAM Infra is increasing. However, there is still a lot to gain for BAM Infra on this point. The main conclusions drawn are listed below.

- *Application of different form of standardisation has resulted in efficiency and effectiveness in the design and construction phase of the projects.*
- *Review and analysis of already established projects are increasing.*
  This is a very good development. If a database would be created, where employees can review other projects and search for specific aspects or components of the database, it will facilitate the review and analysis of established projects.
- *Trade-off made need to be shared*
  In every project, trade-off tables are made. The trade-off tables can provide great insights, and different aspects could be reused. The trade-offs should not be made again for every project individually. This could save time, and it will be easier to identify the optimal solution over time. Within the N18, the trade-offs made in the N261 have been considered; this is a good development.
- *By application of standardise dimensions and combining of standardise components, still, various structures can be created.*
- *Cooperation with the client and suppliers, and together make trade-offs, can be beneficial.*
- *It is technically feasible to develop a viaduct fully out of prefabricated components.*
- *For certain objects, standard details provided by RWS are applied.*
- *Difficult to work in a more project-exceeding: innovations cannot be directly copied, and each project has different circumstances and requirements and therefore different optimal solution.*
  It has become clear that across the different projects there always are similarities. However, an innovation developed specifically for a certain project cannot be directly copied to a new project. The projects are significantly different. This means innovations that at first site look like the could be applied within a new projects eventually are not suitable.
- *Important that already in an early stage the repetition that could be possible to benefit from should be analysed and identified.*
    - *Design should be focussed on the repetition: seek for similarities*
    - *Involve suppliers early in the design project: together think of solutions*
- *The principles of modularization are not applied.*

Although some amount of standardisation is applied by BAM Infra, the principles of mass customization industry are not yet implemented in the current way of working of the company. The principles of modularization have not yet been applied by BAM Infra. However, this approach has potential.

		N33		A12		N261		Reference viaduct		Tender N18	
		Standardize and/or modularized	Prefabrication or In-situ process	Standardize and/or modularized	Prefabrication or In-situ process	Standardize and/or modularized	Prefabrication or In-situ process	Standardize and/or modularized	Prefabrication or In-situ process	Standardize and/or modularized	Prefabrication or In-situ process
Foundation											
	Foundation pad	-	In-situ	X	In-situ	X	In-situ	X	In-situ	X	In-situ (investigate prefab)
	Foundation piles	-	Prefab	X	Prefab	X	Prefab	X	Prefab	X	Prefab
Substructure											
	Intermediate wall/colomn(s)	-	In-situ	-	In-situ	X	Prefab	X	Prefab	X	In-situ (investigate prefab)
	Abutment or bank seat	-	In-situ	-	In-situ	X	In-situ	X	In-situ	X	In-situ (investigate prefab)
	Capping beam	-	Prefab	-	In-situ	X	Prefab	X	Prefab	X	In-situ (investigate prefab)
	Wing walls	X	Prefab	-	In-situ	X	Prefab	X	Prefab	X	In-situ (investigate prefab)
Superstructure											
Core elements	Deck: prefabricated beams	X	Prefab	X	Prefab	X	Prefab	X	Prefab	X	Prefab
	Edge beam: prefabricated beams	X	Prefab	X	Prefab	-	-	X	Prefab	X	Prefab
Extension	Pavement: Asphalt	-	In-situ	-	In-situ	X	In-situ	X	In-situ	X	In-situ
	Edge element (finishing)	X	Prefab	X	Prefab	X	Prefab	X	Prefab	X	Prefab
	Parapets (pedestrians+ traffic)	X	Prefab	X	Prefab	X	Prefab	X	Prefab	X	Combination I+P
	Upstand (schampkant)	-	In-situ	X	In-situ	X	In-situ	X	In-situ	X	Combination I+P
	Safety guards	X	Prefab	X	In-situ	X	Prefab	X	Prefab	X	Combination I+P
Bearings, expansion joints and transition slab											
	Bearings	X	Prefab	X	Prefab	X	Prefab	X	Prefab	X	Prefab
	Expension joints	X	In-situ	-	-	X	?	X	Combination I+P	X	Combination I+P
	Connection between	-	In-situ	X	In-situ	X	In-situ	X	In-situ	X	Combination I+P
	Approach slab	X	Prefab	X	In-situ	X	Prefab	X	Prefab	X	Prefab

Table 3—10 Application of some form of standardization

The conclusions show that it is technically feasible to apply some forms of standardisation in large infrastructural projects and a viaduct. Some first steps are already taken in current practices of BAM Infra. However, they are currently struggling to work in a more project-exceeding manner. This considering their own practices of reviewing established projects, reuse trade-offs or further develop innovations. However, also considering the cooperation with the industry required for the successful application of standardisation and working project-exceeding. A viaduct is suitable for the application of the principles of standardisation and modularization, but the current way of working hampers the implementation, although there are some developments in the good direction.

3.4 IDENTIFY COMPONENTS SUITABLE FOR STANDARDISATION AND MODULARIZATION

Q2.4 - How can it be identified whether or not the application of the principles of standardisation and modularization for objects in the civil infrastructure sector are suitable. And which components of a viaduct can be identified to be suitable for standardisation and modularization?

3.4.1 Method to identify components suitable for standardisation and modularization

To develop a method to identify whether or not the application of the principles of standardisation and modularization for objects in the civil infrastructure sector are suitable, and which components of a viaduct can be identified to be suitable for standardisation and modularization, the method of Vanessa Veenstra is taken as guidance. Vanessa Veenstra distinguishes three phases in her method. Within the method, various methods of other researchers are combined. In this research, the Design for Variety (DFV) method of Martin and Ishii is the most important method that has been applied for the infrastructural object: a viaduct. The method of Design for Variety and the method of Vanessa Veenstra are presented in this section; full explanation and description of step to take are given in Appendix A.14. If the reader is not familiar with this method, it is advised to read the description given in the appendixes first, where after continue reading.

3.4.1.1 Design for variety

Within all industries, the demands on possibilities to offer a high variety of products has increased significantly in the recent years. To stay competitive companies need to deal with this demand for a high variety of products. Kipp and Krause (Kipp & Krause, 2008) emphasise that companies have to constantly adjust their range of products to reduce costs of complexity, which are induced by unnecessary product variants. This can be reached by application of the design for variety method. The method minimises the internal complexity and decreasing costs without reducing the range of products. For construction firms, like BAM Infra, this will mean that they have to reduce complexity, standardise and continuously improve their current products and processes while remaining flexible.

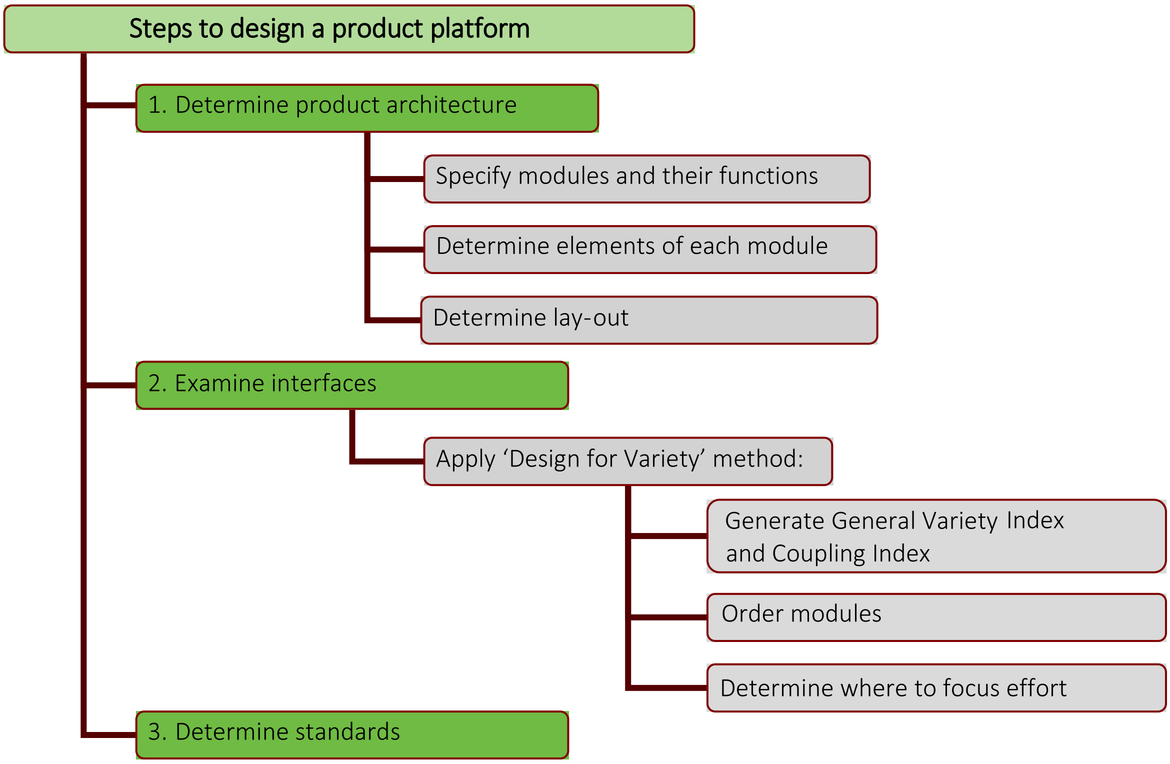
The design for variety method was established by Martin and Ishii (Martin & Ishii, 2002). They defined this as a method for developing standardised and modularized product platform architectures. It is a method for the development of architectures of products with a huge amount of variants. For the method, the different components and their functions need to be identified. In addition, the specific factors, like constraints occurring in different locations or market segments, and (possible) trends that are thought to have an influence, need to be identified. The design team needs to make two tables. First, a table for the General variety index (GVI) needs to be developed. The table considers the possible variety and change of locational circumstances, demands and market developments. Secondly, a table with the coupling between the different components of the product can be analysed. The outcomes of this method are index numbers. Because the design team identifies and analyses the different components and their functions, and the relations between the different components themselves, not only index-value that say something about the product architecture are the result. By going through this process, the different members of the project team will get a deeper understanding of the coupling between functional elements. By filling in the second table, the project team will get deeper insights about factors that possible will occur, and the influence of these factors. This is the estimated changes in specific situations and developments/changes in the market that will have an effect on the product architecture. This approach is described in more detail in Appendix A.14.

3.4.1.2 Protocol for designing product platforms

The protocol for designing product platforms, developed by Vanessa Veenstra is illustrated in figure3—42 (Veenstra, Halman, & Voordijk, 2006). The framework describes the basic elements that constitute a product platform and provides an essential start in the process of designing product platform. The protocol provides practical guidelines and decision rules to help companies develop and manage product platforms effectively. Within this protocol, three main phases can be distinguished. *1) Determine product architecture, 2) Examine interfaces and 3) Determine standards*.

Three main definitions are important:
- *Coupling-index:* A measure of the coupling among the components. It indicates the strength of coupling between the components in a product. The stronger the coupling between components, the more likely change in one will require a change in the other.
Coupling- index R (CI-R), is the coupling index-receiving, this indicates the strength (or impact) of the specifications that a component receives from other components. The coupling index S (CI-S), is the coupling index-supplying, this indicates the strength (or impact) of the specifications that a component supplies to other components.
- *Generational variability index (GVI):* Indicator of the amount of redesign required for a component to meet the future market requirements. The GVI is based on an estimate of the required changes in a component from external (non-controllable) factors.

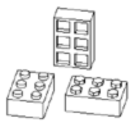
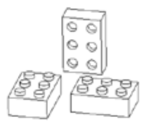
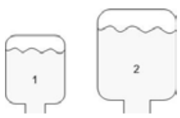
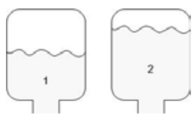
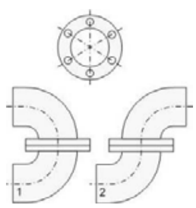
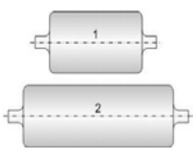
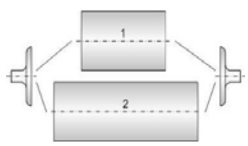
It has to be pointed out that the GVI and CI-R give an indication of how many the components is expected to change. The CI-S is a measure of how likely those changes are to be passed on.



3—42 Protocol for designing product platforms, developed by Vanessa Veenstra (Veenstra, Halman, & Voordijk, 2006)

3.4.1.3 Guidelines for application of the design for variety method

In the article of Kipp and Krause (Kipp & Krause, 2008) different guidelines for application of the design for variety method are identified. The different guidelines are clustered into four categories. In Appendix A15, the categories are explained in more detail. These guidelines can help the project team during the design phase. It gives a clear overview of the possibilities to benefit from the repetition present in products. A few of these guidelines, which are interesting to consider for an infrastructural object are given below.

Design module interfaces compatible.		
Use overdesign to avoid product variants (e.g. tank size).		
Use higher symmetry to generate geometric product variants (e.g. flange design).		
Use cut to fit modularity to create geometric variants (e.g. size variant of a roll).		

3—43 Guidelines for application of the design for variety method derived from Kipp and Krause (2008)

3.5 METHOD APPLIED

In this section the steps that are taken in this research are listed. The method developed and applied is based on the method developed by Vanessa Veenstra, this was discussed earlier in this report in section 3.5. The method of Vanessa Veenstra has been adapted to be suitable for an infrastructural object.

3.5.1 Overview of phases

Phase 1 – Determine product architecture
- *a) Analyse the product and the general background*
- *b) Determine the lay-out*
- *c) Determine the System Breakdown Structure: specify the models*
- *d) Identify the requirements: functional and aspect requirements*
- *e) List components and their function(s)*
- *f) Determine Functional Breakdown Structure.*

Phase 2 – Examine interface: Apply Design for Variety method of Martin and Ishii
- a) Analyse market
    - a. General analysis: determine market needs and identify trends
    - b. Have conversations with experts, various members of the project team and with the client to get a thorough understanding about various aspects of the research field. (infrastructural projects and in specific about a viaduct)
- b) Create General Variety Index table (GVI table)
- c) Fill in GVI table
  Give values of 1, 3, 6, or 9 and rank the chance of occurrence.
- d) Analyse the outcome of the GVI table.
  Which components are most likely to require significant change over time, and/or which components are significantly different in the various situations occurring.

Phase 3 – Determine Coupling-Indexes
- a) Identify the different modules and the lay-out of the structure (can be derived from phase 1)
- b) Develop two tables: direct relationship and parametric relationship
- c) Let different experts and members of the product team fill in the tables.
  Values of 1, 3, 6 or 9 need to be assigned to the different components, considering respectively their direct or parametric relation. It is advised to support the experts and members of the project team with filling in the tables.
- d) Arrange a session
  In this session the experts and members of the product team need to together discuss the tables, and should come to an agreement about the values filled in the table of the coupling indexes.
- e) Analyse results tables coupling indexes
  The tables filled in individually by experts and members of the project team, and the table that was filled in during the session, need to be analysed. The data has to be ranked.

Phase 4 – Draw conclusion
- a) Combine outcome of GVI, CI-R and CI-S in a general table
- b) Identify criteria for how the data should be analysed/ what the data means.
- c) Analyse results and draw conclusions
- d) Determine where to focus effort: where to standardise and where to modularize?
- *e)* Alternatively, apply other strategy: redesign by reducing GVI and CI
  a. Remove current component specifications, this by: 1) Rearrange the mapping of functionality to components, or 2)"Freeze" the specifications.
  b. Reduce sensitivity of the components to changes in the specifications, this by: 1)Reduce internal coupling, or 2) Increase the "headroom" of the specification. This implies designing the product so the components can absorb a large change in the specification before require redesign: "Overdesign".

Every phase will be discussed into more detail future on in this report. First, the steps that need to be taken in the specific phase are explained. Hereafter, the method is applied for a viaduct, and the outcomes of the method are explained and presented.

3.5.2 Phase 1: Determine product architecture

In phase 1, different steps have to be taken:

a) *Analyse the product and the general background*
b) *Determine the lay-out*
c) *Determine the System Breakdown Structure: specify the models*
d) *Identify the requirements: functional and aspect requirements*
e) *List components and their function(s)*
f) *Determine Functional Breakdown Structure.*

3.5.3 Phase 2 – Examine interface: Apply Design for Variety method of Martin and Ishii

The first step in the DFV method of Martin and Ishii is to estimate the General Variety Index (GVI).

The GVI indicates which components are most likely to change over time. The GVI-values are indicators of the amount of redesign that will be required for a component to be able to meet the changed circumstances. The GVI is based on an estimate of the change of a component required due to changes caused by non-controllable factors.

A) *Analyse market*

To develop a GVI-table, first the factors external to the company (the factors that cannot be controlled) that will cause a design to change will need to be identified. Martin and Ishii argue in their approach: *By understanding these ''drivers'' of change, we can begin to plan the product line such that it isolates components that are likely to change. This understanding will help minimize design effort for future products and make design structures common across generations* (Martin & Ishii, 2002). To identify these non-controllable factors a general analysis about the market needs to be conducted, the market demands should be determined and trends should be identified.

A general analysis of the market and the identification of trends can be conducted by:

- Analysis of the demand and wishes of the client for various products/projects that are designed the last 50 years. The period of 50 years is applicable for a infrastructural object, however, this depends on the type of product/project.
- Have conversations with experts and with the client to get a thorough understanding about various aspects of the research field.

However, the project team is free to add other aspects to analyse, as long as it provides insights considering the current and future market conditions.

B) *Create General Varity Index tables (GVI tables)*

Based on the general analysis of the market, the trends identified and the conversations and interviews hold, a GVI-table has to be developed. The table should be proposed to multiple experts to verify if they agreed with the drivers for change and if they had other suggestions or points that were not considered in the table.

C) *Fill in GVI tables: by multiple experts*

The GVI values give an indication of the sensitivity of the different components for changes due to non-controllable factors. Martin and Ishii have defined the GVI value as: "*The generational variety index (GVI) is an indicator of the amount of redesign required for a component to meet the future market requirements"*. In the case of an infrastructural structure, the non-controllable factors are twofold: 1) The changes over time, for example are the changes in the general demand and wishes of the client, changes in regulations and possible trends occurring. 2) The changes required due to the specific locational circumstances and changes required due to (project) specific requirements of the client. Within this research, it refers to what changes in design are required when a reference design would be applied to fit within the specific locational circumstances and requirements. Considering changes over time, what changes are required to the reference design if the circumstances in the market change. Both are addressed in the GVI-table.

The GVI-table has to be filled in with the values of 1,3,6, or 9. The rating description that should be applied is as follows:

GVI - Rating Description

9 Requires major redesign of the component (>50% of initial redesign costs)
6 Requires partial redesign of component (<50%)
3 Requires numerous simple changes (<30%)
1 Requires few minor changes (<15%)
0 No changes required

In addition, the chance of occurrence has to be filled in by the participators. A value of 1, 2 or 3 has to be filled in. This value will eventually function as a repetition factor.

Change of occurrence/likely to happen

3 High chance of occurrence: very likely to happen (chance >60%)

2 Medium chance of occurrence (chance around 40 till 60%)

1 Small chance of occurrence: no likely to happen (chance of 0 till 40%)

The factor was added to the method of Martin and Ishii, to get more insight about what the change of occurrence of the specific circumstances are in the perception of the experts. This could make the outcome of the tables more reliable.

D) Analyse the outcome of the GVI tables.

The outcome of the GVI tables (filled in by the participants) should be analysed. It gives a estimation of which components are most likely to require significant change over time, and/or which components are significantly different in the various situations (locations and specific requirements) occurring. The higher the value of GVI or the GVI * factor (change of occurrence), the more likely it is that this component will require change. This value indicates that these components are interesting to modularize and not appropriate to standardise.

Within the approach of Martin and Ishii the GVI values are ranked and categorised considering a low, medium or high GVI-value . This ranking and categorisation should also be applied in the case when an infrastructural structure is analysed. However, as explained, the factor: change of occurrence/likely to happen, will need to be considered . Therefore, both the GVI and the GVI*factor need to be analysed.

3.5.4 Phase 3 – Determine Coupling-Indexes

With the determination of the GVI it is identified which components are sensitive to change due to non-controllable factors. The components are interrelated, modifications of a module will require change in other (internal) components as well. These are the changes that are needed to keep the total system functioning. To determine this degree of coupling: the coupling-indexes, various steps have to be taken and are explained below.

A) Develop two tables: direct relationship and parametric relationship.

The tables of the coupling-indexes are based on the different modules and the lay-out of the structure that has been identified in phase 1. In figure 3—44 the table for the direct constructive relations for this research is given as example. The table for the parametric relations is idem. Both can be found in Appendix C1.

Coupling - index: Direct constructive relations			Foundation		Substructure				Superstructure							Bearings, expansion joints and transition slab				Non- structural components					CI-S (supply)
Give numbers 1,3,6 or 9									Core		Extension														
Prefabricated concrete viaduct (NL)		B	Foundation pad (pad for intermediate wall/column(s))	Foundation piles	Intermediate wall/colomn(s)	Abutment or bank seat (including foundation pad)	Capping beam	Wing walls	Deck: prefabricated beams	Edge beam: prefabricated	Pavement: Asphalt	Edge element (finishing)	Parapets (pedestrians + traffic)	Upstand (schampkant)	Safety guards	Bearings	Expansion joints (abutment/bank seat and deck + beams at the location of the intermediate pier)	Connection between approach slab and abutment/bankseat	Approach slab	Traffic signs	Lighting	Cables	Water drainage	Camera's and sensors	
A	Foundation		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
	Foundation pad	1																							
	Foundation piles	2																							
Substructure																									
	Intermediate wall/colomn	3																							
	Abutment or bank seat	4																							
	Capping beam	5																							
	Wing walls	6																							
Superstructure																									
Core elements	Deck: prefabricated beams	7																							
	Edge beam: prefabricated beams	8																							
Extension	Pavement: Asphalt	9																							
	Edge element (finishing)	10																							
	Parapets (pedestrians+ traffic)	11																							
	Upstand (schampkant)	12																							
	Safety guards	13																							
Bearings, expansion joints and transition slab																									
	Bearings	14																							
	Expension joints	15																							
	Connection between	16																							
	Approach slab	17																							
Non- structural components:																									
Installations etc	Traffic signs	18																							
	Lighting	19																							
	Cables	20																							
	Water drainage	21																							
	Camera's and sensors	22																							
CI -R (recieve)																									

3—44 Table Coupling-Index

B)   Let different experts and members of the product team fill in the tables.
Values of 1,3,6 or 9 need to be assigned to the relation between the different components, considering respectively their direct or parametric relation. According to Martin and Ishii specification flows are defined as the design information that must be passed between designers to design their respective components. By mapping out the specification flows early in the design process, the team explicitly describes the relationships that couple the parts. Two components are considered coupled if a change made to one of the components can require the other component to change. When there is a strong coupling between modules, the chance is that, by changing a module, an adjacent module must also change.

The different components in the table are listed to the other components of the viaduct; see the table of the coupling indexes. When the table is filled in the question has to be asked: Will a change in component A also result in a required change in component B, or which specific information of component A is needed to design component B. In this example, component A is supplier of information: the Coupling-Index-Supplying (CI-S), and component B the receiving component: the Coupling-Index-Receiving (CI-R). Therefore, CI-S indicates how much information one component will give to other components. And the CI-R indicates how much information one component will receive from other components.

As mentioned before, two tables need to be filled in: 1) Coupling indexes for direct relations, and 2) Coupling indexes for parametric relations. This different relations between the different components should be assigned values considering the following rating description:

Coupling-indexes - Rating description
9   High sensitivity: Small change in specification impacts the receiving component
6   Medium High Sensitivity
3   Medium Low Sensitivity
1   Low sensitivity: Large change in specification impacts the receiving component
0   No specifications affecting the component

- *Coupling indexes – Direct relations*
In the first table it should be filled in if the components have a direct relation with each other. A direct relations is considered when the components are physically connected. Hereafter, the sensitivity of this relation needs to be estimated.
- *Coupling indexes – Parametric relations*
In the second table the coupling indexes parametric has to be filled in. These coupling indexes indicate the parametric relations between the different components. Parametric here refers to "parametric modelling", see definitions at the beginning of this report: *Parametric comes from the mathematics and is defined as: a constant or variable term in a function that determines the specific form of the function but not its general nature, as a is f(x)=ax, where a determines only the slope of the line described by f(x).* (Dictionary.com, 2016) *Within this research parametric modelling is: the process of object creation with defined parameters: involving distances, angles, and rules like attached, parallel to or distance from. By parametric modelling, a general design can be adapted (type appropriate) and scaled to dimensions that fit the specific situation occurring.* When the dimensions of a certain component are changed, this can have influence on other components within the structure. The components that are not directly connected can be influenced, and may require change. For example the dimension of the other components will need to change, for the total structure can still function properly. However, there are limits to the scaling of the components. A change in dimensions of one component can require change in another component. However this component cannot always be scaled to fit the specific circumstances, this is not always optimal or possible. It could be that another type of component can be better suitable. In this case, a different type of component is needed, to replace the component that is not suitable anymore. In case of a infrastructural object, an example of a viaduct can be given: When the dimensions of the deck are increased, the deck will become larger and heavier. This will have an effect on different components that are located below the deck. For example, the foundation piles need to be dimensioned larger to handle the increased forces of the deck. This can be a relatively simple change, when the same type of foundation piles can be applied. However, when the forces of the deck have increased significantly that the type of foundation piles is not suitable anymore, other type of foundation piles will need to be applied.

It is advised to support the experts and members of the project team with filling in of the tables. To get a clear understanding of all the different viewpoint it is important that the experts are not influenced by other experts. The tables need to be filled in individually. It is essential that the experts understand how the table should be filled in. Therefore, the researcher, has to make appointments with the experts to explain and together go through some steps of the tables. In addition, a hand-out with explanation about the approach and how the tables should be filled in has to be developed for the participants. For the research conducted in this research, the hand-out is given in appendix A.16. This hand-out is general and can be used for the analysis of other infrastructural objects as well.

C) Arrange a session

A session with all the participants together has to be arranged. In this session the participants need to discuss the tables together, and should come to an agreement about the values assigned to the different coupling relations. This step was added to the approach of Vanessa Veenstra, because when all experts had filled in the tables no clear relation between the different values assigned could be identified directly. Although, when a clear relations can be identified directly, it still is advised to arrange a session.

During the session the experts can explain their viewpoint and ask each other critical questions. Discussing the table with multiple experts together can provide great insights about how components are coupled and the general product architecture. These insights gained can help with the design when the principles of standardisation or modularization are implemented.

D) Analyse results of the tables of the couplings-indexes

The tables filled in individually by the experts and the tables that were filled in during the session need to be analysed.

The various experts have filled in the table. These values assigned should be summed to derive the GVI-values and the coupling-indexes. It is advised to develop the tables in excel, then the values will be automatically summed. From the coupling tables, two indices are derived. The sum for each row indicates the strength of the information supplied by that component to other components and is referred to as the Coupling Index - Supply (CI-S). The sum for each column is information being received by each component and is referred to as the Coupling Index - Receive (CI-R).The CI-S and CI-R values need to be analysed in a structured way. The ways the values should be structured and analysed is not the same for every product. The project team or researcher should analyse the results based on what should be logical for this specific product. Within the approach of Martin and Ishii the values were ranked and have been categorized in low, medium and high. However, the way this categorisation is established, should be considered per product individually.

3.5.5 Phase 4 – Draw conclusion

A) Combine outcome of GVI, CI-R and CI-S in a general table

The outcome of the tables filled in by the experts should be combined to draw conclusions. For each participant individually a table with the overall results, table from the sessions, and various tables with the results of the participants should be made. This table should contain the GVI, CI-R and CI-S values or ranking for each component, referring to high, medium and low as explained in phase 3. The tables should provide various overviews of the values and by this it should help to draw conclusions form the collected data.

B) Identify criteria for how the data should be analysed/ what the data means.

Martin and Ishii have developed a table for the data analysis of the CI-R and CI-S and GVI combined.
This has been explained in Appendix A.14. The project team should develop criteria for the identification of the outcome of the tables. The method should be based on and be comparable to the method Martin and Ishii apply.

Analyse data in structure way

On the basis of the ranking it is determined which components can be standardised or modularized to get a well working platform. To realize the analysis in a structured way, the components are categorized into high, medium and low categories. Martin and Ishii note the categorization process is not necessary and is only used to visually help in the ranking. The design team is free to define the demarcation line between high and low. In this research the demarcations for the GVI, CI-R and CI-S are based on the raking of the five highest and five lowest values.

Analyse GVI-value

The design teams should first consider the components with high GVI, since these components require high redesign efforts due to changes in the market, or variety in location specific circumstances. While high CI-R components can also require high redesign efforts, the high GVI components generally will have a much greater impact on the redesign efforts. Therefore, the GVI-values should be analysed first. Note that standardisation means that the couplings-indexes, CI-S and CI-R should be reduced.

Analyse CI-S

Another consideration is to standardise components with high CI-S index, since they have a high potential for causing changes in other components. However, it is not always possible to standardise components. Complete standardisation of the product is not possible since some of the components must be able change to meet the changing of client's demands and various locational circumstances. In this research, the components with low GVI values and low CI-R values are considered suitable for standardisation. Components with medium or high GVI value are not considered as suitable to standardise. This will also be the case for other infrastructural structures.

Analyse CI-R
Components with a high GVI and high CI-R value are interesting to modularize. These components are likely to change. Therefore their impact on other parts of the design should be minimized. Modularization means that those components can change with no or little impact on other components. The interface between different components is standardised. An change in one component will not influence the interface, and by this will not influence the components connected to the changed component.

<u>C) Analyse results and draw conclusions</u>
Based on the identified criteria the results need to be analysed. As a first step, the GVI values are analysed without considering the coupling indexes. As explained earlier, the high GVI components generally will have a much greater impact on the redesign efforts than the CI-R or CI-S. Secondly the overviews, the combined outcome of GVI, CI-R and CI-S, made in step A of phase 4 are analysed. Based on the developed criteria conclusions can be drawn in a structured way.

<u>D) Determine where to focus effort: where to standardise and where to modularize?</u>
By the analysis of the data a clear outcome of which components should be modularized, standardised parametrical, standardised, or for which components no clear advice can be derived from the tables. For the components of which no clear advice can be derived, the project team should decide what to do with these components.
In addition, it is important to note that the outcome of the derived tables is not leading. Going through the entire process provides the different participants with new insights that can be used for the application of the principles of standardisation and modularization. Or can contribute to the creation of new innovative ideas. The outcome of the Design for Variety Method should be seen as a starting point for the implementation of the principles of standardisation and modularization to develop a product platform, and should be discussed within the organisation.

<u>E) Alternatively, apply other strategy: redesign by reducing GVI and CI</u>
Within the company is can also be decided not to standardise or modularize the components. Martin and Ishii has made suggestions for another strategy that the company can consider, and are listed below. These are two major approaches to redesign the architecture such that the GVI and CI of a component are reduced, which should lower the future redesign effort needed.

Companies can also reduce or eliminated the GVI created by the specification flows. This can be done by applying the approach listed below:
1) *Remove current components specifications*
    a) Rearrange the mapping of functionality to components
    b) “Freeze” the specifications (is not allowed to be modified)
2)*Reduce sensitivity of the components to changes in the specifications*
    a) Reduce internal coupling (i.e. within the component control volume)
    b) Increase the “headroom” of the specification. This implies designing the product so the components can absorb a large change in the specification before requiring redesign. (“Overdesign”)

In addition, the different guidelines for application of the design for variety method identified by Kipp and Krause(2008), explained in section3.4.1.3 can be considered. These guidelines can help the project team during the design phase. It gives a clear overview of the possibilities to benefit from the repetition present in products.

3.6 OUTCOME: METHOD APPLIED FOR A VIADUCT

In this section, the phases explained in section 3.5 are gone through for the analysis of a viaduct. The results of the steps are presented to identify which components are suitable for the application of the principles of standardization and modularization.

3.6.1 Phase 1: Outcome determine product architecture within this research

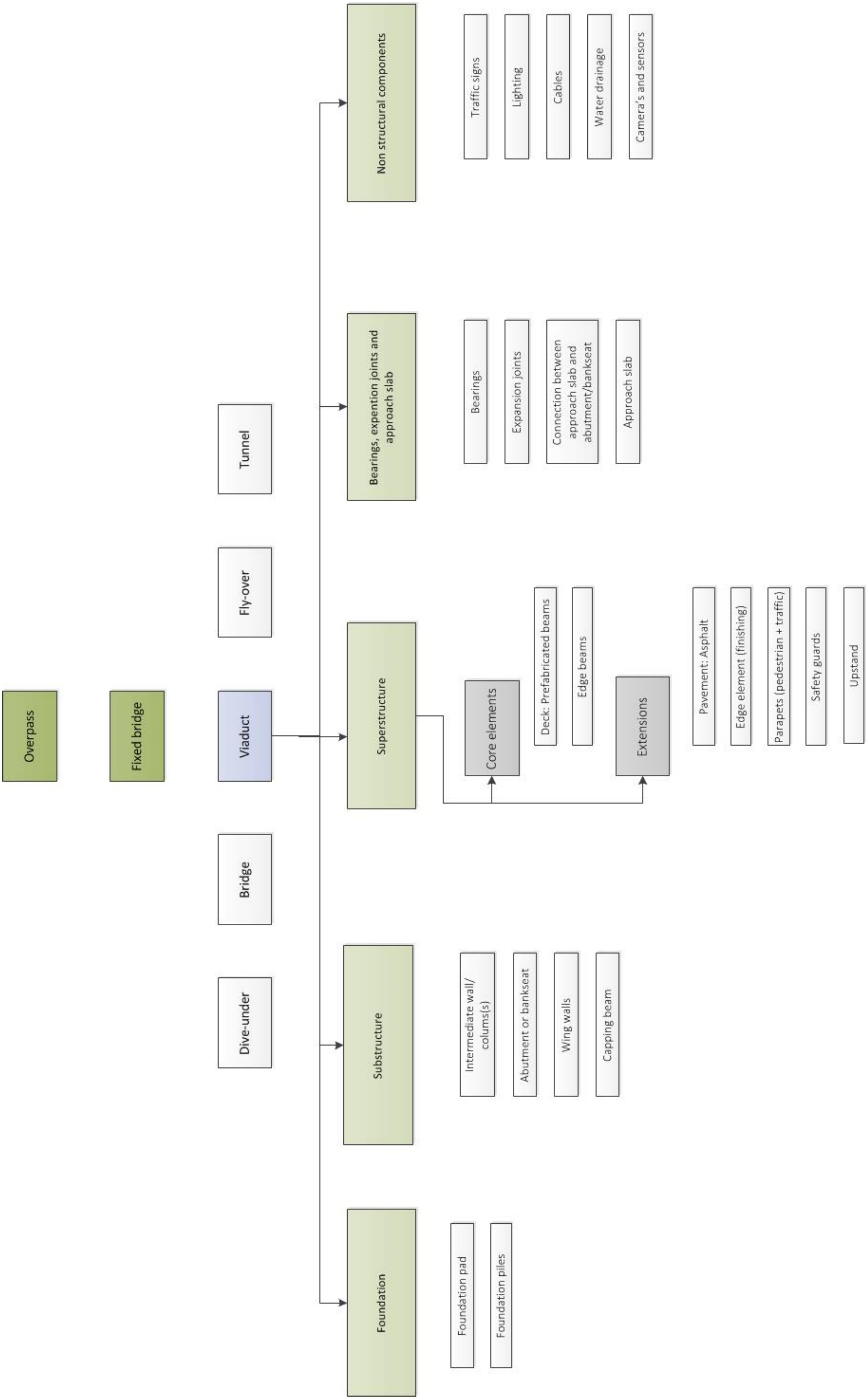
1. ***Analyse the product and the general background***

The analysis and general background of a viaduct has been discussed in section 3.2

2. ***Determine the lay-out***

The layout of a viaduct has been determined, and by this the components of a viaduct have been identified. These have been discussed in section 3.2.

3. ***Determine the System Breakdown Structure: specify the models***



3—45 System Breakdown Structure

4. *Identify the requirements: functional and aspect requirements*

Different type of requirements

The design of the viaduct should meet different requirements. These can be divided into five categories. The categories are listed in explained in more detail below.

- *Functional requirements* - Functional requirements are the requirements (demand and wishes) of the system or object, that the system or object should facilitate/fulfil. Functional requirements can be directly coupled with functions of the system or object.
- *Interface requirements – External* - External interface requirements are imposed on the boundary of a system within the environment, with the aim to provide function, form and spatially alignment of the different objects.
- *Interface requirements – Internal* - Internal interface requirements imposed borders between objects within a system, with the objectives for function, considering both forms and/or to spatially connection or to align the objects within the system.
- *Boundary conditions and/or requirements* - Boundary conditions and/or requirements are the conditions and requirements that imposed boundaries/limits considering the object outside the system. The boundary conditions/requirements limit the possible solution space. Boundary conditions and requirements can be seen as an explicit boundary of the solution space.
- *Points that are becoming more important* - When an overpass construction is designed, in this case, a viaduct, it is essential to analyse the changing market demands, the different trends and technological developments. It is important that these developments in the market be taken into consideration when a viaduct is designed. Currently, there is a trend visible for the possibility to adapt a viaduct to new occurring situations. For example, the viaduct should be designed in such a way that it can be extended in the future, to be able to handle the increase in traffic flow on the viaduct. Also, building in a demountable way, where elements can be reused or can be easily split up for recycling of the materials is a trend occurring.

Requirements overpass construction

A viaduct is an overpass construction. It provides an overpass for different levels of the infrastructural system.

For the purpose of this research, the main requirements of the overpass construction and the road on the overpass are identified. This analysis is conducted considering the relevance of the requirements for the research field. Therefore, not all requirements and more detailed requirements are listed, but a selection is presented below.

<u>Functional requirements of the overpass construction - A</u>

Main function:

A. ***Provide overpass for different levels of the infrastructural system to facilitate unobstructed traffic flow/ facilitate conflict free crossing.***
- Provide unobstructed crossing for fast traffic
- Provide unobstructed crossing for slow traffic

Function constructive structure:

<u>*A1. Carry load*</u>

Able to bear all the applicable different loads.

i. Carry own load: Carry load of all the different structural components
ii. Carry load of variable forces: Traffic + Wind + extra add-ons
iii. Transfer load to other structural components, to eventually transfer the load to the ground.

* Note that the overpass construction should be conformed to the ROK (Richtlijnen Ontwerp Kunstwerken, RWS) and conforms to the RBK (Richtlijnen Beoordeling Kunstwerken, RWS). In the Netherlands, these guidelines are specified by RWS (Rijkswaterstaat).

<u>A2. Provide space</u>

a. *Provide space over*
   - Should facilitate the crossing of infrastructure and unhindered use of the road on the deck of the overpass.
b. *Provide space under*
   - Should facilitate the crossing of infrastructure and unhindered use of the road underneath the overpass construction (the profile of free space should conform to the ROK)

c. *Provide space for inspection, maintenance and replacement of components.*
   - Inspection, maintenance and the replacement of components should be easy and should be possible at all time. Therefore sufficient space for inspection, maintenance and replacement of components need to be available.
d. *Provide space for emergency services.*
   - The overpass construction should provide space for emergency services at all time. (Ambulances, police, firefighters, etc.)

<u>Functional requirements road on the overpass construction – B</u>

Main function:

B. Facilitate road traffic that crosses over or under the viaduct.

<u>*B1. Facilitate road traffic*</u>

a. Guide traffic: manage traffic system
b. Carry load of road traffic
c. Provide clear view for road-users.
d. Provide dry deck (drain rainwater)
e. Block vehicles and people
   i. Block vehicles: prevent vehicles from crossing/hitting of the road on the other part of the viaduct, or prevent vehicles from falling off the viaduct.
   ii. Prevent road users from failing of the viaduct or failing on the road (pedestrians and cyclers)

<u>Functional requirements for the traffic systems and installations.</u>

Main function:

C. Manage traffic system

<u>*C1. Manage traffic system*</u>

- Manage traffic system – General
  a. Provide guidance. (for example marking on the road and traffic signs)
  b. Give directions (permanent signs about route)
  c. Guide traffic interactively (stopping signs)
- Manage traffic system – Inform road user about variable situation
  - Inform road user about current situation of the infrastructural system (example: Inform road user about traffic jam, by digital signs)
- Manage traffic system - Collect data to inform road users and maintenance staff
  - Collect data about the traffic flow, under and above of the viaduct.
  - Collect data about the technical aspects of the viaduct. (the condition/quality of the viaduct, maintenance needed)

<u>Aspect requirements</u>

Aspect requirements are; the requirements for specific characteristics of the system or object that do not directly contribute to the function of the system or object.

1. *Availability*
   a. The overpass has to be designed for functioning for 100 years
   b. Degradation mechanisms that can shorten the remaining life of the overpass crossing should be avoided or controlled: Measures need to be taken.
   c. The viaduct can be “out of function” for a maximum of X hours for X year(s), for maintenance.
2. *Reliability*
   a. Joints need to be watertight, to protect the underlying structure.
3. *Robustness*
   a. The viaduct should be able to handle a clash of a vehicle underneath the deck, and on the deck, this means the structure should not fall apart when a vehicle clashes into the different constructive parts of the viaduct (for example the intermediate wall, abutment/bank seat, wing walls). Moreover, the possible clash should not cause direct risks for the safety of the road users.
4. *Hindrance for the direct environment*
   a. Noise (contact and pulse noise) caused by vehicles passing joints in the overpass construction should be minimised in accordance with RTD 1007-3 "Noise Requirements joints".

b. During construction and the utilisation of the object, the construction of the viaduct or the functioning of a viaduct should not cause or pose any danger to safety and health of the road-users, and the surrounding area(people and animals living in the area, and nature should be preserved)

5. *Boundary conditions design – location specific*
    a. Boundary conditions and requirements can be seen as an explicit boundary of the solution space. Boundary conditions need to be considered; this is specific for the situation in different locations. It can have a direct relationship with the space that is available for the object or imposes limits on the object or system by regulations.
6. *Maintainability*
    a. Components of the overpass construction with a shorter life than the life of the main construction structure should easily be inspected, maintainable and replaceable. Without the need for demolition or damage of other components. Except for joints.
7. *Future proof*
    a. The design of the viaduct should be developed with the future in mind. For example, considering an estimated increase of the amount of traffic crossing the overpass. The viaduct should have sufficient capacity for the first ten until 20 years. In addition, it should be possible to adapt the viaduct to changing circumstances/ demands in an effective way. (expanding the viaduct)
    b. It should be possible to add installations in the future. The overpass construction should have at least three cable conduits (including wells pull and pull wires) with a minimum inner diameter of 90 mm. The exact number of cable piplines and their diameter will be determined by the client.
8. *Safety*
    a. Concrete surfaces of the overpass construction must be protected against the ingress of chlorides coming from de-icing salts. (in Dutch this process is called hydrofoberen)
    b. The drainage of rainwater on the deck of the overpass and the road under the overpass should not provide possible danger to the safety of both roads.
    c. Separation, in the form of parapets, is needed at locations where differences between heights occur. To prevent road user of falling from the overpass construction.
    d. Light level for driving on the road: The light level below the deck of the overpass construction must be sufficient for the road users to have a clear sight and can safely use the road.
    e. Light level for social safety: The light level below the deck of the overpass construction must be sufficient, that it is perceived/experienced as socially safe by the road users of the space.
9. *Comfort*
    a. Provide comfortable transition between the adjacent road and the viaduct.
    b. Provide comfortable driving over the viaduct: smooth road surface, no bumps in the pavement.
10. *Design*
    a. The design of the new overpass construction has to comply with the design provided in the document: aesthetic plan of requirements (Esthetisch PVE kunstwerken)
    b. Cables, pipes and other facilities for passage of cables and pipes of the overpass construction should not be visible for road users crossing the overpass (over or below).
11. *Demountable*
    a. The structure should be demountable at the end of the structures life-cycle. (not by demolition)
    b. It should be possible to reuse different structural components in a new viaduct or another object, with a limited amount of effort required.
12. *Process requirements*
    a. Use structural approach in the design and realisation process.
    b. The contractor should inform the client regularly about the construction process.
    c. Establish feedback at the different points in the project.
13. *Execution requirements*
    a. The structure(s) should be constructed with respect for people and planet.
    b. The structure(s) should be constructed within the approved time-span.

5. List components and their function

In this section, various functions of a viaduct are linked to the components. In Appendix A1, a description of the components and their functions is given, and a table of the function versus components can be reviewed.

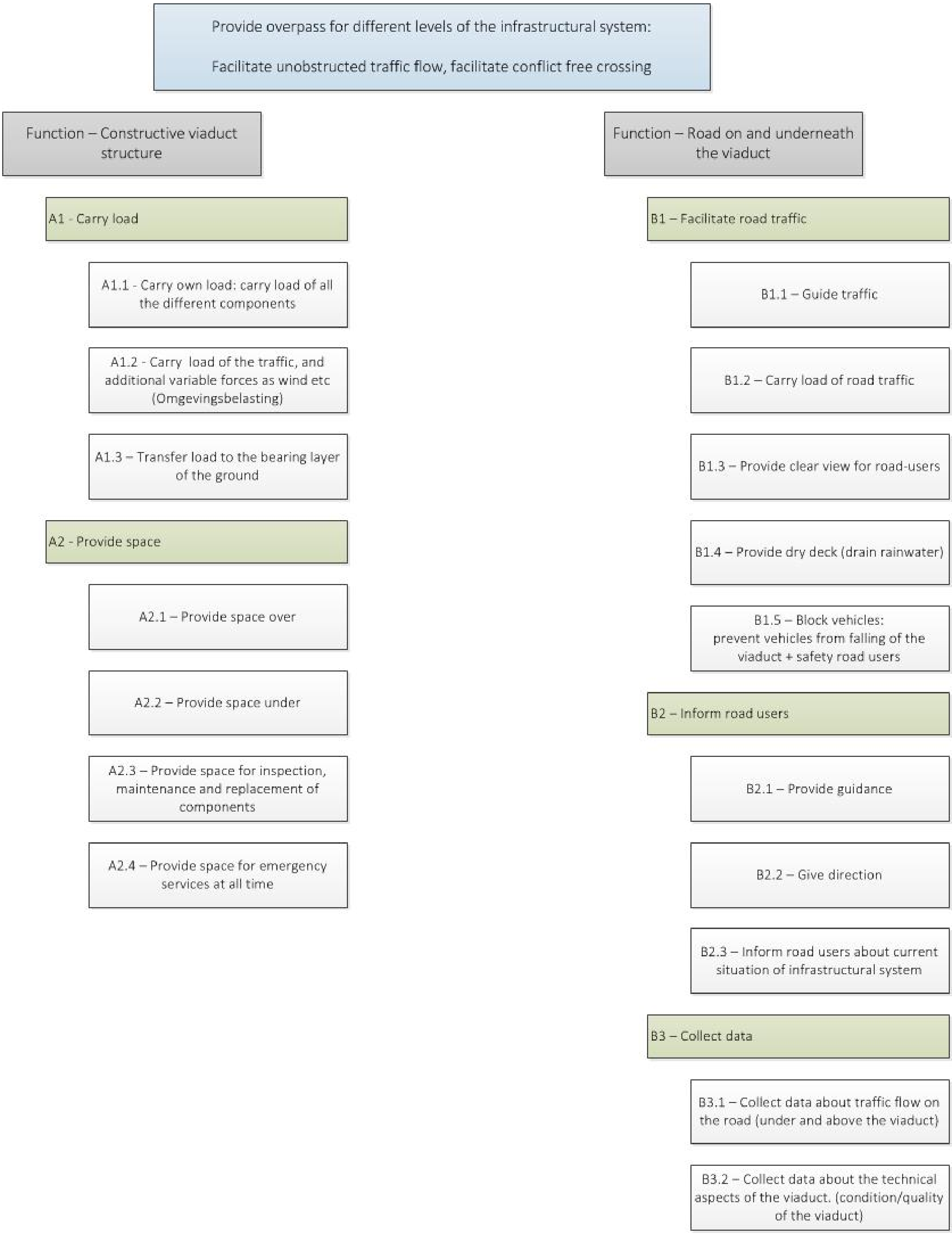
6. Determine Functional Breakdown Structure

In figure 3—46 *below the Function Breakdown Structure of a viaduct is visualised.*

The main function of a viaduct is identified:

Provide overpass for different levels of the infrastructural system: facilitate unobstructed traffic flow and conflict free crossing.

The main functions can be divided into two categories: functions for the constructive structure of the viaduct, and functions for the road on and underneath the viaduct.



3—46 Function Breakdown structure

3.6.2 Phase 2: Outcome - Examine interface within this research

The outcome of the GVI tables indicates that there are different components that will vary significantly between projects and components that are thought to chance due to changing circumstances in the market.

A) Analyse market

Within this research the steps explained in section 3.5.3, phase 2 are taken. First, the external factors that will cause a design to change are identified. To identify these non-controllable factors a general analysis of the market and the identification of trends in this research have been conducted by:

- Analysis of the listed requirements by the client for various large infrastructural projects that have been constructed or procured the last five years.
- Have conversations with experts, various experts of BAM Infra, and with the client to get a thorough understanding of various aspects of infrastructural projects, in specific about a viaduct.

B) *Create General Variety Index tables (GVI tables)*

Based on the general analysis of the market and the trends identified in step A, a GVI table has been developed. The table is proposed to multiple experts to verify if they agreed with the drivers for change and if they had other suggestions or points that were not considered in the table.

C) *Fill in GVI tables: by multiple experts*

Within this research, the GVI-table has been filled in by five structural engineers. The other tables of the coupling-indexes are filled in by the same structural engineers as well.

A group of structural engineers is chosen, because this research focusses on the implementation of the principles of standardisation and modularization considering the constructive relations. Moreover, for a viaduct, the main design decisions are made by the structural engineer. These decisions will be made in an early phase of a project, the other non-structural components should be designed with respect to the structural design. Although, adaptation in design are possible, providing a safe structure that provides an overpass for different levels of the infrastructural system to facilitate unobstructed traffic flow and facilitate conflict free crossing, can only be realised when the structural design is sufficient for bearing the load.

D) Analyse the outcome of the GVI tables.

In this section, it will be discussed which components are identified that are interesting to standardise. Components that are not likely to change over time or their changes has limited impact, are components that are interesting to standardise. Within the GVI the component with a relatively low GVI-value can be interesting to standardise. The GVI*factors indicates which components are interesting to standardise based on the GVI-value multiplied with the chance of occurrence of the situation/factor. The General Variety Index of the components are listed from the total table, see Appendixes C2 and C3. The GVI-tables that have been filled in by the structural engineers have been analysed.

During the research, it became clear that the non-structural components are interesting to standardise, in current projects they are designed based on the same principles. The elements are to a certain amount already standardised. In the table with the GVI-value, this is also confirmed. The non-structural components all have relatively low GVI-values. For the purpose of the outcome of this research, the non-structural components are not included in the ranking of the values of the GVI. Otherwise, the other components that can be interesting to standardise would not become visible.

The data have been analysed for each structural engineer individually. However, based on these data no clear general line in the values could be identified. The values of the different structural engineers given were very diverse. Possible explanations for this are the following:
1) The participants all had a different level of experience with the investigated structure: a viaduct.
2) The value given is a free interpretation. The perception of how sensitive a component is, and how likely it is that it will have to change due to variety of different projects and changing circumstances is subjective.

Because not clear general line could be found in the results directly, the different components are graded from the ranking of components that have the lowest GVI-value and ranking of the components that have the highest GVI-value. The values of the components in these tables, given in Appendix C3-1, indicate on which place the component came in the list, this is different for every structural engineer. By this, the fact that the assigned values are subjective could be overcome. An overview of the values can be reviewed in Appendix C3-2 and in the values are ranked in Appendix C3-3.

The values of the components in this table indicate on which place the component came in the list. The components that are listed to have the highest GVI are identified. The summation indicates the sum of the ranked values given by the structural engineers as highest GVI-value. In addition, the components that are listed to have the lowest GVI are identified. Also, for the lowest values a summation was made that indicates the sum of the ranked values given by the structural engineers as lowest GVI-value.

At first, the data have been analysed and arranged bases on the criteria explained. The components are listed based on their ranking value. A component is considered interesting to modularize if one or more of the criteria listed below are met.

a) *The component is listed as highest GVI for the individual structural engineers (place 1)*
b) *The component is listed in the top 5 highest GVI average (average rating overall structural engineers)*
c) *The component is listed by minimal two structural engineers in the top 5 of highest GVI (individual structural engineer)*

And exactly the other way around of component with a low GVI, that were considered to be interesting to modularize.

a) *The component is listed as lowest GVI for the individual structural engineers (place 1)*
b) *The component is listed in the top 5 lowest GVI average (average rating overall structural engineers)*
c) *The component is listed by minimal two structural engineers in the top 5 of lowest GVI (individual structural engineer)*

However, although this is a very structured approach and is thought to provides great insights into which components are likely to change or not likely to change. It became clear that this method had the same outcome as when the components were only ranked. Therefore, in this specific case, the values only needed to be ranked. The five structural engineers mainly agreed on the values of the GVI, although the tables were filled in individually. However, this will not always be the case when the method is applied. Therefore, for another infrastructural object, these criteria need to be considered first. However, the research team can also propose criteria that they think are the best approach.

As explained above, the values were ranked and hereafter categorised into low, medium and high categories. An example is given in table 3—11and can also be found in C3-1 and C4-1. The components that are marked light blue are the components ranked as the five highest values. The components that are marked red are the components ranked as the five lowest values. The non-structural components that are not considered in the ranking are marked grey. The grey components are the non-structural components that are considered as not applicable. The components that are not marked are the medium values.

GVI * factor - General		GVI * factor - TW	Highest value	Lowest value
Edge beam: prefabricated beams	8	472	1	17
Deck: prefabricated beams	7	436	2	16
Intermediate wall/colomn(s)	3	411	3	15
Abutment or bank seat	4	363	4	14
Foundation piles	2	348	5	13
Foundation pad	1	282	6	12
Capping beam	5	273	7	11
Bearings	14	267	8	10
Pavement: Asphalt	9	261	9	9
Water drainage	21	261		
Expension joints	15	240	10	8
Upstand (schampkant)	12	228	11	7
Edge element (finishing)	10	189	12	6
Safety guards	13	182	13	5
Parapets (pedestrians+ traffic)	11	143	14	4
Wing walls	6	135	15	3
Lighting	19	108		
Connection between	16	69	16	2
Approach slab	17	69	17	1
Cables	20	39		
Camera's and sensors	22	30		
Traffic signs	18	27		

Table 3—11 Example - ranking of values

Hereafter, the outcome of the tables about the GVI are combined in an overview and again ranked. To identify which components have the highest and which components have the lowest GVI-value considering the values assigned by all the structural engineers individually. The overview of the combined results is given in Appendix C3-2. The overview of the combined results that are ranked is given in Table 3—12 for the highest values and in Table 3—13 for the lowest values, these tables are given below to give an illustration of how the values are analysed. These tables are also given in Appendix C3-3. It is advised to review the tables in the Appendices C, to get a thorough understanding of how the data has been analysed.

Highest value	GVI - General - Ranked highest values (1-5)	component number	GVI - GW	GVI - APG	GVI - MM	GVI - TW	GVI - MH		Sum
			1	2	3	4	5		
1	Deck: prefabricated beams	7	1	4	2	2	2		9
2	Edge beam: prefabricated beams	8	4	5	1	1	4		11
3	Abutment or bank seat	4	2	6	4	4	1		16
4	Capping beam	5	3	8	7	7	3		25
5	Foundation piles	2	8	2	3	5	10		28
6	Intermediate wall/colomn(s)	3	9	7	6	3	5		30
7	Foundation pad	1	5	10	5	6	7		33
8	Expension joints	15	10	1	11	12	9		43
9	Bearings	14	7	3	12	10	13		45
10	Pavement: Asphalt	9	6	11	8	8	16		49
11	Wing walls	6	11	15	9	15	8		50
12	Safety guards	13	15	12	10	11	6		54
13	Upstand (schampkant)	12	16	14	15	9	11		65
14	Connection between	16	12	9	14	16	17		68
15	Edge element (finishing)	10	13	13	16	13	15		70
16	Parapets (pedestrians+ traffic)	11	17	16	13	14	14		74
17	Approach slab	17	14	17	17	17	12		77

Table 3—12 Overview results GVI-general - Structural engineers individually - Ranked

Lowest value	GVI - General - Ranked lowest values (1-5)	component number	GVI - GW	GVI - APG	GVI - MM	GVI - TW	GVI - MH		Sum
			1	2	3	4	5		
1	Approach slab	17	4	1	1	1	6		13
2	Parapets (pedestrians+ traffic)	11	1	2	5	4	4		16
3	Edge element (finishing)	10	5	5	2	5	3		20
4	Wing walls	6	7	3	9	3	10		22
5	Connection between	16	6	9	4	2	1		22
6	Upstand (schampkant)	12	2	4	3	9	7		25
7	Safety guards	13	3	6	8	7	12		36
8	Pavement: Asphalt	9	12	7	10	10	2		41
9	Bearings	14	11	15	6	8	5		45
10	Capping beam	5	15	10	11	11	15		47
11	Expension joints	15	8	17	7	6	9		47
12	Abutment or bank seat	4	16	12	14	14	17		56
13	Foundation pad	1	13	8	13	12	11		57
14	Intermediate wall/colomn(s)	3	9	11	12	15	13		60
15	Edge beam: prefabricated beams	8	14	13	17	17	14		61
16	Foundation piles	2	10	16	15	13	8		62
17	Deck: prefabricated beams	7	17	14	16	16	16		63

Table 3—13 Overview results GVI-general - Structural engineers individually - Ranked

The green values, are the values that have been assigned the ranking of 2,3,4 or 5. The purple values, are the values that have been ranked as 1, considering the highest or lowest value assigned by a structural engineer individually.

The column sum in Table 3—12 and Table 3—13 are considered to develop the categorisation of the GVI that will be applied in for the identification of components that are suitable/interesting to standardise or modularize. This categorisation of low, medium and high, is given in Table 3—14. Again these were categorised by considering five highest and the five lowest values. This outcome of the GVI values of the five structural engineers combined is the input for the table of the GVI and CI to identify which components of a viaduct are suitable/interesting to standardise or modularize.
For the GVI this combined outcome is taken because the GVI-tables filled in by the structural engineers have a lot of similarities and mainly agree with each other, but also some differences occurred. The GVI table considered the locational circumstances that are of influence on the design and components of a viaduct, but also the possible circumstances in the future. For this research the outcome of the combined GVI-values is considered, this is based on the way how Martin and Ishii have analysed their data for the Design for Variety Method.

GVI	component number	GVI - Ranked: high	GVI Ranked: lowest	GVI: Low,Medium,High
Foundation pad	1	7	13	Medium
Foundation piles	2	5	16	High
Intermediate wall/colomn(s)	3	6	14	Medium
Abutment or bank seat	4	3	12	High
Capping beam	5	4	10	High
Wing walls	6	11	4	Low
Deck: prefabricated beams	7	1	17	High
Edge beam: prefabricated beams	8	2	15	High
Pavement: Asphalt	9	10	8	Medium
Edge element (finishing)	10	15	3	Low
Parapets (pedestrians+ traffic)	11	16	2	Low
Upstand (schampkant)	12	13	6	Medium
Safety guards	13	12	7	Medium
Bearings	14	9	9	Medium
Expension joints	15	8	11	Medium
Connection between	16	14	5	Low
Approach slab	17	17	1	Low

Table 3—14 GVI- Outcome structural engineers combined

*<u>Difference GVI and GVI*factor</u>*

As explained earlier in this chapter, the GVI*factor has been added to the design for variety method. The GVI*factor indicates the effect of the situation/factor, multiplied with the change that this situation will occur. Application of this factor can give a more detail indication of what the GVI means for the current market. Therefore, these values should be analysed . However, in this case-study of a viaduct, the GVI and GVI*factor did not differ significantly. When the categorization of low, medium, high is considered almost all the components have the same categorisation of low, medium and high. Only the components: intermediate wall/column(s), capping beam, wing walls and upstand differ. See Table 3—15 below.

Difference GVI and GVI*factor	component number	GVI: Low, Medium, High	GVI*factor - Low, Medium, High		Different
Foundation pad	1	Medium	Medium		
Foundation piles	2	High	High		
Intermediate wall/column(s)	3	Medium	High		X
Abutment or bank seat	4	High	High		
Capping beam	5	High	Medium		X
Wing walls	6	Low	Medium		X
Deck: prefabricated beams	7	High	High		
Edge beam: prefabricated beams	8	High	High		
Pavement: Asphalt	9	Medium	Medium		
Edge element (finishing)	10	Low	Low		
Parapets (pedestrians+ traffic)	11	Low	Low		
Upstand (schampkant)	12	Medium	Low		X
Safety guards	13	Medium	Medium		
Bearings	14	Medium	Medium		
Expansion joints	15	Medium	Medium		
Connection between	16	Low	Low		
Approach slab	17	Low	Low		

*Table 3—15 Difference GVI and GVI*factor*

Reviewing the GVI a GVI*factor individually has been applied because it can give insight into what the GVI-values actually means. However, in this research, the values of the GVI*factor are not significantly different from the GVI-value. Therefore, further in this report, only the GVI-values are considered. These values will be ranked based on their five highest, and five lowest values ranked per structural engineer or considering all structural engineers together.

3.6.3 Phase 3: Outcome of the coupling-indexes within this research

This section explains how the outcome of phase 3, describe in section 3.4.5, of this research of a viaduct are analysed. The coupling-indexes derived from the tables filled in by five structural engineers are analysed.

A) Develop two tables: direct relationship and parametric relationship.

The tables are based on the different modules and the layout of a viaduct that has been identified in phase 1. The tables are given in Appendix C1-2 ad C1-3.

B) Let different experts and members of the product team fill in the tables

The two tables have been filled in by the five structural engineers. The values of the different structural engineers given were very diverse. An explanation for this is given below.

1) The different structural engineers involved all had a different level of experience with the investigated structure: a viaduct. It became clear that the structural engineers with more than 20 years of experience saw more relations and assigned significant higher values than the structural engineers who have been working as structural engineers for around five till ten years. The structural engineers with more experience saw more relations between components. In addition, the structural engineers who worked with viaducts often identified more relations and gave higher values compared to the structural engineers that did not work with viaduct often but were specified in other structures.

2) The value given is a free interpretation. The perception of how sensitive a component is, and how likely it is that it will have to change due to variety of different projects and changing circumstances is subjective.

The numbers 1,3,6 and 9 had to be assigned to the relations between different components. However, the perception of the structural engineers considering the values can be different.

C Arrange a session

Because not clear general line could be found in the results, a session with the structural engineers together has been held. During the session, the different structural engineers had to decide together on the values that needed to be filled in. During the session, the structural engineers could explain their viewpoint and ask each other critical questions. The together filled-in tables, therefore, provides many insights and is reliable. In this research, only the table of the coupling-indexes direct relations has been discussed in the session.

D) Analyse results of the tables of the couplings-indexes

As stated before, the values assigned to the direct and parametric coupling relations between components were very diverse, large differences between the values filled in by the five structural engineers occurred. Therefore, the data has to be structured in a different way. The same approach as with the GVI-value is applied; the data has been ranked. For every table filled in by a structural engineer individually and the tables filled in during the session, the values are ranked.

Structure data for analysis

The values have been ranked from high to low. The five highest values of CI-R or CI-S assigned by a structural engineer are marked with high. The five lowest values of the CI-R or CI-S are marked with low. The values in between the five highest and the five lowest values are marked medium. In this study, the module with the components: cables, water drainage, traffic signs and cameras and sensors are not considered for the ranking. When the tables were filled in individually by the structural engineers, it became clear that these non-structural components are considered to be components that have no or limited influence on the design of a viaduct. Therefore, these components are not considered in the ranking of the values.

An example of the ranking is given in Table 3—16. The ranking of all the different tables, both the direct and parametric relations with the CI-R and CI-S values can be found in appendix C7-1 and C7-2.

The components that are marked light blue are the components ranked as the five highest values. The components that are marked red are the components ranked as the five lowest values. The non-structural components that are not considered in the ranking are marked grey; these are not applicable. The components that are not marked are medium values.

Direct constructive relations - CI-R	component number	Average CI-R	High, Medium, Low	Ranking – from high to low
Direct constructive				
Abutment or bank seat	4	40,2	High	1
Upstand (schampkant)	12	38,6	High	2
Edge beam: prefabricated beams	8	38,2	High	3
Deck: prefabricated beams	7	26,4	High	4
Expansion joints	15	24,4	High	5
Capping beam	5	23,6	Medium	6
Bearings	14	22,2	Medium	7
Pavement: Asphalt	9	18,4	Medium	8
Edge element (finishing)	10	14,6	Medium	9
Cables	20	12,4	N/A	
Foundation piles	2	11,8	Medium	10
Intermediate wall/column(s)	3	10	Medium	11
Wing walls	6	10	Medium	12
Foundation pad	1	9,6	Low	13
Water drainage	21	9,2	N/A	
Safety guards	13	8,4	Low	14
Approach slab	17	7	Low	15
Connection between	16	6,8	Low	16
Parapets (pedestrians+ traffic)	11	5,6	Low	17
Lighting	19	4,4	N/A	
Camera's and sensors	22	2,2	N/A	
Traffic signs	18	1,6	N/A	

Table 3—16 Example, ranking values

3.6.4 Phase 4: Outcome - Draw conclusions within this research

A) Combine outcome of GVI, CI-R and CI-S in a general table

The outcome of the tables filled in by the structural engineers should be combined to draw conclusions. Within the Appendixes, C8 and C9 overviews of the combined outcome are presented.

B) Identify criteria for how the data should be analysed/ what the data means.

Martin and Ishii have developed a table for the data analysis of the CI-R and CI-S and GVI combined; this has been explained in Appendix A.14 For the purpose of this research also a table for the identification of the outcome of the tables has been developed and is given in section 3.8. The method is based on and is comparable to the method Martin and Ishii apply.

C) Analyse results and draw conclusions

As explained, the high GVI components generally will have a much greater impact on the redesign efforts than the CI-R or CI-S. The analysis has already been explained in more detail in Section 3.7.2, Phase 2: the outcome of the GVI. Secondly, the overviews made in step A of phase 4 are analysed. Based on the developed criteria conclusions can be drawn in a structured way.

D) Determine where to focus effort: where to standardise and where to modularize?

As explained, the conclusions that are drawn are not leading. By going through all the different steps, the participant will derive a thorough understanding of the design and the relations between the components for a specific structure. These insights gained can be of great value when a new design approach or design needs to be developed. In section 3.8, the results of the method applied are discussed.

E Alternatively, apply another strategy: redesign by reducing GVI and CI

Within the company is can also be decided not to standardise or modularize the components. Although there currently may be too many constraints and barriers for the development of a standardised interface and modular design, there are other steps the company can take to benefit from the application of the principles of standardisation and modularization. Martin and Ishii have made suggestions for another strategy that the company can consider. These are two major approaches to redesign the architecture such that the GVI and CI of a component are reduced. By this decrease the impact on certain components of possible changes in non-controllable factors and internal changes, which should lower the future redesign effort needed. The result of the steps taken in this research provides great insight for the possible application of these strategies for a viaduct.

- <u>*Remove current components specifications*</u>
  - *Rearrange the mapping of functionality to components*

In section 3.7.1, phase 1 of the method applied, the product architecture of a viaduct is analysed, and a system breakdown structure and function breakdown structure of a viaduct have been identified. The structures are representative of the general way a viaduct is designed in the Netherlands. However, the main function of a viaduct: *provide overpass for different levels of the infrastructural system to facilitate unobstructed traffic flow/ facilitate conflict free crossing,* can also be established in a different way. Redesign can take place by rearranging the mapping of functionality to components. The project team can question themselves if this function is really required to deliver the main functions and other requirements, or is this function present due to the way viaducts are designed currently, and can this function also be realised in a different way by another component. In addition, it can also be questioned if a component is needed for the functioning of a viaduct or to meet other requirements, and if the function of this component cannot be combined with other functions in other components or possible design of a new component. However, for an infrastructural object, this is more complex compared to the situation where the project team still has a bit of freedom to change the specifications, referring to the requirements in an infrastructural object that are demanded by the client.

  - *"Freeze" aspects of the specifications and/or design (is not allowed to be modified)*

The "freeze" of aspects proposed by Martin and Ishii, is from the view of freezing the specifications of a product. By freezing a specification, for example freezing the power consumption of a product, one standard is chosen. This is also applicable for BAM Infra, they can choose to make certain practices or components the standard. By this, no standardised interface has to be developed, but certain aspects of the design can be frozen, these are not allowed to be modified. A design freeze is defined as: "*A design freeze is a binding decision that defines the whole product, its parts or parameters and allows the continuation of the design based on that decision".* (Eger.T, Eckert.C, & Clarkson.P.H., 2005) The aim of freezes is to reduce the likelihood of further engineering changes and allows structuring and planning of the design process. The "freezing" can be applied at the level of components, but also at the level of connecting the components. The type, dimensions, materials applied, connections, etc. The in-house research for a reference viaduct already has provided the first step for this approach. However, freezing certain aspects also has the negative side effect that it decreases flexibility. A right balance between standardisation and flexibility is essential.

- <u>*Reduce sensitivity of the components to changes in the specifications*</u>
  - *Reduce internal coupling within the components*

The tables developed give great insight into which components are most likely to require change, due to changes in non-controllable factors and due to changes in coupled components. A strategy can be to reduce the internal coupling between modules, to decrease the need for redesign when changes occur. The components that have a high GVI value should be analysed, and their coupling with other components should be reduced. When a certain change occurs, as it is most likely that this change will occur considering the high GVI, the impact of the change will be minimalised.

  - *Increase the "headroom" of the specification. This implies designing the product so the components can absorb a large change in the specification before requiring redesign. ("Overdesign")*

In the project of the N261 and the tender of the N18, this strategy has already been applied. Various standardised dimensions for the span and height of the deck are nailed down. At the beginning of the project, it has been investigated if there was repetition in the spans for the viaducts that needed to be constructed. A certain repetition was present, and therefore three different lengths of the deck could be applied. However, the increase of headroom can also be considered for trends occurring, for example, to already anticipate on increasing regulations.

In addition, to the suggestions of Martin and Ishii, the different guidelines for application of the design for variety method identified by Kipp and Krause(2008), explained in section3.4.1.3 can be considered. These guidelines can help the project team during the design phase. It gives a clear overview of the possibilities to benefit from the repetition present in products.

3.7 INTERPRETATION DATA

Data collected, considering the tables filled in by five structural engineers individually and with a group session, are discussed in this section. Based on the tables it can be identified which components are interesting to modularize or standardise, to achieve an effective platform. In this research, this is based on the GVI, GVI*factor, CI-R and CI-S values.

To analyse and identify which components can be standardised or modularized, the components are ranked from high to low and low too high. The GVI, GVI*factor, the CI-R and CI-s can be used to balance the commonality potential and differentiation needs within a product family. From a design point of view, the CI-R and CI-S rankings indicate the difficulty of standardisation or modularizing of components.

GVI – General Variety Index
Components that have a high GVI value and/or GVI*factor value are proposed to modularize. The value indicates that it is most likely that the component will require adaptation or a different type of the component needs to be applied. Components that have a low GVI and/or GVI*factor are proposed to standardise. The low value indicates that it is most likely that the design of the component will not require change or a relatively small adaptation is required. Based on the GVI tables these are components that are suitable to standardise.

CI-R – Coupling Index Receive
The CI-R value gives insight about how much input/dependency relations are present between the specific component and other components of the design. It indicates the amount of information needed to design the specific component individually.

CI-S – Coupling Index Supply
The CI-S value gives insight into the amount of information supplied to other components that are dependent and/or should fit this specific component. A high CI-S indicates that the component has a high potential for causing changes in other components.

As explained before, in section 3.6, the design for variety method is a method for developing standardised and modularized product platform architectures. The coupling indexes indicate how many relations the specific components has, and by this how sensitive the component is for change. To develop a standardised components or a modular architecture, the CI-R and CI-S values should be decreased, compared to an integral design. When a change is made in the design, on the level of a component or on the level of the total architecture, it is preferred that as little as possible components need to be redesigned. Therefore, the value of the coupling-indexes should be lowered. However, this always has to be balanced. Lowering the values is not always the best solution, and integral design can also be beneficial. Therefore, it is essential to consider the impact of changes on the component, the impact the components has on other components and the occurrence and impact of changes in non-controllable factors. The GVI, CI-R and CI-S value give great insight into these aspects, and help to identify which components should be standardized or modularized, and also which components are not suitable to standardise or modularize.

Which conclusions can be drawn of the outcome of the GVI tables and the table of coupling-indexes is explained in Table 3—17, given below. Only a few examples are discussed in detail, to provide insight in why components should be standardised, standardise parametrical or modularize.

GVI	*CI-R*	*CI-S*	*Should standardise or modularize*	*If outcome is not clear or standardisation: the values of CI-R and CI-S parametric have to be considered*
Zero	*Zero*	*Zero*	Apply one standard. *The situation that all indexes are zero will almost never occur. Components will always have coupling relations with other components. Moreover, the demands, requirements and regulations will change over time.*	-
Low	*Low*	*Low* *Medium* *High*	Standardise *Because of the low GVI, it is interesting to standardise or modularize this component. When the GVI and CI-R both are relatively low, it is advised to standardise this component. The component is not likely to change, due to shifting demands of the client, or other market circumstances. The low value of the CI-R indicates that the component is only limited influenced by the other components connected to this component. It is likely that the component will not need to be adapted, as the component is not dependent on a high*	X

			amount of other components. *If both GVI and CI-R are relatively low, the CI-S value does not have a significant influence on the decision to standardise or modularize. When the CI-S value is high, it is advised to lower this value. The decrease of the CI-S index can be established by the application of some form of standardisation. By standardising the component, the CI-S value will decrease.*	
Low	*Medium*	*Medium*	Standardise *GVI is the most important index considering the decision to standardise or modularize. As explained, when the GVI is low, this indicates that the component should be standardised. To benefit from the principles of standardisation and modularization, it is advised to lower the CI-R and the CI-S. The decision if the components need to be standardised or standardised parametrical depends on the CI-R value parametric and CI-S value parametric. If these both are medium, or one of them is high, it is advised to standardise parametrical. If both are low, or one is low and the other medium, it is advised to standardise.*	X
Low	*Medium*	*Low*	Standardise *However, when the CI-R and CI-S Parametrical are medium or high, the advice is to standardise the component parametrical.*	X
Low	*High*	*Low*	Modularized *Based on the low GVI-value, it is interesting to standardise the component or the interface between components. When the CI-R value is relatively high, it will be more difficult to apply a standard or standard interface. A high coupling of components is present. Therefore, this component should be modularized.* *In this situation, the CI-S value does not have a significant influence on the decision to standardise or modularize.*	-
Low	*High*	*High*	Modularized *Based on the low GVI-value, it is interesting to standardise the component or the interface between components. However, when the CI-R value is relatively high, it will be more difficult to apply a standard or standard interface. A high coupling of components is present. Therefore, this component should be modularized as the component have a relatively high receive and supply index, and is likely to change and to require change in other components when a coupled component is changed.* *In this situation, the CI-S value does not has a significant influence on the decision to standardise or modularize. However, lowering the CI-S value is desired.*	-
Medium	*Medium*	*Medium*	Not clear if to standardise or modularize *In theory, it is always possible to standardise or modularize certain components. However, although this is possible, it is not always beneficial. The components with medium values are less interesting to standardise or modularize. Not sufficient can be gained by this approach. The project team should decide what to do with these components.*	X
Medium	*Low*	*Low*	Not clear if to standardise or modularize *These modules are straightforward to standardise, because of the low coupling indexes. However, the medium GVI means that the changing demands and wishes of the client and changes in the market will have to be considered. If changes occur, this will affect the design. However, the GVI has a medium value, and by this the influence from non-controllable factors that require change in the design is medium. Therefore no clear conclusion can be drawn. The*	X

			project team should analyse the filled in tables, and should discuss if they want to standardise or modularize. However, It should be noted that from a design point of view, the CI-R and CI-S rankings indicate the difficulty of standardisation or modularizing of components. Therefore, it will be relatively easy to standardise or modularize these components.	
High	*Low*	*Low*	Modularize *These modules are straightforward to standardise, because of the low coupling indexes. However, the relatively high GVI means that the changing demands and wishes of the client and changes in the market will have to be considered. As these are likely to occur and will affect the design. It is therefore advised to modularize these components. By appliance of a standard interface different option can be developed without affecting or require change in other components.*	-
High	*Low*	*High*	Modularize	-
High	*High*	*Low*	Modularize	-
High	*High*	*High*	Modularize	-
High	*High*	*Zero*	Fully modularize *Note that fully modularization of a product is not possible. Components will always have coupling relations with other components; this implies that a product will always have a certain degree of modularity.* *However, if both the GVI and the CI-R are relatively high, this means that it is very likely that the component need to be adapted to new market conditions, or need to be adapted because the connected components are changed. Therefore, it is advised to modularize the component. Several types can be developed. However, when for each situation a very specific design is demanded, it would be wise for the project team only to standardise the interface, and not providing options. The component can then be designed fully to the specific requirements and locational constraints. In this way, the impact of the components on other components will be decreased, and the components can be designed independently from each other.*	-
High	*High*	*Low*	Modularize *If both the GVI and the CI-R are relatively high, this means that it is very likely that the component need to be adapted to new market conditions, or need to be adapted because the components that are connected are changed.*	-
High	*High*	*High*	Modularize Alternatively, when modularizing the component is too complex: Design specific solution *If all three values, GVI, CI-R and CI-S are high, it is not interesting to standardise. It is likely that a specific component needs adaptation to changing market condition and demands the clients. The specific component is dependent on a lot of other components. In addition, when this component is adapted/changed, it will have significant impact on the total design, as many components are dependent on the information of this specific component for their design. It can be interesting to modularize this component, but this is very complex, due to the high amount of coupling. It is not impossible, but it is better to make a specific design (solution), as adapting the standard is only beneficial to a certain amount. If the situation is too unique, it is not interesting to apply standardisation or modularization, designing a solution from scratch is more appropriate.*	-

Table 3—17 Interpretation values - standardise or modularize

3.7.1 Steps to take: analyse outcome tables

The outcome of the different tables filled in need to be analysed. How these outcomes have been derived from the tables is explained in this section.

Analyse values and draw conclusions.

The outcome of all the three tables: GVI-tables, Coupling Indexes Direct and Coupling Indexes Parametric, are clearly documented. Moreover, various overviews of the outcome are developed and analysed. In this first step, the GVI, CI-R Direct and CI-S Direct are considered. Based on these three indexes it is identified if standardisation, standardisation parametrical or modularization is applicable, or if no clear conclusion can be drawn. The outcome of the filled in tables by five structural engineers individually and one table during a session together can be reviewed in appendixes C1 till C 10. How the different values of the GVI, CI-R Direct and CI-S Direct are evaluated and by this identified which components are suitable for standardisation and/or modularization is given in Table 3—18. Four different conclusions can eventually be the outcome: standardise, standardise parametrical, modularize, or not clear.

Step 1 – If GVI is high, it does not matter if the coupling indexes are low, medium or high. The conclusion that should be drawn is that the component should be modularized.
Step 2 – Only the components with a GVI that is low are medium still have to be reviewed. If the CI-R Direct is high, this component needs to be modularized.
Step 3 – If the components with a GVI and CI-R Direct that are both either low or medium are still left, the project team should consider the CI-S Direct. For the interpretation of these values, Table 3—18 should be applied.

GVI	*CI-R Direct*	*CI-S Direct*	*Interesting to*	*Outcome or decision is to standardise: the CI-R and CI-S value parametric need to be considered.*
High	*High*	*Low*	*Modularize*	-
High	*High*	*Medium*	*Modularize*	-
High	*High*	*High*	*Modularize*	-
High	*Medium*	*High*	*Modularize*	-
High	*Medium*	*Medium*	*Modularize*	-
High	*Low*	*High*	*Modularize*	-
High	*Low*	*Medium*	*Modularize*	-
High	*Low*	*Low*	*Modularize*	-
Medium	*Medium*	*Medium*	*Not clear*	*X*
Medium	*Low*	*Low*	*Not clear*	*X*
Medium	*Medium*	*High*	*Not clear*	*X*
Medium	*High*	*Medium*	*Modularize*	-
Medium	*Low*	*High*	*Not clear*	*X*
Medium	*Medium*	*Low*	*Not clear*	*X*
Medium	*Medium*	*High*	*Not clear*	*X*
Low	*Low*	*Low*	*Standardise*	*X*
Low	*Low*	*High*	*Standardise*	*X*
Low	*Medium*	*Medium*	*Not clear*	*X*
Low	*Medium*	*High*	*Standardise*	*X*
Low	*Medium*	*Low*	*Standardise*	*X*
Low	*High*	*High*	*Modularize*	-
Low	*High*	*Low*	*Modularize*	-
Low	*High*	*Medium*	*Modularize*	-
Low	*Low*	*Medium*	*Standardise*	*X*

Table 3—18 Interpretation values

When it is concluded, based on the three variables (GVI, CI-R Direct and CI-S Direct), that the structure has to be modularized. For these components, this is the final conclusion. These components are interesting to modularize (have potential). However, when based on the three variables the conclusion is that the component should be standardised, then the outcome of the CI-R Parametric and CI-S Parametric (CI-Rp and CI-Sp) also need to be analysed and taken into account. Table 3—19 below, gives an overview of what the outcome will be considering different CI-R and CI-S Parametrical values.

Outcome or decision is to standardise	*CI-R – Parametrical*	*CI-S - Parametrical*	*Approach*
	Low	*Low*	*Standardise*
	Low	*Medium*	*Standardise*
	Low	*High*	*Standardise parametrical*
	Medium	*Low*	*Standardise*
	Medium	*Medium*	*Standardise parametrical*
	Medium	*High*	*Standardise parametrical*
	High	*Medium*	*Standardise parametrical*
	High	*Low*	*Standardise parametrical*
	High	*High*	*Standardise parametrical*

Table 3—19 When outcome or decision is to standardise

The components were no clear conclusion can be drawn, are the components that have a GVI of Medium, and where the CI-R or CI-S values are medium or low (not high). The project team will have to decide if they want to standardise or modularize these components. If the project team makes the decision of standardising the components, then the same criteria as for components that were directly identified to standardise should be applied. The same criteria, listed above, should be considered. For example, the project team decides to standardise a component and the coupling indexes parametric are both high. This means that it is likely that although a standard can be applied in the various situations, this standardised component will change in dimensions. Therefore, it is advised to standardise parametrical.

Combine conclusions
Now the conclusion from the tables from the structural engineers individually and the sessions are known. These conclusions are combined in one table, to compare the results and define the general outcome. This table is given in Appendix C11.

Additional step that can be taken
In the GVI-tables the structural engineers were also asked to fill in the change of occurrence of specific locational circumstances or market developments. The values of 1, 2, or 3 were assigned. The GVI-value times this factor gives the GVI*factor. However, the GVI and GVI*factor only result in four different outcomes of the assigned categories low, medium and high, compared to the GVI. This should be analysed by the project team. However, in this research it had not effect on the general outcome.

3.7.2 Results of the tables

In this section, the conclusion drawn out of the tables filled in will be discussed.

The outcome of the analysis of the components of a viaduct by the method applied, can be reviewed in the various tables given in the appendixes C1 till C11. The tables give great insight in how components are coupled and which components are most likely to change. Many steps have been taken to be able to derive a conclusion from the values, and several tables are given in Appendix C. The general outcome can be summarised with the tables below, and are also given in Appendix C.

The conclusions drawn were considered in two ways. The result of the tables filled in by the structural engineers individually are combined with the result of the session hold with the structural engineers, this is given in Table 3—20.In the session, the structural engineers together had to agree on the values assigned. The structural engineers share their viewpoint and discussed why they have assigned certain values. Therefore, the outcome of this session is very valuable. The outcome of this sessions has the same weight for the results as the outcome of combined table of all the values assigned by the structural engineers individually.

As explained in section 3.7.1 till 3.7.3 the values were divided in low, medium and high. A table for the interpretation of these values is developed, this has already been discussed and can be reviewed in section 3.8. Based on the low, medium and high, a conclusion can be drawn if a component is interesting to modularize, standardise parametrical, standardise, or no clear conclusion could be drawn. To combine the outcome of the tables of the structural engineers individually and the session, on general outcome of the tables filled in by the structural engineers individually had to be derived. How many times a conclusion was drawn: modularize, standardise parametrical, standardise, or not clear, is analysed. When a majority of the advice was for example to modularize, the conclusion drawn was to modularize this component.

However, there were also components where no clear conclusion could be drawn because the majority of the outcomes were "not clear". Therefore two conclusions were made: without not clear and a conclusion that did consider not-clear. Without not clear is considered as the most reliable data. When a component is marked as not clear, this mostly means the value were in-between the values to standardise or to modularize and can be considered as "neutral". In addition, always almost all shared view occurred without considering the not clear. However, the conclusions drawn that did take the not clear into account, are also considered. The conclusion was different for two components, the foundation pad and intermediate wall/column(s).

However, when the tables with of low, medium and high are analysed again, the outcome standardise parametrical is considered as more appropriate. In addition, the session also had that outcome.

The combined outcome of the structural engineers individually (without not clear) and the outcome of the session are combined in one table, to draw a conclusion. This is given in Table 3—23.

Based on the data collected in this research , components that are interesting to standardise or modularize are identified. The result is given in Table 3—23. Components that are interesting to modularize are: foundation piles, abutment or bank seat, capping beam, deck: prefabricated beams, edge beam, edge element, upstand and expansion joints. Components that are interesting to standardise parametrical are: foundation pad and intermediate wall/column(s). Components that are interesting to standardise are: wing walls, parapets, connection between and approach slab. For four components, no clear conclusion could be drawn based on the data considered. These are pavement, edge element, safety guards and bearings, and need to be further analysed.

As discussed in section 3.6.5 it is important to note that Martin and Ishii have pointed out that the outcome of the derived tables is not leading. Going through the entire process provides the different participants with new insights that can be used for the application of the principles of standardisation and modularization. And can contribute to the creation of innovative ideas. The result should be seen as a starting point for the implementation of the principles of standardisation and modularization to develop a product platform. The outcomes should be further analysed and discussed within the organisation.

It has to be noticed that some components that are identified to be suitable for the application of standardisation and modularization are already standardised to some degree in the current practices of BAM Infra. However, there is still a lot more to gain. Based on the viewpoint of five structural engineers the most suitable approach is identified, but other aspects than reviewed by this method will have an influence on the decision for BAM Infra for which components the principles of standardisation and modularization should be applied.

Session structural engineers								
Session structural engineers	component number	GVI (average ranked 1-5)	CI-R direct	CI-S direct	CI-R parametric (average individual)	CI-S parametric (average individual)	Interesting to (GVI and CI-R and CI-S direct)	Conclusion (GBI, CI-R and CI-S direct and parametrical)
Foundation pad	1	Medium	Low	Low	Medium	Medium	Not clear	Standardise parametrical
Foundation piles	2	High	Low	Low	High	High	Modularize	Modularize
Intermediate wall/colomn(s)	3	Medium	Low	Low	Medium	Medium	Not clear	Standardise parametrical
Abutment or bank seat	4	High	High	High	High	High	Modularize	Modularize
Capping beam	5	High	High	High	High	High	Modularize	Modularize
Wing walls	6	Low	Low	Low	Low	Low	Standardise	Standardise
Deck: prefabricated beams	7	High	High	High	High	High	Modularize	Modularize
Edge beam: prefabricated beams	8	High	High	High	High	High	Modularize	Modularize
Pavement: Asphalt	9	Medium	Low	High	High and low	Low	Not clear	Not clear
Edge element (finishing)	10	Low	Medium	Medium	Medium	Medium	Not clear	Standardise parametrical
Parapets (pedestrians+ traffic)	11	Low	Low	Low	Low	Low	Standardise	Standardise
Upstand (schampkant)	12	Medium	High	High	High	High	Modularize	Modularize
Safety guards	13	Medium	Medium	Low	Medium	Low	Not clear	Not clear
Bearings	14	Medium	Low	Medium	Low	High and Low	Not clear	Not clear
Expension joints	15	Medium	High	High	Low	High	Modularize	Modularize
Connection between	16	Low	Low	Low	Low	Low	Standardise	Standardise
Approach slab	17	Low	Low	Low	Low	Low	Standardise	Standardise

Table 3—20 Outcome session structural engineers

Suitable approach		Structural engineers - individual										
Component	Component number	General outcome - GW	General outcome - AGP	General outcome - MM	General outcome - MH	General outcome - TW	Modularize	Standardise parametrical	Standardise	Not clear	Conclusion (with not-clear)	Conclusion (without not-clear)
Foundation pad	1	Standardise parametrical	Not clear	Not clear	Standardise parametrical	Not clear		2		3	Not clear	Standardise parametrical
Foundation piles	2	Modularize	Modularize	Modularize	Modularize	Modularize	5				Modularize	Modularize
Intermediate wall/column(s)	3	Not clear	Not clear	Standardise parametrical	Not clear	Not clear		1		4	Not clear	Standardise parametrical
Abutment or bank seat	4	Modularize	Modularize	Modularize	Modularize	Modularize	5				Modularize	Modularize
Capping beam	5	Modularize	Modularize	Modularize	Modularize	Modularize	5				Modularize	Modularize
Wing walls	6	Standardise	Standardise	Standardise	Standardise	Standardise		5			Standardise	Standardise
Deck: prefabricated beams	7	Modularize	Modularize	Modularize	Modularize	Modularize	5				Modularize	Modularize
Edge beam: prefabricated beams	8	Modularize	Modularize	Modularize	Modularize	Modularize	5				Modularize	Modularize
Pavement: Asphalt	9	Not clear	Not clear	Modularize	Not clear	Modularize	2			3	Not clear	Modularize
Edge element (finishing)	10	Standardise	Standardise parametrical	Not clear	Not clear	Standardise parametrical		2	1	2	Not clear	Standardise parametrical
Parapets (pedestrians+ traffic)	11	Standardise	Modularize	Standardise	Standardise	Standardise parametrical	1	1	3		Standardise	Standardise
Upstand (schampkant)	12	Standardise parametrical	Modularize	Modularize	Modularize	Modularize	4	1			Modularize	Modularize
Safety guards	13	Standardise	Modularize	Standardise parametrical	Not clear	Not clear	1	1	1	2	Not clear	Not clear
Bearings	14	Modularize	Modularize	Modularize	Not clear	Not clear	3			2	Modularize	Modularize
Expansion joints	15	Modularize	Not clear	Not clear	Modularize	Modularize	3			2	Modularize	Modularize
Connection between	16	Standardise	Standardise parametrical	Standardise	Standardise	Standardise		1	4		Standardise	Standardise
Approach slab	17	Standardise	Standardise	Standardise	Standardise	Standardise parametrical		1	4		Standardise.	Standardise.

Table 3—21 Outcome structural engineers individual combined

Suitable approach		Outcome (with not-clear)		
Component	Component number	Conclusion (individual, with not-clear)	Conclusion (session)	Result (with not-clear)
Foundation pad	1	Not clear	Standardise parametrical	Need to be analysed further
Foundation piles	2	Modularize	Modularize	Modularize
Intermediate wall/column(s)	3	Not clear	Standardise parametrical	Need to be analysed further
Abutment or bank seat	4	Modularize	Modularize	Modularize
Capping beam	5	Modularize	Modularize	Modularize
Wing walls	6	Standardise	Standardise	Standardise
Deck: prefabricated beams	7	Modularize	Modularize	Modularize
Edge beam: prefabricated beams	8	Modularize	Modularize	Modularize
Pavement: Asphalt	9	Not clear	Not clear	Need to be analysed further
Edge element (finishing)	10	Not clear	Standardise	Need to be analysed further
Parapets (pedestrians+ traffic)	11	Standardise	Standardise	Standardise
Upstand (schampkant)	12	Modularize	Modularize	Modularize
Safety guards	13	Not clear	Not clear	Need to be analysed further
Bearings	14	Modularize	Not clear	Need to be analysed further
Expansion joints	15	Modularize	Modularize	Modularize
Connection between	16	Standardise	Standardise	Standardise
Approach slab	17	Standardise.	Standardise	Standardise

Table 3—22 Result with-not clear

Suitable approach		Outcome (without not-clear)		
Component	Component number	Conclusion (individual - without not-clear)	Conclusion (session)	Result (without not-clear)
Foundation pad	1	Standardise parametrical	Standardise parametrical	Standardize parametrical
Foundation piles	2	Modularize	Modularize	Modularize
Intermediate wall/column(s)	3	Standardise parametrical	Standardise parametrical	Standardize parametrical
Abutment or bank seat	4	Modularize	Modularize	Modularize
Capping beam	5	Modularize	Modularize	Modularize
Wing walls	6	Standardise	Standardise	Standardize
Deck: prefabricated beams	7	Modularize	Modularize	Modularize
Edge beam: prefabricated beams	8	Modularize	Modularize	Modularize
Pavement: Asphalt	9	Modularize	Not clear	Need to be analysed further
Edge element (finishing)	10	Standardise parametrical	Standardise	Need to be analysed further
Parapets (pedestrians+ traffic)	11	Standardise	Standardise	Standardize
Upstand (schampkant)	12	Modularize	Modularize	Modularize
Safety guards	13	Not clear	Not clear	Need to be analysed further
Bearings	14	Modularize	Not clear	Need to be analysed further
Expansion joints	15	Modularize	Modularize	Modularize
Connection between	16	Standardise	Standardise	Standardize
Approach slab	17	Standardise.	Standardise	Standardize

Table 3—23 Result without not-clear

PHASE FOUR

Implementation

4 EMPIRICAL RESEARCH: IMPLEMENTATION

Q3 - How can the principles of standardisation and modularization be implemented, within the current structure and strategy of BAM Infra?

4.1 LESSONS LEARNED: OTHER INITIATIVES

Q3.1 - What lessons can be learned from the successes and failures of already established initiatives/projects considering the principles of standardisation and modularization, from within the company BAM?

4.1.1 Lessons learned – Product

This research is not the first initiative that BAM Infra has taken to make use of the repetition that occurs, by application of some form of standardisation. For this research it is interesting to review the initiatives that are already established to learn from their practices.

The initiatives that will be discussed in this section are:

1. *W&R concept for modular housebuilding – Waarde & Riant*
2. *Click and construct – Web application tool for the design of a small simple bridge*
3. *Standard railway underpass design - Tunnel Alliances with ProRail*
4. *Reference viaduct research, conducted within BAM Infra*
5. *Gravity based foundations*
6. *Modular development and construction – BAM Bouw & Techniek*

4.1.1.1 W&R concept – Modular housebuilding

W&R stands for" Waarde & Riant". In English, this means "value and riant". When all the companies within the Royal BAM Group are considered, the W&R housebuilding project is the most successful project that benefits from standardisation. This project is executed by the housing department of BAM. They work with a semi-standardised design and process, they have developed a product platform. Within these projects they work with a reference design, this reference design is the starting point of the project. This design can effectively be changed by removing or adding components, and other parameters can be adjusted according to the specific details of every project. The different components can be drawn from the database of the product platform. Although the new designed will be constructed of standard parts, it will still be very different from other houses, because the design can vary significantly by combining different standardised parts. Within the W&R concept, an 80%-20% rule is applied. This means that 80 percent is the same in every project and only 20 percent is left to be fully adjusted. In addition, because the building parts are standardised, the process is standardised as well. The process of the assembly has been standardised and optimised from project to project. This building process is executed by the same teams every time and by this learning takes place. Within the W&R house-building, the teams are not only employees of BAM. Many longer-term collaboration with suppliers and sub-contractors are established. The contributions of these co-makers to the projects have been standardised as well.

The W&R concept is considered to be a very good tool within the dynamic construction industry. It enables BAM Housing to cope with the increasing demands of the clients and the high level of competition within the industry. With this concept, BAM Housing can deliver houses that meet the wishes of the client for a significantly lower price than with the traditional way of working -. They can deliver variety, in an effective and economic way.

The W&R project makes it possible to repeatedly build the same houses, but with different aesthetic requirements and space layout measurements. The concept revolves around five basic pillars. These five pillars are the essentials aspects that have contributed to the success of the W&R concept, these pillars are listed below.

1. *Reference design*
   This standardised design is the starting-point for the design of the actual house. The reference house holds approximately 80% of all the information regarding design, planning and building processes. This means 80% of the design is already standard, and only 20% of the design has to be adapted/designed for a specific project.
2. *Continuous process*
   During every project and even project transcending, the process for foundation deposit is continuous. This process is independent of other processes. The W&R concept is also beneficial in their construction process because they are trying to use their capacity for the full 100%, referring to the LEAN-principle of limiting waste. This available production capacity consists of an amount of projects, several production teams and involved co-makers. With this production capacity and standardised construction process, it is possible to develop projects from the reference house and to

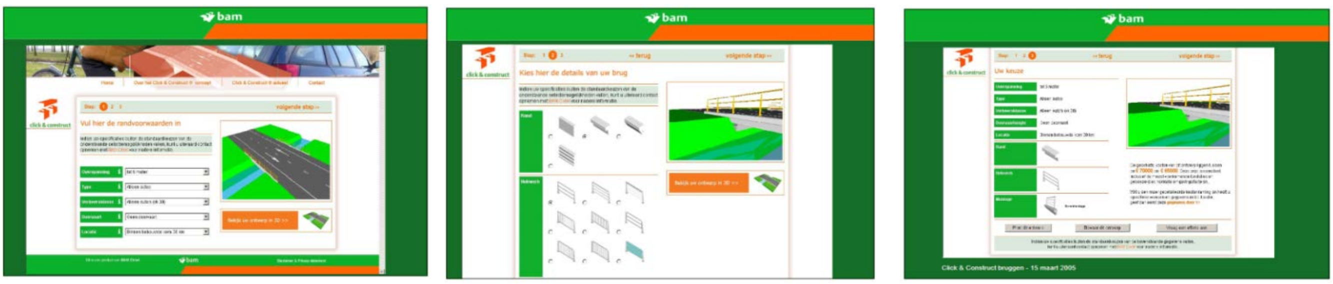
realise these projects in a row. Here the production process remains the same, but the location and the product are different.

3. *Fixed project team*
   Within the W&R concept, three members of the project team are fixed, this to transfer knowledge throughout various projects. The fixed project members are the project manager, project leader and executor. These are the three functions that are considered to be essential to work project-exceeding and take the experience and lessons learned to the next project. However, also the building teams that assembles the houses on the site are mostly put together by employees that are familiar with the process and products and have experience with working with each other.
4. *Co-makers/ Co-production*
   From the start of the W&R concept several suppliers are adopted as co-maker. Here, the suppliers are involved from early stages of each project, and no other suppliers are considered.
   An important advantage of working with the same parties within the different projects is that they are used to each other, and their experience makes all the different parties work as well-oiled teams. As a result, the failure costs are reduced and the construction time can be optimised. In addition, the quality can be increased. Learning will take place by going from one project to another and knowledge, and expertise will be shared between the co-makers and the construction company.
5. *Client focused action*
   Bam housing can offer an efficient development process for a product with a good price vs. quality ratio. In the initiation phase, the client and the architects together decide which reference design is appropriate for their project, and what budget will be suitable for this. Then together with the client a design will be developed and compared with the initial requirements and budget. The price vs. quality ratio in every project is more or less the same. In every project, around 80% is already known, because any development starts from the reference which is completely recorded in specifications, working and detail drawings. During the development, clear, transparent and fast communication about the possibilities, impossibilities and conditions and the effects on the price of the required adjustments to the reference is needed. In consultation, client, architect and contractor should together search for an optimal solution.

4.1.1.2 Click and construct

The click and construct project is an initiative of BAM Infra and BAM Infraconsult, to develop a web application for the development of small bridges. The basic idea behind the development of the web application, which can be referring to as a configurator (tool) for simple small bridges, was to provide civil servants of municipalities and provinces, and architects and urban planners with a tool that could give a conceptual idea for the small bridge. A 3D-model and estimation of cost and building time are the output of the web application. The web application could be used at *www.bouwjeeigenbrug.nl.* Within the web application, key figures of the small bridge and the specific location could be entered. For example how long and wide the bridge has to be and which functions the bridge should facilitate, considering the forces that the bridge will have to be able to handle. In this way, it is a fast and efficient tool to gain insight on what this small bridge would look like, the costs and the building times required.

Although the web application has been completely developed, and the website was lounged, the initiative has not been a success. The tool was mainly developed for a very early stage of projects. It is considered to be a good tool for a rough estimation and concept idea of the small bridge. However, during the development of the web application, it became clear that the situations for the construction of the bridge were significantly different in practice. However, only a limited amount of variety was considered in the web application. Therefore, the web application only gave an indication, but no more than this. The directors were the mainspring behind the initiative. When the directors left the firm, the initiative was put on hold and has not been developed further.



4—1 Illustration of the web-application for a small bridge

4.1.1.3 Standard railway underpass design

At the department of structural modelling at the company BAM Infraconsult, a standardisation initiative has been developed. A PDE-research about the standardisation of a railway underpass design has been established. The design of the process for railways, as well as parts of the final product, has been standardised. This research was conducted in the context of the Tunnel Alliances between Pro-rail and three other contractors. At that time, ProRail was aiming to replace existing railroad crossings with tunnels, throughout the whole Netherlands within a period of four years.

The research has been conducted by Maryia Smahlei. The standardisation aims to create a design solution which can function as a reference design and can be transformed to be suitable for specific locations by parametric modelling. The design can be reused multiple times, thus reducing the costs and optimising the design process. The outcome of the research was a conceptual framework for a standardised railway underpass. Several design standardisation concepts have been developed. These design standardisation concepts are based on making choices between different options, considering the horizontal and vertical boundaries of the different situations demands and based on the foundation type that is suitable for the specific location, the tunnel structure material type and the placement techniques available. This developed design concept has been presented in a BIM application model and will help to automate the design process for railway underpasses. Nevertheless, it has to be noted that the concept developed can be applied not only for tunnels. Also, in other similar contexts, where the same design solution might be utilised multiple times. (Smahlei, 2014)

Currently, BAM Infra is optimising the process and product design of the railway underpasses. Two railway underpasses have been realised already, but both projects were not lucrative, as the costs were higher than the price the railway underpass was built for. The process for optimisation is facilitated by the cost-leadership team. They organise group meetings and brainstorm sessions with various employees from different departments and disciplines involved in the standard railway underpass. Everybody's viewpoint counts. By doing this, they try to find ways to lower the costs. The cost-leadership program for railway underpasses started around April 2016, and some ideas have already been implemented. BAM Infra has a contract with ProRail for the railway underpasses, and they will be building around 50 railway underpasses in the next five years. The high number of underpasses that need to be realised makes working with co-makers very attractive. Currently, BAM Infra is developing the concept of a standardise railway underpass further. When the concept is mature enough, they want to involve co-makers.

4.1.1.4 Reference viaduct – research in-house

Within BAM multiple attempts have been made considering the development of a standard reference viaduct. The idea behind the development of a reference viaduct is that the design can be reused within different projects and can be adapted to specific situations. To support project which contains viaducts within the different phases: tender, design and execution phase. The most recent report is of 2014. This report further considers the already earlier drawn conclusions of other studies for the development of a standard viaduct. The research focusses on the standardisation of a viaduct design, based on standardised components. The different components of a viaduct are analysed, reviewed, and trade-offs between different options for components are made. The objective of this research was to develop a reference viaduct, which could be used as a starting point for the design of viaducts within an infrastructural project. Here a learning curve could be established to optimise the total process. The idea behind this was that project lead times, failure costs and risks could be decreased. Although the report has been a good first start for the development of a standard reference viaduct, the report has not been finished, due to reorganisation practices within the Royal BAM Group. The report has not been developed further, however various experts think it the initiative should be taken up again. They still feel that it is possible and will be beneficial to develop a reference.

4.1.1.5 Gravity based foundations – Foundation for offshore windmills

A new project within BAM is the development of gravity based foundations for offshore windmills. Within this project, BAM is collaborating with Van Oord to design, manufacture and install the reinforced concrete gravity based foundations (GBF) for the offshore wind industry. It is a self-buoyant hybrid solution that consists of a concrete caisson with a steel shaft. The base is cast onshore and installed into position offshore using standard vessels, obviating the need for heavy lift equipment. The basic GBF solution has been specifically designed for deep water applications and has undergone various model testing. This basic design has been standardised and functions as a reference design. The design can be adapted to suit a range of water depths, wave heights and seabed conditions of the specific location.

In figure 4—2, a 3D-view of the gravity based foundations is given. The figure gives an impression of how the reference design can be adapted and/or scaled for various locational circumstances.

4—2 Gravity based foundation: 3D-view

4.1.1.6 Modular development and construction

At the company BAM Bouw & Techniek, they started working on modular development and construction. They develop modular concepts for installations within utility buildings which can be used in different market segments. The concepts are not applicable to only one project, but can be reused in different projects. Currently, this focusses on the modular design and construction of catenaries. This concept entails product standardisation as well as process standardisation. An optimal logistic building process where the different modules are assembled within the building helps to reduce failure costs and decreases the building time. BAM Bouw & Techniek make use of one digital library (database). By combining the standard modules and adding and remove components, the final designs are made with the use of BIM. The designs are a combination of pre-designed standardised modules. These modules have been put together based on their functional requirements. The created BIM-model contains the different components and modules, but also how these components and modules will be combined considering the schedule (planning). On location, the execution team only has to assemble the prefabricated modules. BAM Bouw & Techniek is further developing this concept of modular development and construction for the installations within utility buildings.

A comparison of the various initiatives/projects is made and given in Table 4—1, below.

Initiative/project	Year of the first developments	Project-exceeding	Parametric modelling	Aesthetic aspect are important	Market push vs market pull (demand driven)	Current status
W&R concept for modular housebuilding	1992	X		X	Market push	Successful concept
Click and construct	2005	X	X	X	Market push	The “click and construct” bridge has been introduced in the market, but was no success. Reasons mentioned: a) The market was not ready for the new approach, b) Because of reorganisations within BAM Infra the initiative stopped, at that moment there were other priorities, c) No analysis, to see if the concept was asked by the market, was conducted.
Standard railway underpass design	2014	X	X	X	Market pull (demanded by Pro-Rail)	Research of Maryia Smahlei resulted in a good concept and is taken into consideration for the design of the standard railway underpass. Currently, BAM Infra has put a team together to design a standard. However, this is highly complex. The design should meet the specific requirements of ProRail, the Provinces and the Municipalities involved. Every location is a bit different, but the constraints mainly are the demands and wishes of the client. These are diverse for every project.
Reference viaduct research	2012	X		X	Current market pull, but has potential to become market push	Research needs to be continued
Gravity based foundations	2015	X	X		Market push (Concept delivered by BAM)	The design is finished. In August 2016, the first gravity based foundations are realised. If this project is a success, the design might also be applied in a project in Denmark.
Modular development and construction	2014	X	X		Market push (already designed system will be implemented)	Successfully applied, and is developed further.

Table 4—1 Comparison of the various initiatives

By review of documents and interviews conducted with various employees of BAM, considering the different initiatives at BAM, the Table 4—2listed below is defined. The five pillars of the W&R concept have already been explained earlier in this chapter. The viewpoints of the experts that have been interviewed are analysed. From this analysis, it can be concluded that the perspectives of the experts can be narrowed into the five pillars of the W&R concept. The pillars are developed for the house-building industry, but can also be applied to the infrastructural sector. The five pillars that are used are as follows.

- *Reference object (RO)* - A design or model that is used for the physical characteristics on the standardised/modularized concept.
- *Building process (BP)* - A continuous process to build the standardised/modularized concept.
- *Project team (PT)* - The team that works on and realizes the standardised/modularized concept.
- *Co-makers (CM)* - The subcontractors and suppliers that work with BAM to realize the standardised/modularized concept.
- *Client focus (CF)* - Involves the role of the client within the total process of the development and realization of the standardised/modularized concept.

	Reference object (RO)	Building process (BP)	Project team (PT)	Co-makers (CM)	Client focus (CF)	Number of pillars applied
W&R concept for modular housebuilding	*X*	*X*	*X*	*X*	*X*	*5*
Click and construct	*X*				*X*	*2*
Standard railway underpass design	*X*	*X*		*X* *(working on it)*		*3*
Reference viaduct research	*X*	*X*	*X*	*Want to involve co-makers*	*X*	*4*
Gravity based foundations	*X*	*X*		*X*		*3*
Modular development and construction	*X*	*X*				*2*

Table 4—2 Application of the five pillars within the various initiatives/projects

A broader description about the five pillars present in the initiatives/projects is given in appendix A19.

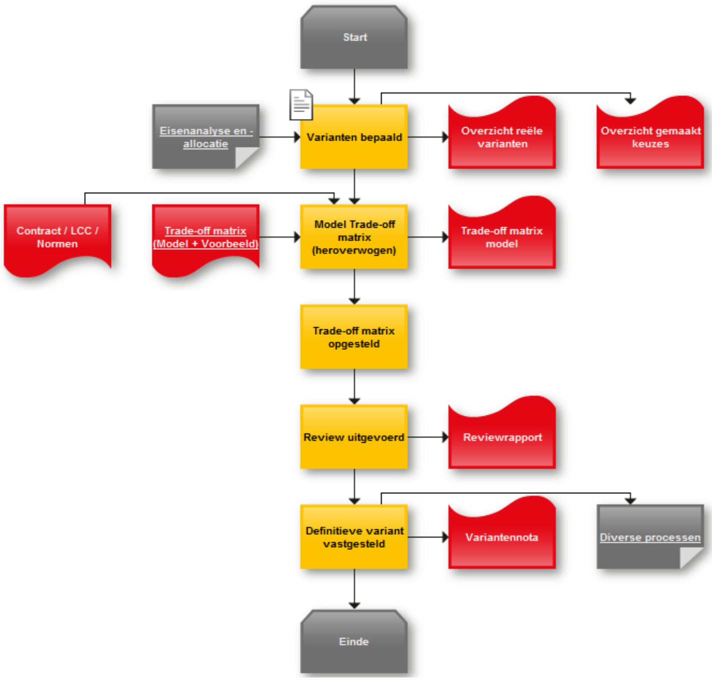
4.1.2 Lessons learned – General process

The initiatives that will be discussed in this section are the initiatives of BAM Infra to optimize their processes:

1. *Process Management System Infra (PMI 2.0)*
2. *Cost-leadership program*

4.1.2.1 PMI 2.0 – Process Management System Infra

The PMI 2.0, which stands for Process Management System Infra, is an initiative from BAM Infra consult. Within BAM Infraconsult the department Design management focusses on the development and capturing/archiving of project- and design- management. This by standardising the various processes within large projects. The PMI 2.0 is a tool that guides the project. It is a guideline considering what steps needs to be taken in which order and who should be involved in the different phases. The process management system is implemented in different projects over the entire company of BAM Infra. Currently, three different phases of a project are elaborated on: a procurement manual, a project management system and an asset management system. The employees of BAM Infra can review this manual and the different systems to apply these guidelines/steps in their current projects.



4—4 PMI 2.0 model

To keep the PMI 2.0 up to date, develop it future and constantly optimise, a database has been developed. The different projects that apply the PMI 2.0 share their approach and experience with other project teams by lessons learned. The database keeps track of all the deviations to the PMI 2.0 process that occurred in projects. In addition, the members of the different project teams can suggest improvements. The deviations in the PMI 2.0 process and suggestions made will be analysed. By this points that need to be improved will become visible and possible solutions can be implemented and tested within different projects. The PMI 2.0 process will be re-evaluated and will be changed if needed. Together the PMI- method is improved and optimised continually. BAM Infra wants to increase the appliance of the PMI 2.0 in their projects.

As stated, the PMI 2.0 is a new initiative, and this new approach is being implemented within new projects of BAM Infra. However, the processes are not embedded in the organisation yet. The prescribed processes of the PMI 2.0 model are guidelines for the employees to follow, for example, see figure 4—4. Implementing these specific models in all the different project can be beneficial. It provides a structured method to analyse and make chooses for certain design aspects.

4.1.2.2 Cost –leadership

Cost- leadership is a new initiative within BAM Infra and has started in March 2016. Cost-leadership focusses on the efficiency of the company BAM Infra. The idea behind the cost-leadership program is to mobilise the right knowledge, to think together of smart and creative solutions to lower the costs. In the current market of the construction industry being able to deliver projects on low costs is very important, as procurement is on the lowest price, considering prices versus quality ratio. The improvements that cost-leadership can bring are, for example, a tighter schedule, creative ways to develop and construct different objects, reducing waist and standardisation of processes. Currently, four employees of BAM Infra are working on the cost-leadership program. They review data, processes, tenders and projects to see what lessons can be learned and what should be improved. The cost-leadership team analyses current processes and works with the employees of BAM Infra to make them aware of their way of working, to give advice and tools that can help the employees to work more efficient and to share their knowledge within the company. Brainstorm sessions are organised, in which different disciplines together think of idea's that could lower the costs of tenders and project. Hans Verhoef, a member of the cost-leadership team, argues that; "Cost-leadership is not something you just apply, it is a way of thinking. Every employee of BAM Infra can be of influence". The cost-leadership program wants to raise awareness of the current way of working and transfer the experience and knowledge within the organisation, by this BAM Infra can distinguish themselves from other construction companies.

For the tender process, the cost-leadership team recently listed 10 golden rules; 1) *Diverse team, 2) Know the work and contract, 3) Make use of expertise and experiences, 4) Focus on what makes the difference, 5) Clear and challenging goals, 6) Think further than current practices, 7) Think is variants and options , 8) Have conversations with the client, 9) Have conversations with the suppliers and sub-contractors, 10) Challenge yourself, nothing is impossible.*

4.1.3 Lessons learned from the initiatives

W&R concept for modular house building – Waarde & Riant

- *Be true to the concept* - The five pillars of the W&R-concept, contribute to the success and have to be followed at all times. The five pillars are; 1) Reference house, 2) Continuous process, 3) Fixed project team, 4) Co-makers, 5) Client focused. 80% of the design is fixed, as the reference households hold around 80% of all the information regarding design, planning and the building process. Only 20% of the design is variable.
- *Fixed design* - The more a design is fixed, the less expensive it will become. Therefore, the concept will only be successful when the 80-20% rule is applied. Demanding more variety will come at high(er) costs.
- *Repetition* - Make use of repetition considering both product and process.
- *Optimise* - Continuously optimise product and process. However, do this by planning evaluation-moments at front. Do not optimise within a current project, apply the optimisation within new projects.
- *Work together* - Co-production and working with co-makers can be very beneficial: "the whole is greater than the sum".

Click and construct – Web application tool for the design of a small, simple bridge

- *Keep end-user in mind* - During the development of a new tool, it is essential to keep the end-user in mind. The click and construct tool was a first start of a configurator. However, during the design, it was not analysed from the view of the end-user. A tool was developed were the end-users had no interest in, and therefore was not used.

Standard railway underpass design - Tunnel Alliances with Pro-rail

- *Process and product need to be aligned* – Both process and product have to be standardised and should be aligned to fully benefit from the concept: process and product are interrelated.

Reference viaduct research, conducted within BAM Infra

- *The reference should still offer sufficient variety* - Although the 80-20% rule of the W&R-concept would be ideal, it is not always possible. In the case of a viaduct, the standard reference still needs a significant amount of variation. Otherwise, the solution will not fit the situation. So that the standard design can be adjusted based on different variable

- *Application of a standard or other form of standardisation is not always the best option* - When there has to be made too much adaptation, it is better to design a viaduct from scratch, as the adaptations will result in high costs, and eventually the end-product becomes more complex and will be more expensive compared to when a design for the unique situation will be developed from scratch.
- *Clear flowcharts need to be developed* – Clear flowcharts needs to be developed, where the trade-offs that currently still have to be made within each project need to be clearly documented. Preventing the project team from "reinventing the wheel".

Gravity based foundations

- *Sufficient room for innovation* - The gravity-based foundations are innovative and completely different from other solutions within the offshore windmill industry. Thinking about the future, thinking "out of the box" and being creative will bring BAM Infra further. There should be sufficient room for designers to investigate and apply innovative solutions. ("We cannot solve our problems with the same thinking we used when we created them" – Albert Einstein)
- *Diverse project-team* - It is good to have a diverse project team, also containing people with less or no experience in a certain work field, as they will not be biased and still have an open minded view. They see less restriction and think about the project in a different way compared to people who have experience in the work field.

Modular development and construction – BAM Bouw & Techniek

- *Have one shared vision* - If standardisation and modularization will be implemented within BAM, it is important to be aware of the scepticism of different employees considering the concept. It is important to convince the project team, and to work on the concept together with a shared vision and clear goals in mind.

Process Management System Infra (PMI 2.0)

- *Create support* - A standard framework where the different steps to take are fixed, referring to standardised processes, can be beneficial. However, the standard framework will not always be applied. Employees of BAM Infra will not adopt the new approach immediately. Therefore, it is important to explain why these steps can contribute and support of the employees is needed.
- *Regular evaluation*s - Regularly evaluate projects, and learn from these projects for projects in the future.

Cost-leadership program

- *Everybody's idea counts* - All employees of BAM Infra can contribute to efficiency and the lowering of costs. Not only should the opinion of the management be reviewed, but also the opinion of the people that are lower in the hierarchical structure should be considered. Everybody has a different view on current practices. (You do not have to be big, to be big)
- *A small change can have a large impact.* - The changes can be within all the different levels and processes in the organisation. (It does not have to be big, to be big)

4.2 CRITERIA FOR A NEW APPROACH

Q3.2 - What are criteria that the new approach should conform to, to benefit from the principles of standardisation and modularization, and to eventually establish a product platform for a viaduct?

4.2.1 Criteria identified for a new approach

The literature study on standardisation and modularization in the construction industry and the complexity of the infrastructure sector concludes that the benefits of the principles of mass customization can also be obtained in the construction industry. For standardisation and modularization to be of value in the construction industry, the developed method is required to cope with the complexity involved. In addition, the construction companies will have to change their way of working. Different factors have an effect on if the new way of working that benefits from the repetition that occurs will be successful. Criteria that a new approach should have for the successful application of standardisation and modularization, therefore, have been identified and formulated. These identified criteria are based on the literature study, the review of the different initiatives within BAM and conversations and interviews conducted with experts. The criteria's are:

- *Client = King (meet the demand and wishes of the client)*
- *Establish a learning curve: constant feedback loops*
- *Continuously adapting and improving product and processes*
- *Clear trade-offs need to be made: only standardise and/or modularize elements that are suitable, and are of benefit.*
- *Clear communication and transparent information exchange.*
- *Project team should work autonomously (mainly design phase)*
- *Flexibility is needed: right balance*
- *Early involvement of all the different disciplines*
- *Provide a protocol of which steps should be taken going through the different phases (more detailed design and realisation phase)*

In addition, the main changes in the market that are needed for implementing and fully benefit from the new approach are listed.

- *More freedom in design: functional project description (reduce complexity)*
- *New way of working: movement from market pull towards market push*

Explain criteria that the new approach should have into more detail

- *Client = King (meet the demand and wishes of the client)*
  The standardised and/or modularized concept should meet the requirements, demands and wishes of the client. It is important that concept fit the need of the market. Even though a concept could be functioning great, if the client is not interested in the concept, it will never become a success. (W&R concept), (Lessons learned). For successful innovation, contractors are dependent on their clients (Lim, 2016). However, clients have been perceived as conservative. They are not instrumental for innovation. It is important to involve the client in the development processes.
- *Establish a learning curve: constant feedback loops*
  It is essential that during the various phases of the project, the project team continuously review if they meet the requirements of the project. However, also when the project is finished and in the utility phases the construction work and processes should be reviewed. By this, the project team will become aware of which approaches are the most beneficial and which approaches are suitable for the different situations occurring. If the different members of the project team are not aware of the faults they have made, the same faults will be made in other projects all over again.
- *Continuously adapting and improving product and processes*
  Products and processes need to be constantly improved and should be adapted to changing market conditions. Insights gained during projects should be considered in the following projects. The concept should evolve with the time. (Perminova, Gustafsson, & Wikström, 2008). Product and processes can be improved and adapted to new circumstances, based on the experience gained from established projects.
- *Clear trade-offs need to be made: only standardise and/or modularize elements that are suitable, and are of benefit.* (Giezen, 2012)
  Only standardise or modularize elements that are suitable, and are of benefit should be standardised and/or modularized. At the beginning of the project, trade-offs considering designing from scratch or make use of a reference will need to be made.
  - Not all product and processes that can be standardised and/or modularized also should be standardised and modularized. Clear trade-offs will need to be made. In some situation, an integral design can be more beneficial

than a standardised and or modularized design. Different aspect will need to be reviewed, keeping in mind which aspects are considered as important.

- In addition, at the beginning of a project, it is important that the goals are clear, to be able to make clear trade-offs based on these goals and the relative importance of the different aspects. A decision has to be made if the application of the principles of mass customization will be suitable and beneficial for this specific project. When the standardised and/or modularized design has to be adapted significantly, due to location circumstances and unique features the client demands. Designing the object from scratch can be a more suitable approach.

This has also been emphasised by Gibb. There is a conflict between maximum standardisation and flexibility. The implications are that it might lead to design impotence when the level of standardisation is higher than desired. However, it has to ensure optimal implementation. Gibbs, therefore, argues that maximum standardisation is not always the best option, flexibility is needed. (Gibb, 2001)

- *Clear communication and transparent information exchange.* (Thiry & Deguire, 2007) (Davies, Gann, & Douglas, 2009) (Choi, 2014) (Jensen, Olofsson, & Lessing, 2015). (Larsson, Eriksson, Olofsson, & Simonsson, 2014) (Jansson, 2013) (Jensen, 2014).
    - Clear communication and transparent information exchange within the project team, as between the construction company and sub-contractors is of great importance for project success. The different parties involved all should have the same end-goals in mind, and the weight given to the different aspects should be clear for all the parties. In addition, transparent information exchange is essential to make sure the different products and processes comply with each other. By this, the end-goal can be established together.
    - Clear communication and transparent information exchange are essential in construction projects. However, this is also essential when a project is finished. The steps taken and argumentations why this approach is chosen should be documented properly. So that the project can be reviewed by others and the different approaches that have been successful can be applied in new projects.
- *Project team should work autonomously (mainly design phase)*
  When a construction company wants to implement standardisation and/or modularization, it is important that the project teams are self-managing. The management team should entrust their experts only once, and then the approach will be adopted and taken further by the experts. Developing a framework with contain steps to take and flowcharts can be a very effective tool to make sure a certain approach is obtained. The project teams should apply the demanded approach and should continue to apply this approach during various phases of the project and within other projects. However, the framework needs to be sufficiently flexible. By this, the project team can take different initiatives, learn from previous projects and optimise product and processes continually. Without the need for the management team to interfere in this process. The project team needs to work independently from the management team. They should be self-managing. (Gann & Shalter, 2000).
- *Flexibility is needed: right balance*
  The concept should not be star but should be flexible, be able to be adapted to the different situation occurring. (Priemus, Bosch-Rekveldt, & Giezen, 2013). Standardisation is the exact opposite of flexibility and for both can be argued why it is of value in construction projects. In construction, flexibility needs to be combined with standardisation. The flexibility gives the ability to deal with specific locational circumstance and client requirements, while application of standardisation benefiting from economies of scale. At the beginning of a project should be determined what the balance between the two opposites ends is aimed for, this has an effect on the choices made in the design and realisation methods among others. (Arif, 2012). It will make us able to deliver customised products at a relatively low price. If there is not sufficient flexibility in the concept, the application of the standard concept will not meet the specific locational circumstances and the requirements of the client.
- *Early involvement of all the different disciplines*
  For the application of the principles of mass customization, it is important to collaboration between all the different disciplines is established at the beginning of the project. It is vital that all parties involved have one common goal, and that they shared their viewpoint. Great insights can be gained when parties discuss the project into more detail at the beginning of a project. By this, they are aware of the ideas, trade-offs, limitations and concerns of the other parties involved. Eventually, this will result in less discussion in later on phases, and more optimal processes and design will be the outcome. For a specific project that constantly come back, like the W&R concept, it is even advised to make use of co-makers/co-production. Developing and optimising the concept together can be very beneficial.

- *Provide a protocol of which steps should be taken going through the different phases (more detailed design and realisation phase)*
  Within the W&R concept, a fixed project team is applied, so that they get used to each other's way of working and together optimise their product and processes, as they learn from each project and get more experienced with the techniques applied and experienced working with each other. For an infrastructural object or a large infrastructural project, it will not be possible to work with a fixed project team. However, it is important that all the members of a project team be aware of the steps that will be taken. A protocol will provide this and will help the project team to work in a structured and systemized manner.

The main changes in the market that are needed for implementing and fully benefit from the new approach are explained in more detail below.

- *More freedom in design: functional project description (reduce complexity)* (Wood & Gadibo, 2006)(Van Goudzwaard, 2015) (Bertelsen, 2003).
  The client should only formulate functional requirements and only limited aesthetic requirements should be listed. The construction companies need to have sufficient freedom in design to be able to benefit of the repetition that occurs; applying the principles of standardisation and modularization. In addition, too many requirements will make the project more complex. Moreover, possible solutions cannot be applied as, for example, the material to apply within the design is already fixed, although application of a different material could be more beneficial than the material listed by the client. More freedom in design will give the construction companies more freedom to innovate and apply their best practices.
- *New way of working: movement from market pull towards market push*
  For the implementation of the principles of mass customization for the construction industry, a new way of working is needed. This within the construction company, as within the total construction industry. It would be ideally if the construction company will offer products, which can be established by creating a combination of different standardised and/or modularized components that they have designed at front.

Within this research, the assumption is made that a movement from market pull towards market push will occur, as currently trends can be seen, and initiatives of different companies and even provinces and municipalities are taken (referring to "the bouwcampus" and Platform WOW).

4.3 DEVELOPING MODULAR PLATFORM-BASED PRODUCTS AND SERVICES

The current construction industry can be characterised by having arm's-length relations between the suppliers and the construction companies: the buyers. Within other industries, the principles of standardisation and modularization are already well known and adopted. In these industries, the modular product architectures and the buyer-supplier relationships are aligned. However, this alignment has not yet occurred in the construction industry. Although the different actors within the construction industry are aware that the implication of a supply chain structure can be very beneficial, most construction firms still approach every project as a new one-off effort. They do not apply the principles of standardisation and modularization. They do not make use of the implementation of a supply chain structure referring to the establishment of a product platform. The buyer-supplier relationships in these traditional construction settings can be characterised as a typical market exchange relationship. Within the traditional setting, this means that information exchange between the different firms takes place mainly during the bidding and contract negotiations. The suppliers do not get involved in the design of the components, and the components are usually manufactured based on the drawings and requirements of the buyer. (Hofman, 2010)
BAM Infra is currently trying to change this way of working, by already involving suppliers early in the project and together design a solution for the specific situation. However, this remains project-based, and a supply chain structure is not implemented. There are no continuous long-term relationships between the different companies. The lack of this continuous long-term relationships has been pointed out by Dubios and Gabbe (Dubois & Gadde, 2002) as the main reason for the construction industry's failure to increase in efficiency and innovation. Most relationships are project-based, this means there are no continues long-term relationships. After a project is finished, both parties go on to their next project, and the ideas, opportunities, innovations and lessons learned are not taken further, they are lost on individual projects. Therefore, it is difficult to innovate, to learn from and to optimise the current products and processes.

Researches within other industries have already concluded that alignment of the product architecture and the supply chain structure design are complementary and that this alignment leads to a better performance. (Hofman, 2010)
In the research of Erwin Hofman about modular and architectural innovation in loosely coupled networks, the house building industry is analysed and concluded that the alignment between product and modules and contractor-supplier relationships is founded to be contingent on four drivers;

1) The degree of variety in customer demands
2) The extent of the required supplier investment
3) The extent of dependence on suppliers knowledge
4) Intentions of both the supplier and the buyer in a relationship.
   The intentions with-in the buyer-supplier relationship gives an indication whether the supplier relationship is aimed at: 1) efficient development and production, 2) learning and transferring knowledge between firms, and 3) The wishes to stay flexible.

These findings are more or less the same for the infrastructural sector of the construction industry and are applicable as well.

If BAM Infra wants to establish a product platform, by applying the principles of the mass customization industry, they need to be aware that they cannot accomplish this alone, cooperation with other parties is needed. In a decentralised business network, as the construction industry is, the different parties do not have sufficient bargaining power to force partners to adopt the new design rules. Most suppliers will not be willing to adopt the new design rules for the product. The suppliers have several reasons for this (Hofman, 2010):

a) *New standards* - The new design rules require adapted working routines and production lines. Because of this change that is required the suppliers are reluctant to adopt a new standard.
b) *Design for manufacturing and material knowledge* - The initial module designs were not aligned with the manufacturing practices. The suppliers are of the opinion that when they would be involved in the module development, this could have been improved and the new module design would be more aligned with the current manufacturing practices of the suppliers.
c) *Scale of the project(s)* - Most traditional project-based contracts only result in relatively small production batches. The willingness to make a relation-specific investment is, therefore, limited, as the investment needs to be earned back. However, this will generally not be the case, as most of the time, the innovation is only applied in one project.
d) *Knowledge* - The suppliers had only limited knowledge about the new design rules and how they should be applied. In addition, the suppliers also had no experience with co-maker relationships.
e) *Capacity* - The current construction market is buoyant, and suppliers have only a little or no surplus capacity at all. The work that is required to conform to the new design rules from external customers has little attraction.

Although BAM Infra is a large company they still depend on other companies for resources and competencies/expertise that they do not have in-house, which are required for the development, production and construction of the different components for the construction and the realisation of large infrastructural projects. For example, BAM Infra is dependent on suppliers of prefabricated concrete components. They do not have their own factory and do not have all the required specific expertise in-house. Both the construction company and the supplier need to invest in this new relationship as they are mutually dependent on each other. However, in practice, it is difficult to find suitable suppliers that are willing to make the relation-specific investment. The project-based short-term contracts are still dominant, and the supply chain of the construction industry is not familiar with the stable long-term co-operative relationships. The preferred supplier will therefore always ask for sales guarantees. The suppliers are only willing to invest if they are convinced that the production they need to deliver will be a sufficient amount, it should be enough to result in an acceptable return on their investment. However, for infrastructural projects, this is a bit different. During the interview with Kees Quartel, head of the sales department of Spanbeton, it became clear that the suppliers are open to together develop new innovative concepts. Kees Quartel argued that when BAM Infra is tendering, they have to put effort into the design. In most situations, this requires more effort than the compensation that is given when the contract is not awarded. Therefore, it is a risk. If BAM Infra does not innovate, they will not win the procurement. However, innovation in the construction industry, cannot be established by one company alone. Spanbeton and BAM Infra need each other for this. Both should focus on winning the project together and not see each other as competition. BAM Infra and Spanbeton need to cooperate, and on the basis of trust. Working together on one project will result in working together on other projects as well in the future. Working together has become essential. Otherwise, both Spanbeton and BAM Infra will be outcompeted.

It can be concluded that if BAM Infra wants to develop a product platform for a viaduct they should establish long-term relationships with suppliers. In addition, it is essential that BAM Infra integrate suppliers into the process, their knowledge about certain aspects that BAM Infra has no or limited knowledge of, can improve the module design and the design rules, related manufacturability, product performance and production costs. The input of supplier knowledge in the development phase will improve the quality of the design rules and directly lead to increased adaptation of these rules by the suppliers.

It is important to note that the development of a product platform is not always a good approach. It should only be considered when it is clear that the modular platform can be reused in future products. In most cases, this can be very risky. Halman et al. (2003) have emphasised that the main risks to be considered are the uncertainties in forecasting future consumer demands, the integration of existing elements, and the major impact of any mistake made early in the development phases (Halman et al., 2003).

4.4 IMPLEMENTATION OF THE PRINCIPLES OF STANDARDISATION AND MODULARIZATION

Q3.3 - How can the principles of standardisation and modularization be implemented and what are important points to note and steps to take, to be able to benefit from the principles and to provide continuous optimisation and innovation?

4.4.1 Requires effort from all parties

Akintoye, Goulding and Zawdie emphasise that to promote and retain competitiveness, the construction industry needs to focus on innovation and the improvement of their processes. They argue that innovation in construction is essential. (Akintoye, Goulding, & Zawdie, 2012). They and other experts emphasise that a paradigm shift in thinking is now required, as explained the literature review. According to Akintoye et al. (2012), this should contain proactively engages structured initiatives that purposefully align to proven innovation concepts, techniques and applications. Important here are: continuous improvement, to achieve significant productivity improvement, and the role of people, process and technology. These aspects need to be linked and integrated to ensure that innovation is constantly guided and reviewed by measurable process improvement initiatives. The opinion of Akintoye,Goulding and Zawdie is also applicable for BAM Infra. In addition, Akintoye,Goulding and Zawdie point out that different governance organisation and important stakeholders within the industry influence and drive construction innovation. It will require new thinking and by this new approaches need to be established, and this will also influence the current relationships within the industry. In the infrastructural sector of the construction industry, this is also the case currently. During the research, it has become clear that implementing the principles of standardisation and modularization requires effort from all parties involved. This has already been pointed out in the literature review and is confirmed when conversation and interviews were held with experts of BAM Infra. For example, currently, the listed requirements are too specific, and not sufficient room for innovation is present. This is only one example why how the market of the construction industry currently works will have to be changed. This change has to be implemented gradually. Implementing this new way of working will not be easy. The construction industry has been a stable industry for many years, and all the processes are based on this stable market.

4.4.2 Labelling of project to develop a configurator

Although implementing the principles of standardisation and modularization requires effort from all parties involved. It is essential that BAM Infra already start investing in this new approach. To be able to benefit from the change of the market situation when the described change will occur. Development of a configurator for internal use within the company will be and effective tool to be able to meet the various demands of clients and their unique situation, by combining already applied/established concepts and techniques.

Before a configurator can be developed, data needs to be collected about projects that have been realised or designed. Currently, this data is not clearly structured, and experts of BAM Infra do not have access to the data of other projects. In addition, when they do have access, there is an information overload. Knowledge management is essential for all companies in every industry. Clear and simple knowledge management will help BAM Infra to continues improve their current practices. Within BAM Infra, a fragmented culture is still present. However, the different departments should work together more closely and should share their knowledge, innovations and other ideas. Just giving the experts of BAM Infra access to all documentation will not change the current situation. There is too many data, and the data is not structured clearly. The knowledge and expertise need to be shared between the different departments of BAM Infra. However, it has to be shared in an effective and efficient way.

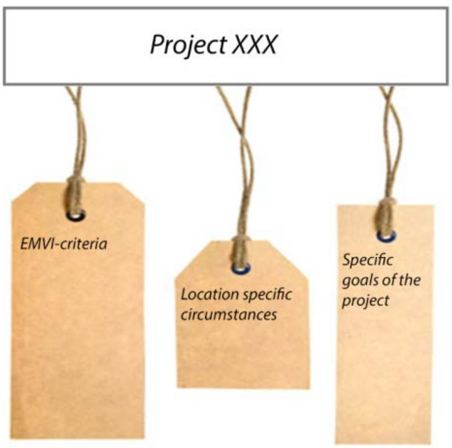
Labelling of projects: collect data

To be able to share the knowledge and expertise in an effective and efficient way, first data about the projects established and the current projects should be collected in a structured way. Hereafter, a database can be developed. Within this research, a new approach is suggested. It is suggested to develop a labelling method to document the data about the various projects in a structured way.

The labelling of projects is with three goals in mind:

1. *Development of a database*
2. *Development of a search engine*
3. *Development of a configurator.*

All three goals are explained further below.



4—5 Illustration of the proposed labelling system

1. Development of a database
A database should be developed. For the experts of BAM Infra, it should become easy to access the data of various projects so that this data can be reviewed and the lessons learned can be considered within other projects. This can be established by the development of a simple form. The form should be filled in within the different phases of a project: during and after the completion of the project. It should be a digital form that is directly linked to the database that should be developed. The form should be filled in by the different disciplines, and the data should also be sorted by discipline within the database. In this way, the information that is relevant to a specific discipline can be found easily. For the certain members of the project team considering one specific discipline, then immediately have an overview of the data about already established and current projects with specific focus on their work field. These projects, and by this the knowledge and expertise, can be reviewed. It can be analysed if the approach, technique, innovation or other aspects can be applied within the new project. In addition, per project a general overview should be given, this overview should be based on the forms filled in by the different disciplines. The project leader and/or project managers should be responsible for filling in the general form that should provide an overall overview of the project.

2. Development of a search Engine
A search engine should be developed based on the labelling of the projects.
Four possible searches are identified. When the database is sufficiently mature, other categories can be added if needed.
1. Search by object (for example: viaduct, railway overpass, etc.)
2. Search by component (considering trade-off-tables and innovations developed)
3. Search by project, considering already established and current projects.
4. Search characteristic, requirements and specific goals of the projects.

4—6 *Search based on the characteristics of a project, by application of a labelling system*

Currently, within BAM Infra, the lessons learned, knowledge and expertise are shared mainly from employee to employee. The lessons learned, knowledge and expertises are shared during cooperation within a project, or just because they talked about it during lunch. People contact each other to get information about projects they heard of that might be applicable and/or useful for their current project. However, because there is no general database, this knowledge is not easy assessable and stays within in the minds of the people. If an experts want to know more about a specific project or innovation, it should contact the people who involved in this project. However, due to the reorganisation a database considering who were involved in a certain project is not present. This means an extensive search within the entire organisation of BAM Infra is required to get insight into the possible approach, innovation or new initiative. It will require a lot of effort and time. However, when the right people are found, the experts that have been involved in the development need to look op the data. However, in most cases, they do not have access to the specific folders any longer. Also, the data that can be found is not structured. Therefore, it is very hard for an outsider to know which documents are interesting to review for a certain project and no overview of the project is given. The proposed approach of labelling by which a database will be developed should change this.

Above the scenario is explained where the experts did hear of the project or development. However, the experts will not always know about every new development or project. If people do not know about practices, they cannot review these and the new developments and lessons learned will not reach the employee. In this way, the learning curve and continuous optimisation of products and processes are hampered. However, when a database is developed, the experts should consult the database by the research engine considering the goals, EMVI-criteria or other characteristics of the project they started to work on. The experts can gain insight by reviewing other projects that are comparable.

The general database for the various projects should contain the different aspects of a project and should provide different levels of detail that are appropriate for different phases of a project. Some suggestions for aspects that need to be covered in the database are: the concept, drawings (of all the different phases), planning related documents (construction time and lost vehicle hours etc.), locational circumstances: soil conditions, specific infrastructural situation the project had to be realised in, requirements of the client, budget: based on procurement price and as-built, specific themes, goals, EMVI-criteria and other characteristic of the project: sustainability, building demountable, speed of the construction process, safety conditions on-site, maintenance etc.

3. Development of configurator
A configurator can be a good tool to facilitate knowledge management, and learning and designing in an efficient and effective way. Configuring a product is “putting together a product from well-defined building blocks (modules) according to a set of predefined rules and constraints (Hvam, Martensen, & Riis, 2008). Configurators exist to standardise and expedite the

engineering design process by enabling the reuse of existing results and knowledge. The configuration of modular platform architectures also facilitates the effective use of information and its transfer between the different domains. (Jensen, 2014).

Within this research, the idea of a configurator is based on the database and search engine proposed to develop. Two type of application of the configurator are distinguished.
1. Configurator that gives suggestions for other projects that had to deal with the same characteristics. Or other approaches, innovations, etc. that could also be applied to the new project
This configurator is different from the research engine discussed above. The project team does not search based on the specific aspects but has to put all the requirements, specific locational circumstances, budget available and other characteristics into the configurator. These are pre-listed in the configurator, and the project team should select the aspects that are present in the new project. Within the database, it has been documented which approach or new developments have been successful and which were not successful. The review of all the projects is documented in a structured way.
2. *Configurator that eventually gives an outcome of how an optimal design for this project should look like, considering the combination of the different type of components that have to be applied.*
The configurator should contain flowcharts that make decisions based on different aspects of the project: the requirements, specific locational circumstances, budget, building time, EMVI-criteria, etc. However, this cannot be developed immediately. First sufficient project needs to be documented in a structured way by the labelling of projects proposed. Moreover, more research needs to be conducted considering the trade-offs that should be made within the different projects. It is essential that the configurator does not give one specific answer. Three or four different projects need to come out of the configurator, with a clear description of which aspects could also be suitable for the new project. These projects and their different aspects can then be analysed. This human factor is essential. It requires the organisation to be effective, but remain flexible and able to deliver unique projects.

<u>*Some advantages of the development of a database, by which eventually a search engine and configurator can be developed.*</u>

- *Modular design*
  When a modular design is applied, the application of a configurator will be possible and less complex because the interfaces are standardised. The tool can efficiently combine different components, to create an optimal solution.
- *Provide a great chance for continues optimisation by working project-exceeding.*
  Due to a general database, search engine and configurator innovations will be taken further and are transferred to new projects. It will make BAM Infra able to work in a more project-exceeding way.
- *Possible to contact experts involved in the project to get more insights.*
  Considering all three developments proposed a list of members of the project team with their function and contact information should be created. If an employee is triggered by a certain approach, innovation or specific project, they first can review and analyse the documents that are in the database. This just by going through the database, use the search engine or review the projects that are proposed by the configurator. If they are still interested to possible, apply the approach, innovation or learn from a project they can contact experts of the project team to get more insights.
- *Makes it possible to compared different design alternatives (fast and effective)*
  When a modular architecture is developed, components can be mix and matched. By this different alternatives, design can be developed and compared relatively fast.
- *Fast estimations about time and costs*
  In the database, the planning and costs of projects are documented. Based on these documents the project team can make fast estimations about time and costs considering reused method and components or comparable designs.
- *Will facilitate the process of trade-offs that need to be made.*
  Flowcharts are embedded in the system, and the results of other projects can be reviewed.

<u>*Some constraints of the development of a database, by which eventually a search engine and configurator can be developed.*</u>
Needs to be updated regularly
It is important that the database and configurator are regularly updated. To make sure the outcome of the configurator still is the most optimal solution, and that the recently realised projects or innovations arecan be considered.

- *Experts need to use the database, search engine and configurator*
  It is essential that the experts will use the database, search engine and configurator. Moreover, apply successful concepts again in their new projects. However, therefore sufficient projects need to be documented in the database. Furthermore, the database, search engine and configurator should be easy to use. Otherwise, people will be redundant to use these tools.

4.5 Current situation at BAM Infra: Other findings found

In this section observations made and finding found during this research by having discussions with experts of BAM Infra and the interviews conducted are discussed. The findings have contributed to the formulated advice in the following chapter: chapter 5.

4.5.1 Conclusion of the survey: Main insights derived.

In this section, some conclusions that have been derived from the survey conducted are summarised. The survey, given in Appendix A, asks questions about the applicability of the implementation of the principles of standardisation and modularization within BAM Infra. The survey has been sent to experts of the department multidisciplinary contracts of BAM Infra, the five structural engineers that have participated in this research, the planning engineers and the heads of the different departments of BAM Infraconsult. This group has been chosen because they are mainly experts and will have knowledge about, and understand the principles of standardisation and modularization. The outcome of the survey can be found in Appendix A.19. In addition, in Appendix A.20 the most interesting questions are elaborated on. To get a thorough understanding of the conclusions summarised it is advised to read Appendix A.20.

Current situation in the company

- *Experts are aware they are constantly reinventing the wheel within their projects. And are aware that the current way of working is not optimal, and the efficiency needs to be increased. When a new way of working will be implemented, it is important that the experts see the need to change. Within BAM Infra the experts are aware of the problem. Therefore it is likely that there will be a support to implement a new strategy.*
- *Not in all projects, there are constant feedback loops during the various phase of a project. Here still a lot can be gained.*
- *Within BAM Infra there is continuous optimisation of product and process, but this is mainly based on own experiences. It is not established in a structured way. Still, a lot can be gained.*
- *In general, the participants think the communication between the different disciplines that are working on a project are not always effective and efficient and needs to be improved*

Knowledge management

- *Experts would review and analyse established projects if this would be facilitated, for example with a database. Currently, the review is mainly only by experience gained in other projects. The insights gained are not transferred in a structural way.*
- *Experts of BAM Infra are aware of how important it is to share insights gained and lessons learned from the various projects, both within their own department and other departments of BAM Infra.*
- *Around 95% of the experts agree that a database that is available within the organisation for everyone should be developed. It can be the first step towards a more project-exceeding approach.*

Implementation of the principles of standardisation and modularization

- *The experts of BAM Infra/Infraconsult are mainly positive about the application of the principles of the mass customization within their industry and company.*
- *Experts think the implementation of a common interface can help to improve the communication within projects, considering the communication within the companies and the communication with other parties involved from outside the company.*
- *Almost all experts agree that to be able to fully benefit from standardisation and modularization, product and process need to be aligned.*
- *The experts are positive that when BAM Infra/Infraconsult would implement the principles of standardisation and modularization within their organisation, still sufficient freedom in design will be present.*
- *The experts are mainly positive about the development of a configurator that can be used by the project team (configurator for internal use)*
- *The majority of the experts is of the opinion that the (more functional) requirements of RWS are still too specific and the possibilities to innovate are limited.*
- *The tender phase (47.8%) and the realisation phase (28, 4%) are the phases of a project were standardisation and modularization will have the biggest positive effect.*
- *The considered most important reason to implement standardisation and modularization is the building costs. In addition, the building time, increase of quality and faster development in the design phase, are considered as important.*
- *The considered most important advantages of standardisation and modularizations are: cost efficiency(80,6%), efficiency in the design phase (70.1%) and higher efficiency and productivity by optimisation of processes(56,7%).*

- *The considered most important disadvantages of standardisation and modularizations are: High initial costs(50,7%), Product platform needs to be managed and monitored (46.3%), and product platform need to be constantly adapted, to meet the constant changing market.(43.3%)*

Restrictions

- *Experts of BAM Infra/Infraconsult experience the "beeldkwaliteitsplan" as a binding document. 89, 5% of the participators experience the document as binding.*
- *The majority of the experts is of the opinion that the (more functional) requirements of RWS are still too specific and the possibilities to innovate are limited.*
- *The experts agree that early involvement of suppliers as clients such as RWS, ProRail, municipalities and Provinces to think along / work on the design (co-production) within a project should be considered. It will make it possible and easier to apply a standard or modular design within a specific project.*

Technical constraints and possibilities

- *The experts are of the opinion that the components of a viaduct: the deck, the edge beam, the approach slab and the abutment/bank seat have to most potential to standardise and/or modularize.*
- *The experts are mainly positive about the idea to make less use of connecting elements/components by depositing with concrete and the application of a "click"- system*
- *Developing a click-system will be very complex*
- *Around 85% of the participants does think it is possible to construct a viaduct only out of prefabricated parts (no in-situ)*
- *Most experts are positive about building up a component of a viaduct out of prefabricated moulds, which eventually becomes part of the construction.*

4.5.2 Other findings – Observations and interviews

During the duration of this research the researcher has spent many hours at the office of BAM Infra at Gouda, and by this has experienced the atmosphere within the company. By having conversations in the hallway and during lunches, in addition to planned meetings and interviews, the viewpoint of the various experts considering the research topic some important observations have been made that contribute to the given advice of this research. Some observations and point of interviews that have not been elaborated on before are listed in this section.

In addition, in Appendix B.1 fifteen interview have been fully worked out, and a qualitative analysis of the most important interviews is presented in Appendix B.2. The qualitative analysis has been divided into categories and gives great insight into the problem perceived, the opinions of experts and the current situation within BAM Infra. It is advised to read the qualitative analysis to get a thorough understanding of the viewpoint of the various experts interviewed.

Other findings – Observations and interviews

- *Highly complex structure -* During the filling in of the various tables, it became clear that although a viaduct may look like a relatively simple object, there are numerous coupling relationships between the components. Most components have a high degree of coupling. From this, it can be concluded that current viaducts are integrated designs.
- *Highly complex problem*
  An infrastructural object is identified as a CoPS by Hobday. The principles of the mass customization industry cannot be transferred to the infrastructural sector of the construction industry. Infrastructural projects are more complex than the production of mass customised products. There are many stakeholders involved, and they all have their own specific demands and requirements.
- *Want to work with innovative materials: no freedom and high risk* –Within the company the various experts think that working with other materials, for example, composite, provides great opportunities. However, in most situations application of innovative material is not possible, due to the listed requirements. In addition, the risks are too high.
- *If the client does not ask specific point, it will not be developed by the contractor* – This implies that if RWS does not specify certain aspects, this will not be developed by the contractors. Developing and applying innovations will result in high initial costs and higher risks. However, the example of building demountable with the idea that various components can be reused within projects, or that structures can be easily adapted to changing circumstances, etc., will not be developed by the contractor if RWS does not specify this.
- *Mind-shift is required*
  Within the company the opinions about the implementation of the principles of standardisation and modularization is diverse. The management team and higher educated people within in the company do believe that the principles can also be implemented within the construction industry. They are also aware that there are a lot of barriers, but thinks it

is possible and will be beneficial if BAM Infra would apply the principles. However, further down in the company, people are mainly sceptical. They argue that every project has its own unique circumstances and requirements, no standard can be applied. And the idea of standardising the interface is not considered as an option. If BAM Infra wants to implement the principles of standardisation and modularization support of the employees will be essential. Therefore a mind-shift is needed. The viewpoint of the employees of BAM Infra is perceived as the biggest barrier to implementing the principles of standardisation and modularization.

- *Reorganisation made people more open to a new approach*
  People will be more open and willing to accept the new approach that will be implemented, due to the reorganisation that took place. Because the company has gone through a hard period, people are more aware that a new approach is needed.
- *The researcher got very positive reactions during informal conversations*
  People within the organisation, mainly high educated people, are very enthusiastic about the research and are very interested in the outcome. The research topic is something that is seen as a potential opportunity for BAM Infra and should be investigated further. The conducted in-house research and the fact that it was restarted for a second time in 2012 also shows that there is a high interest in the research topic.
- *BAM Infra should work as one company* - BAM Infra currently does not work as one company. The various departments are not open to share their knowledge and expertise. However, they are one company now and they should act like that.
- *Cooperation with other parties is needed, but some employees are also afraid to cooperate with other companies.*
  When the market parties would be involved already at the beginning of the project, both parties can explain their point of view, the constraints and the effect of possible ideas can be discussed. This gives great insight for both parties, and together they can make trade-offs for the specific project.
- *More freedom and trust for the contractors is needed to apply standardisation and/or modularization*
  Although RWS formulates their requirements in a more functional manner*,* experts still experience little design freedom. The "beeldskwaliteitsplan" is still experienced by the project team as binding. However, the provinces are not aware that this document is limiting the design freedom.
- *The new contract forms make it possible to apply the principles of mass customization. However, the maturity of the contract forms is not sufficient.*
  The maturity of the new contract forms is not sufficient. Still, faults and limitations are present. The contract forms are developed further, and people are used to the old way of working and have to change their way of working and gain experience with the contract forms. In addition, the contract forms current do not give the design freedom that is desirable for the implementation of the principles of standardisation and modularization.
- *More awareness of the architect and other disciplines about their decisions is needed.*
  It is important to analyse the step and decisions made considering an object. Some steps that are taken and decisions made are not based on analyses of the most optimal solution. It is based on experience. However, if certain steps and decisions would be analysed, it will be seen that the way currently a design is made is not always optimal and other possibilities maybe lead to a better result for lower costs.
- *Can question why we do not work as other countries* - Various experts have argued that within other countries standardise viaducts are applied. For example, Switzerland has four types that can be chosen. Therefore, it can be questioned why this is not possible in the Netherlands. They have to deal with the same European norms and regulations. It implies that the more country specific regulations and the regulations, demands and requirements of provinces and municipalities are hindering the application of standardisation and modularization.
- *Maintenance, adaptability and building demountable are currently not sufficiently reviewed in projects.*
  The principles of standardisation and modularization provide many opportunities for building demountable, possible to adapt a structure, and maintenance by replacing certain components. However, within current projects, these aspects are not reviewed sufficiently. This is mainly because, in the old contract forms, the construction company was not responsible for the maintenance, and therefore only limited data about these aspects are documented.
- *Convince client to cooperate*
  Will be hard to convince the client to cooperate with the proposed new approach: the development of a product platform. The client does not experience the same benefits as the contractor, for the municipalities and provinces, there is not sufficient repetition to benefit from.
- *People gave up -* Already tremendous effort has been put into the development of a standardise viaduct, however not with success. People that once believed that a reference design could be developed and then could be adapted to the situation occurring, by only adapting deviations, have given up. They emphases that it is not possible in the current market conditions.
- *Mind-shift and effort of all parties in the total market of the construction industry are required*

To fully benefit from the principles of standardisation and modularization the entire industry needs to change their way of working and should invest in the new approach. All parties point at other parties why they cannot implement the approach. It is a continuous cycle. Therefore, the construction companies, general government and clients should together discuss possibilities.

PHASE FIVE

Advice & Discussion

5 SYNTHESIS: ADVICE

In this chapter of the research, the synthesis will be discussed. It will elaborate on the advice for BAM Infra. For this advice the outcome of all three sub-questions of this research are take into account.. Essential aspects for BAM Infra to consider are explained. Hereafter, practical advice for the implementation in two phases and which steps to take are given.

5.1 ESSENTIAL ASPECTS TO CONSIDER

Considering the implementation of the principles of standardisation and modularization within BAM Infra, there are various opportunities and possibilities. However, for successful implementation of the principles, the main points that need to be considered by BAM Infra are listed and explained below.

Main points that need to be considered - General advice

- *Balance standardisation with flexibility*
- *Application of the method developed*
- *Knowledge management is vital: gather data in structured way*
- *Feedback loops are essential for optimisation*
- *A mechanism has to be developed to apply the principles based on the data gathered (configurator)*
- *Provide protocol: steps to take*
- *Create support and change the way people analyse problems and design solutions*
- *Development of a standardised interface independently of the tenders or projects.*
- *Possible for employees to suggest improvement: collect ideas*
- *Cooperation is essential: within and outside BAM Infra*
- *Trade-offs need to be made: management team eventually has to decide*

Other points that will have influence on the possible implementation of the principles of standardisation and modularization

- *Requires effort from all parties in the construction industry, and a mind-shift is needed*
- *Data is not the only constraint: Maturity of BIM*
- *Future is unknown: conduct market analysis on a regular basis*

Main points that need to be considered - General advice

- ***Balance standardisation with flexibility: combining standardisation and modularization is the key***

BAM Infra currently already applies some form of standardisation, and benefits of the repetition occurring within specific projects, see section 3.4 However, standardisation alone is not the solution to be able to deliver projects the market demands in an efficient and effective way. By standardisation BAM Infra can benefit from the repetition that occurs in design and construction, this will result in fewer costs. Standardisation can be very beneficial because procurement is mainly on lowest price. Standardisation offers the possibility to design and build an object for the lowest price in a fast way. However, by choosing one standard, there will not be flexibility to adjust or cope with different project-specific circumstances or specific demands and wishes of the client. An infrastructural object mainly has to deal with a lot of different circumstances; a flexible approach is essential. Therefore, an approach that combines standardisation and modularization is proposed: mass customization. The basic idea of mass customization is to improve the flexibility of the end product while maintaining standardisation and economies of scale. By combining standardisation and modularization of the components by creation and development of a modular architecture will still leave considerable flexibility in the configuration of the final product even if the standardisation of components and parts increases. However, clear trade-offs need to be made when standardisation and/or modularization is considered. Only elements that are suitable and are thought to be beneficial should be standardised or modularized.

By application of a standardised interface, it is possible to make a design by combining already work-out modules. A decoupled modularized product architecture using interchangeable modules interfaces provides the ability to combine the different module variants for the development of various designs, suitable for different specific circumstances and requirements. By combining these predefined standardised modules, various end-products can be realised that do fit the specific circumstances and requirements without the need to make a design from scratch. It will save time, cost and will increased the quality, without losing flexibility.

- *Application of the method developed for identification of components of a viaduct that are applicable for standardisation or modularization*

Based on a literature review conducted and conversations with experts of BAM Infra, the province of South-Holland, and a supplier, it can be concluded that the principles of mass customization also have potential for the infrastructural sector, as discussed in section 1.3. Before BAM Infra starts implementing the principles of standardisation and modularization within their current way of working, it should be first investigated if a certain infrastructural object is potentially applicable for this new approach. This research was focused on a viaduct. Based on the result of the empirical research it can be concluded that a viaduct is suitable for the implementation of the principles of standardisation and modularization. Components that are interesting for the application of the principles of standardisation and modularization for have been identified. If BAM Infra wants to apply standardisation and modularization within their projects, it is advice to use the method developed and applied in this research. It will provide the project team with great insights and will highly contribute to the effective development of standardised and modularized objects. A step-by-step approach of the method applied that can be used by BAM Infra is given in section 3.6.

- *Knowledge management is vital: a model for documenting current practices in a structured and clear way is proposed.*

Currently, the knowledge management within BAM Infra is considered to be insufficient. Various experts in the company have pointed this out. The way current practices are documented and knowledge is transferred needs improvement. The projects and insights gained are not documented and shared in a structured way. By this, BAM Infra misses out on valuable opportunities. They can learn from these previous projects and innovations can be developed further. The steps that have been taken and decisions made within projects should be documented in a structured way. Knowledge management is vital to be able to continuous improve products and processes and by this be able to realise projects in an efficient and effective way.

In this research, a solution is proposed. It is proposed to collect project data in a structured way, by the application of a labelling system. During all the life-cycle phases of a project, a form will need to be filled in by the different members of the project team. This considers the characteristics of the projects, the requirements of the client, the trade-offs made and explanation of why a certain decision is taken, etc. By collecting and combining data in a structured way, a general database, a search engine, and a configurator can be developed, as explained in section 4.4.2. The database should be updated regularly and should not only consider the design phase. Other phases of the project and life-cycle phases of an object should be analysed and documented as well. Only by collecting data about the total life-cycle, considering the negative and positive point, it will eventually be possible to find the most optimal solution.

However, the project team should be given sufficient time to review their results and to fill in the form. Currently, no or only limited time is available. The experts have to go on to the next project. This can be tackled by providing a clear protocol and demand the filling in of the form after various predefined phases or deliverables. Otherwise, the various members of the project team maybe will not clearly remember the steps they have taken and why certain decisions were made. In addition, by embedding the filling in of the form within the current processes of the design of a project, the review can be divided into small parts. The risks that the review will not be conducted, or only limited, because the experts have to move on to the next projects, will decrease.

The database should be used by the experts within various projects. For the experts, it should be possible to analyse new innovative projects but also the projects that have been realised several years ago. These analyses of and the feedback loops within the different phases provide great insight in the total life-cycle of the project/object. The insights gained can contribute to the development of new designs and clear trade-offs based on real data can be made. The development of a general database and search engine will facilitate the continuous optimisation and innovation of the practices of BAM Infra. Moreover, it will contribute to working more project-exceeding. In addition, if the database is sufficient mature a configurator can be developed that can make suggestions and configure an object out of already designed modules. With the collected data, it can configure the optimal solution for a specific situation occurring.

- *Feedback loops are essential, reviewing established practices were no feedback is provided will not result in optimisation.*

When data is collected in a structured way, and a database has been developed, the next step is to review the projects. However, simply copying existing solutions will not be appropriate in all the various situations, the project team should clearly analyse the solution because simply copying can lead to inefficient module designs. There should be awareness that it is essential to analyse the steps and decisions made considering an object. In current practices, some steps that are taken and decisions made are not based on analysis of the most optimal solution. They are made based on experience; the decision is made based on what has been applied before. However, if the project team would analyse their decisions and steps, they will see that the way they currently design is not always optimal and other possibilities may be more optimal. Therefore, it is essential that the project team makes clear trade-offs and review why certain decisions are taken within established projects, to make decisions what to apply within their current project. Sufficient feedback loops should be embedded in the design phase, but also feedback loops in the other phases of the lifecycle of a project/object should be applied. To know which aspects of the solution applied within already established projects should be reused and which should not be reused, it is essential that clear feedback loops will be applied; this will facilitate the optimisation of products and processes.

- *A mechanism has to be developed to apply some form of standardisation and modularization based on the data gathered.*
  - *Pre-selection of solutions based on the characteristics of a project. (Form of standardisation)*

The development of a modular architecture is very complex, and it requires significant amount of valuable data. Therefore, it will not immediately be possible for BAM Infra to develop a standardised interface. In this current situation, pre-selection of solutions based on the characteristic of projects is advised. At the start of a project, the project team should review already established projects that are comparable to the situation they are facing. These projects will be stored in a database and can be used as a reference for new projects. In addition, based on the characteristics that come back relatively often, basic concepts can be developed that will best match the specified requirements and circumstances. Although every situation is unique and many variables are of influence on the processes and the products, the most plausible options should be worked out completely. Different already worked-out designs can be used as a starting-point. The project team should analyse the specific situation and demands, and should make a choice at the beginning of the project. The most suitable concept should be chosen and can be adapted to the specific circumstances and requirements. There should be various concepts the project team can choose from to avoid that the concept needs to be adapted significantly. The more adaptations that have to be made, the more expensive the object will become. Therefore, not only one standard viaduct needs to be developed, but multiple types that are suitable for the various circumstances. The process, of what to choose based on the characteristics can be standardised. Trade-offs matrixes and flow-charts should be incorporated into decision models and can be facilitated by the development of an ICT-tool. However, the pre-selection of solutions will not result in sufficient flexibility in the long-run. Therefore, when sufficient data is collected, the insight gained by this approach should be used for the development of a modular architecture and the development of a configurator.

  - *Developing a design out of modules (by application of a configurator)*

When sufficient data is collected by clear documenting of projects, by application of a form that is filled in the various projects, a design support system can be developed. A configurator standardises and expedites the engineering design process by enabling the reuse of existing results and knowledge. A configurator puts together a design from well-defined modules, while considering the requirements and locational constraints of the project. With a configurator, the most optimal solution for a specific project can be found. The different criteria that are present within projects will result in a different optimal combination of modules/different optimal solutions. The development of a modular architecture, where the interface is standardised and a product platform can be developed is the ultimate vision for this research. However, this will not be possible immediately. First, a standardised interface needs to be developed, and sufficient data needs to be collected to be able to develop a configurator. Therefore, it is advised that BAM Infra first starts with making various standardised concepts that can be pre-selected and applied as a starting point, as explained before in this section. The insights gained will become input for the further implementation of standardisation and modularization.

- *Provide protocol: steps to take*

By providing protocols, by prescribing the steps that need to be taken within the various phases of a project, the experts will have clear guidelines and the processes will be standardised. Currently, a model about which steps should be taken within the tender and design phases is being further developed within BAM Infra, the PMI-model discussed in section 4.1.2.1 This kind of model/protocol should also be developed for the new approach. The project team should go through the provided protocol and the standardised processes autonomously. By prescribing which steps should be taken the new way of working will become embedded in the culture within BAM Infra. In addition, the steps can be documented in a structured manner. The database in combination with a protocol will facilitate continuously optimising/improving products and processes. Feedback loops should be embedded within the protocol. Also, when developing the protocol there should be awareness that processes and products are interrelated, a standardised process can result in a standardised product. Below, some important aspects that should be incorporated in the protocol are listed:

- *At the start of a project, the project team should always review and analyse already established comparable projects. The search engine and configurator should be used.*
- *The protocol should contain pre-described evaluation moments for feedback loops. At these moments the form for the development of the database needs to be filled in.*
- *When possible points of improvement or innovative ideas are found, and the project is already in the final design phase, these points or innovations should not be addressed within the current project. However, the improvement points or idea for innovation should be suggested for possible application in new projects.*

- *Create support and change the way people analyse problems and design solutions*

Currently, the opinions about the principles of standardisation and modularization within BAM Infra are diverse. There are experts that do believe in the concept and think it is technically feasible. However, they argue that the development, as well as the implementation of a modular architecture, will be very complex. The general viewpoint of the employees is that the application of the principles is not realistic, they argue that projects are too unique and the application of a reference design is not possible within the current market conditions. To successful implement the principles of standardisation and modularization sufficient support from within the company is essential. This support can be created by:

  - *Raising awareness and let employees experience the method*

Making people aware of the benefits that the new approach can bring is essential for effective implementation. People should be looking into standardisation and modularization as a solution. The awareness can be established by coming up with "prove". Data out of other industries and data from within the companies can be used to convince the various employees. For example, the projects where some form of standardisation is applied, discussed in section 3.3, can be put forward as an example for projects where standardisation was successful. In addition, it is important that people gain insights by experience, the way people analyse problems and design solutions will need to be changed. Developing an integral design is significantly different from developing a modular design. It requires different processes. It is advice to first raise awareness by providing prove. Secondly, let employees experience the new way of working by organising workshops. When the new way of working will actually be implemented it is essential that the employees will be guided through this process, clear frameworks need to be developed. To give insights into how the principles of standardisation and modularization can be implemented, it is proposed that the method applied developed in this research for identifying the components that are interesting to standardise or modularise, should be gone through by the various employees.

  - *Use current situation in your favour.*

By introducing the implementation of standardisation and modularization quick after the organisational transition that has taken place, it could also facilitate the change. People will be more willing to accept a new way of working, as it appeared that the old way of working was not sufficient anymore. They are aware that change is needed. Clear guidelines and frameworks should be provided, then instead of having to cope with abstract cultural changes, the employees will have a specific way of working to focus on. In addition, the employees can work autonomously, without the interference of the management team.

Although it might seem an impossible task to get employees to work and think in a different way, it is possible. At the start of this research, people were mainly sceptical about the implementation of standardisation and modularization of a viaduct. However, during the last eleven months, people became more open to the approach as the researcher showed the findings and asked people about their experiences and opinion. It is experienced that people are willing to change. However, it is important that they are informed what the idea behind this change is and that a clear framework is provided for them to apply the new way of working. If no framework will be provided, people will not know what to do and will go back to the old way of working. In addition, the people of various disciplines and hierarchical layers need to be mobilised to think along of how this new approach can become a successful strategy. By this, the various experts will be motivated, as they feel like their opinion counts and have gained insights about the importance of the manner.

- *Development of a standardised interface should be developed independently of the tenders and development of designs within projects.*
  - Within the current construction industry, the contract forms are too complex and too specific to experiment with new approaches and innovations. By analysing established and current projects, various aspects can be considered. The design of a new concept has to come from the current situation and the future circumstances identified. Therefore, the potential to innovate by application of the principles of mass customization should be considered in the current and future market. When a standard interface is developed, it should not be directly implemented within various projects; this is too risky. The first time a company does something different, there is a high risk for failure and will mostly be more expensive than the traditional approach. This risk cannot be taken at a broad scale. First, the concept needs to be tested in a pilot and hereafter applied in some small project. The concepts need to be continuously improved and optimised and have sufficient maturity before the concept can be implemented companywide. In addition, when a pilot is launched, this should be established with collaboration with the client (RWS). Otherwise, the risks will be too high for BAM Infra
  - A research and development team should be appointed for the implementation of the principles of standardisation and modularization. As discussed above, within the current projects there is not sufficient freedom to experiment with the new approach. Secondly, the people do not have the time and possibilities to focus on a new work model within the projects they are working on. Therefore, the management team should give priority to certain innovation/idea's/projects by providing time and freedom for the analysis and development of certain ideas.

- When a standardised interface is developed, it is important that a facilitator is appointed to help the project team with the successful implementation of standardisation and modularization in their project.

▪ *Possible for employees to suggest improvement: collect ideas*

Within the W&R concept employees of different disciplines and hierarchal levels can suggest improvements. These potential improvements are analysed by a development team once a year. If the development team sees potential in certain points, these are investigated and eventually developed further. This should also be possible within BAM Infra, it should be easy for employees to share their ideas, the ideas should be uploaded to a shared folder. In addition, within a project various possible design concepts are created, and eventually, one concept is chosen to be worked out fully. These other concepts developed also need to be clearly documented. These innovative ideas should be combined with possible ideas for improvements from experts, Therefore, it should be possible for experts to make suggestions and share their ideas within the company. The ideas can be reviewed by experts when a new design has to be made and can by analysed and possibly developed further for application in a new project. In addition, these possible innovations or points for improvement need to be reviewed by the management team around two times a year. Ideas that they consider as very promising, that have not been developed further can be selected. For the selected ideas time and money needs to be provided to further investigate the idea, within or outside the current projects. Due to contractual constraints or high risks, some ideas cannot be applied within new projects. However, these promising ideas should be investigated, these can result in great successes. It is advice to assign a project team to a specific concept; this allows project teams to focus on a concept without distraction from other subjects.

▪ *Cooperation is essential: A standardised interface will result in more possibilities for cooperation, reduce the risk, and will provide effective information exchange.*

It should be noted that when a standard interface is developed, this will result in more opportunities for cooperation. The standardised interface already provides the information that other companies need to develop additional products. Other companies can develop specific parts or "add-ons" for the modular product without the need for BAM Infra to share their design. By this BAM Infra can improve their product without the need to invest in this specific field and fully giving away their design. In addition, it will provide effective information exchange will facilitate cooperation between the different parties involved, both within as outside BAM Infra. The following points are applicable for BAM Infra.

5—1 *A standardised interface will facilitate cooperation*

o *Cooperation between the various departments and/or companies within BAM Infra.*
In the reorganisation that took place, around forty companies have been combined into one company: BAM Infra. Although these companies are merged, they do not work as one big company. It has been observed that some departments are afraid to share their knowledge and expertise within the company. However, the different departments should work together and share their expertise and experiences. By working together, they can establish more: "the whole is greater than the sum of parts".

o *Cooperation with other companies outside BAM Infra*
The current relationships are short-term, project-based and people are sceptical about sharing of knowledge, this should change. Cooperation with other companies in the sector can also be very beneficial; long-term relationships need to be developed. Although BAM Infra is a big company, it will not have all resources and expertise in-house. By co-production, other companies can complement BAM Infra on certain points, and by sharing their expertise, the competition can be out competed. (The W&R concept and the lean approach of Toyota, that are both successful concepts, apply co-production.)

o *Early involvement of all the different disciplines*
Within a project, early involvement of all the different disciplines can reduce failure costs and increase the quality of both the process as the product. It is important that the various parties are aware of the constraints and effects their decision will have on all the different aspects of the total project.

▪ *Trade-offs need to be made: management team eventually has to decide*

Although, it can be concluded that the application of mass customization has great potential for a viaduct. It is still up to the management team of BAM Infra to decide if the principles of standardisation and modularization will be implemented within the new approach. Three platform related trade-offs, identified by Halman, Hofer and Van Vuuren (2003), will need to be made (Halman, Hofer, & van Vuuren, 2003);

- *Flexibility in product design versus restriction through a platform.*
- *Efficiency in the development and realisation of single products versus high initial effort*
- *Low differentiation through the platform versus distinct positioning through individual elements.*

__Other points that will have influence on the possible implementation of the principles of standardisation and modularization__

For these factors, BAM Infra does have influence but needs the effort of other parties as well. Partners in the whole supply chain will need to follow.

- *Requires effort from all parties in the construction industry, and a mind-shift is needed*

When BAM Infra wants to implement the principles of mass customization, they should be aware that this requires effort from all parties involved. Awareness should be raised that the principles can be very beneficial for all parties within the construction industry. Therefore, it is advised to join already existing platforms or take the initiative to establish a new platform with other big parties within the industry. When BAM Infra gradually will implement the principles of standardisation and modularization the partners that deliver products to BAM Infra will follow, they are dependent on BAM Infra for the continuity of their business. However, the client is the limiting factor. Only when the client will provide more freedom in design, it is possible to fully benefit from the principles of standardisation and modularization.

- *Data is not the only constraint: Maturity of BIM*

Although, currently the data that is needed for the development of a database, search engine, and configurator is not accessible in a structured way, and therefore cannot be used. It is important to note that there is another limiting factor to fully benefit from the proposed database, search engine, and configurator. Currently, the maturity of ICT-developments, referring to BIM, is not sufficient enough to facilitate the concepts of standardisation and modularization and by that for the development of a digital product platform. And the development of a product platform by the appliance of BIM will require a significant amount of time because everything has to be built into BIM. However, within around five till ten years BIM-model will become an attribute that contains all the knowledge and experience of a design and its components. BAM will be mature enough to use BIM not only as a database but also as a knowledge tool with simulations. Application of BIM in this way will stimulate the application of a modular structure. However, to be able to identify the most optimal solution by the application of and configurators, two aspects are essential. First, the maturity of BIM. Secondly, the collection of structured data about projects conducted in different phases of the product's life-cycle.

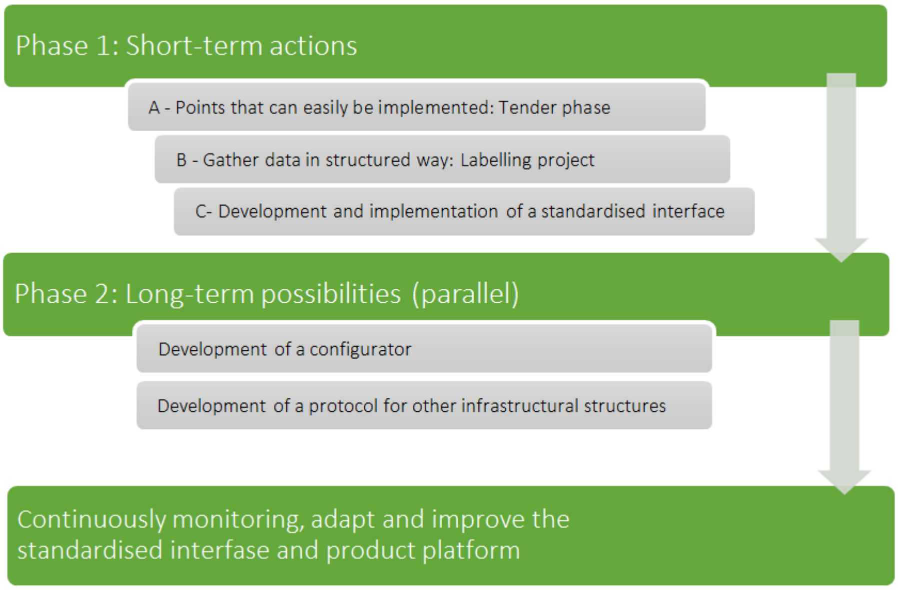
- *Future is unknown: conduct market analysis on a regular basis*

Although this advice takes the upcoming developments in the infrastructural sector into account, there is are always circumstances and uncertainties that cannot be predicted or anticipate on. It could be possible that due to the development of self-riding cars, less extensive infrastructure is needed. The vehicles will be better aligned, and less traffic will occur. This development could influence the number of viaducts that have to be built or expanded the coming years. Although the future cannot be predicted, the company should monitor the developments in the market, and conduct a market analysis on a regular basis.

5.2 IMPLEMENTATION OF PRINCIPLES IN TWO PHASES

As explained in the introduction of this thesis, a new approach for realising projects needs to be implemented for BAM Infra to remain competitive. A proposed solution is given: implementation of the principles of the mass customization. However, the implementation of the principles of standardisation and modularization, as investigated in this research, should be established without negatively influencing the current projects. In addition, it is very risky to fully switch to a new approach. The company does not have sufficient experience with this approach and the products and processes still need to be optimised. Therefore, an advice is given for BAM Infra to implement the principles of standardisation and modularization gradually in two phases. The advice takes the essential aspects identified in section 5.1 into account. By implementing the principles in two phases, the current practices can still continue, and the company can gain experience, learn from and optimise processes within the new approach. In the meantime, data can be gathered in a structured way, so that it will become possible to develop a modular product platform based on the best practices. If BAM Infra already investigates and invest in this new approach, it can give them a great step ahead of other construction companies.

In figure 5—2, a schematic overview of the phases is given. The phases and their steps are further explained below.



5—2 Schematic overview of the proposed phases

5.2.1 Phase 1 – Short-term actions

The implementation of certain aspects of the principles of standardisation and modularization will contribute to the current practices. Also, it will be an important input for further implementation and development of the new strategy. To implement the principles of standardisation and modularization successfully within the organisation, various steps have to be taken in the short term. These steps are required to accomplish this new approach and to be able to fully benefit from this approach in the future. Some steps can already be implemented within the company without the need to develop a standardised interface, this is explained in step A. Some changes in the way of working will be required to make implementation of the principles in the future possible and less complex, this considers the development of a database, this is explained in step B. And finally, a standardised interface needs to be developed, this is explained in step C. All steps are given below.

5.2.1.1 Step A: Points that can be easily implemented in current practices

In the tender phase, the main decisions about the design are taken. It is important that in the design phase the principles of standardisation and modularization are considered as early as possible. Therefore, a protocol for tenders is suggested and should contain the following steps:

- *Analyse already established projects*
  The project team should analyse the practices of various comparable projects, to learn from these projects and possibly apply the innovative practices with the new tender. When the database with a search engine that will be developed is sufficient mature it should be used. However, when a database is not sufficiently mature, the project team should contact the project team of comparable projects that have been established recently. These projects need to be analysed to see what already has been designed and investigated. The tender team can build forward on these

concepts and trade-offs made. By this, the project teams are not "reinventing the wheel" all the time, and it will help to optimise products and processes.

- *Look for the repetition at the start of a project*
  At the start of a project, the tender team should look for repetition. The essence of the principles of mass customization is to benefit from the repetition that occurs, while still providing sufficient variety.
- *Trigger the project team to think out of the box*
  At the beginning of each project, the requirements that are presented to the project team should be made less complex. The members of the project team will experience more freedom, and ideas can then be generated. The project team should brainstorm about possible concepts and how these can be realised. When a few concept are chosen to develop further, the tender team should think about how the quality of the project can be increased or how costs can be decreased. Because the requirements are made less complete, and by this less complex, people now start to think of possibilities instead of problems. In a later phase, when one concept is chosen and should be worked out, the other requirements/constraints need to be considered.
- *Involve suppliers early in the project*
  It is advised that suppliers should be involved already at the beginning of the project. By this, both parties can explain their point of view, the constraints and the effect of possible ideas can be discussed. It will provide great insight for both parties, and together they can make trade-offs for the specific project. However, as explained in section 4.3, this requires the development of long-term relationships.
- *Continues feedback-loop*
  A the start of the tender, evaluation moment should be planned for the various phases of the tender, to provide continues feedback-loops. These feedback loops should consider the general aspects of verification of the requirements, but also at the end of every phase, it should be evaluated if the costs can be decreased or quality can be increased. This by benefitting of the repetition occurring, possible innovations, or reuse of designs and innovations from other established projects. The entire tender team should be involved in this. The first phases, when the concept is developed, are the most important phases considering the application of the principles of standardisation and modularization. By developing a concept, the various disciplines will have clear guidelines and something to hold on in the further phases of the project.

5.2.1.2 Step B: Gather data in a structured way
A form for structural documenting during all phases of the projects, by application of a labelling system based on the characteristics and requirements, should be developed. This has been explained in section 4.4.2. The development of this form lies outside the scope of this research and therefore will not be discussed. It is proposed as a possible topic for further research.

5.2.1.3 Step C: Development and implementation of a standardised interface (product platform)
The development of a standardised interface should be developed independently of the tenders and development of designs within projects. A possible step-by-step approach is presented below:

- *Put together a research and development team*
  A research and development team has to be put together that will be responsible for the first steps of the development and implementation of a product platform. The research and development team should contain professionals out of various disciplines involved in the design of an infrastructural project. This is vital to make sure all the different viewpoints are taken into account and should make distinguish between professionals with a lot of experience and professionals with less experience. It is important to have a team with diverse backgrounds considering: age, discipline, amount of experience, biased or open minded and experience of various projects. In this way, the insight gained during these different project can be shared. In addition, facilitators should guide the project team. These facilitators should come from within the company, to understand and get the respect of the members of the research and development team. And facilitators with no expertise with construction should be hired. They have experience with the development of product platform and they are not biased, have an open view, and can help when the research team going through the various phases.
- *Market analysis*
  First, the project team should analysis the current project portfolio and the expectation for the future by conducting a market analysis. By the analysis, trends are occurring, and possible technological developments that are likely to occur that will have a significant effect on products and processes in the infrastructural sector can be identified. Based on the market analysis, BAM Infra should already think further about how they could meet these possible new demands occurring. If the demands become realistic, the company has already considered this scenario and action can be taken directly.

- *Identify objects that are constructed relatively often: repetition*
  Investigate and identify the infrastructural objects that are interesting for the application of standardisation and modularization. This can be based on the already conducted general market analysis. Eventually, the management team should decide which object they would like to investigated and/or develop further.
- *Apply method develop within this research to identify which components are suitable to standardise or modularize.*
  The method developed in this research should be applied by the research and development team. It will provide the team with great insight about the architecture of the infrastructural object and will identify components that are interesting for the application of standardisation or modularization, as explained in chapter three.
- *Analyse already established projects and investigate how the standardised interface could have been realised in already established projects.*
- *Develop a concept for a standardised interface (based on already established projects). The concepts should fit within the current framework contracts to ensure the concepts can be used multiple times and by this benefit from the repetition that occurs.*
- *Analyse projects that are currently in the design phase: adapt the concept of the standardise interface based on insights gained.*
- *Apply the standardised interface in a pilot project and improve/optimise the modular architecture(standardise interface)*
- *If the pilot was successful, continue with more projects*
- *Continues optimization*
  The interface designed should constantly be optimised. Eventually, one final interface should be chosen as the standard; this is the standard interface that should be applied within in all projects. Due to this standardised interface, it is possible to develop a configurator. In combination with the data of established projects considering various phases, the configurator can mix and match options to develop the most optimal design considering the circumstances and requirements present.
- *Research and development team should be involved: focus on learning and development in a project exceed manner.*
  Important that research and development team is involved in all the projects where the standard interface is implemented. The research and development team needs to monitor innovative practices and the appliance of the interface developed. They should focus on the learning and development in a project exceeding manner.

5.2.2 Phase 2 – Long-term possibilities

The steps taken in phase one, provide a basis for possible step on the long-term. These steps should be applied in parallel. The steps are the following:

5.2.2.1 Development of a configurator

The development of a database with a search engine as proposed in section 4.4.2 will be very valuable when sufficient project are documented in this database. It will facilitate working project-exceeding and continuously optimising products and processes. However, BAM Infra can take the application of the principles of standardisation and modularization further by development of a configurator. The configurator can find the most optimal solution by combining different modules (standardised elements) that are collected in the database. The digitalisation and ICT-developments in the construction industry will highly contribute and will be essential for this approach to be successful. Finding the most optimal solution with big-data science will become possible in the coming years. However, data from established projects considering all phases of the project, trade-offs made, and the advantages and disadvantages is needed.

5.2.2.2 Development of a protocol for other infrastructural objects

Based on the experience gained in step C, a protocol should be developed for the development, implementation and application of a standardised interface for other infrastructural structures. This protocol can be derived from the steps that have been taken during the development of a standardised interface for a viaduct. It will be based on the steps presented in this research. However, more detailed step by step description and other experiences of the research and development team should be incorporated. The protocol should be followed when BAM Infra wants to apply the principles of standardisation and modularization for other infrastructural objects. The development of a protocol will make it easier for various departments of BAM Infra to also implement the principles, and a network within BAM Infra can be developed.

5.2.3 Continuously monitor, adapt and improve standardised interface and product platform

When a standardised interface and product platform are developed the company should continuously monitor, adapt and improve the standardised interface and product platform.

6 DISCUSSION AND LIMITATIONS

In this section, the results and limitations of the research are discussed. First, the main limitations will be identified. Secondly, this sections addresses the technical feasibility and identification of components suitable to standardise or modularize, and explains why certain steps considering the method developed and applied within the research are taken to increase the reliability of the method. Hereafter, some aspects of the advice given are discussed.

6.1.1 Discussion of results - General limitations

This thesis aimed to find an answer to the main research question stated in section 1.5.3: "*What are the opportunities/possibilities for BAM Infra to apply the principles of standardisation and modularization for viaducts?*" To answer this main research question, several steps have been taken. A literature review was conducted, experts have been interviewed, and a survey was sent out to experts of BAM Infra. In addition, the general design of a viaduct, and various projects where some form of standardisation have been applied considering a viaduct were analysed. A method for the identification of components that are suitable for the application of the principles of standardisation and modularization was developed and is applied to a viaduct. In the synthesis, the insights gained from the literature review and the empirical research were combined, to give BAM Infra advice on the implementation of the principles of standardisation and modularization.

According to this research, there are many possibilities and opportunities for BAM Infra to implement and apply the principles of standardisation and modularization within their current practices. A viaduct has been the main focus of this research and is considered to be suitable for the application of the principles. Others researchers, as discussed in the literature review, have emphasised that the principles of mass customization can also be applied and will be beneficial in the construction industry. However, only limited research has been conducted to confirm these statements. Therefore, this research was conducted to extend the research field and cannot be compared, but is an extension of other studies. Within this research, the technical feasibility as well as the implementation of the principles of standardisation and modularization for an infrastructural object, a viaduct, are discussed.

To analyse how valid the results and conclusions of this research are, a critical question needs to be asked: *Is this thesis sufficient to answer the research question?* It can immediately be concluded that no research can include all aspects that have an influence on the problem or can explain all obtained results. A research is limited by the scope, discussion about methods, obtained results, and limitations are always present. In this research as well, the general factors that influence the research are the listed below. Additional limitations are given in Appendix A22.

- *Self-reported data: based on objective sources* - The steps taken in this research are mainly based on existing literature, past experiences of experts and observations made during the research. Self-reported data is limited by the fact that it cannot be independently verified. The self-reported data can contain potential sources of biases; this could have implications on the result of this research. It has an influence on the findings and their reflection on reality.
- *Lack of available data: access to folders and data is not structured*
  - During this research, it has been difficult to find the right data. Within BAM Infra, there is no general database that can be reviewed by experts working in the company. The data about previous and current projects is not accessible. In addition, the data that is accessible is not structured, which makes difficult for an outsider to get insights in which documents will be valuable for the research.
  - A limitation of this research was that for the analysis of large infrastructural projects where a form of standardisation has been applied, the main input was the opinion and experiences during the project of various experts involved. The trade-offs made in the design phase were not clearly documented. Therefore, it is not clear why certain decisions were made. Various meetings and interviews with experts that were involved in one of the projects were held. However, because the projects are very large and a lot of different disciplines are involved in making a decision, it is very hard to get a good overview of decisions made and the reason why they were made. In addition, the experts admitted that not always clear trade-offs were made, but decisions were taken based on different experiences of the project team. These choices were not further investigated, but are applied because they were successful in other projects. However, other possibilities could have been successful as well. Because it is not clearly documented and some experts cannot remember why certain choices were made, it is difficult to analysis these practices. Although by having meetings and conduction of interviews with various experts per project, the main choices and why these were made could be identified.
- *Market-shift* - In this research, the assumption was made that there will occur a shift in the current construction industry from the traditional market pull towards market push. Also, it is assumed that the various parties in the construction industry are open for implementation of the principles of mass customization. Therefore, in this research also other parties that are concerned with the implementation of the principles of standardisation and modularization in the construction

industry were considered. However, it was not possible to involve all parties that will be involved, and although trends can be identified, we cannot be certain that a mind-shift will occur.

- *Selective group -* This research was conducted at the department multidisciplinary contracts of BAM Infra, this has an influence on the results. The researcher has mainly spent time at this department. Therefore, the inputs for this research mainly came from the people within this department. In addition, also other experts from BAM Infra consults were involved. However, both are mainly experts, which are high educated and open for a new approach. This group has been selected because they have knowledge of and understand the principles of standardisation and modularization. Considering the diffusion of innovation of Rogers, these experts can be seen as the early adaptors.
- *Applicable for BAM Infra only* – The results of this research are mainly applicable for BAM Infra. The outcome of the general variety index and identifying the coupling relations between elements are very general and focused on a viaduct. These values can be applicable to other construction companies as well. However, the results and findings will not be applicable for all countries. The procurement, demands, regulations and general way a viaduct is designed and constructed differ significantly from the practices in the Netherlands. In addition, the advice given is based on the current situation of BAM Infra and will therefore only be applicable for BAM Infra.
- *The approach could not be tested* - And finally, an advice and method are proposed for BAM Infra. The proposed advice and method can be reflected on by various experts of BAM Infra. Ideally, to identify the value of the proposed advice and method, these should be implemented and tested in its whole in the current strategy of BAM Infra. However, this is not realistic and was not possible for this research.

Although extensive research has been conducted and various conclusions are drawn, this research does not include all aspects. Not all findings can be regarded as certain, due to the general factors discussed above. In this research, it has been analysed whether or not the principles of standardisation and modularization are suitable and can be beneficial for the application in the infrastructural sector of the construction industry. Four deliverables are the outcome of this research, these deliverables have contributed to answering the main research question, as discussed in section 1.6.1.6. From the perspective of BAM Infra, the findings are valuable, but a more practical experience considering the method, advice, and further development of various aspects of this research is required. This research, therefore, can be the starting point for BAM Infra to investigate the approach further and eventually possibly implement the principles of standardisation and modularization.

6.1.2 Discussion of results – Reflection on method developed and applied for a viaduct

In this research, was found that there are possibilities and opportunities to apply the principles of standardisation and modularization for infrastructural objects. It is technically feasible to apply the principles of standardisation and modularization on a viaduct. To be more specific: it is technically possible to develop a viaduct by combining pre-designed components in a standardised interface. A method has been developed for the identification of these components of an infrastructural object that are suitable for standardisation or modularization and has been applied for a viaduct. Various components are identified that are suitable for standardisation or modularization.

The method of Vanessa Veenstra (Veenstra, Halman, & Voordijk, 2006), was used as a guideline to develop a method that could be applied within this research. The method of Vanessa Veenstra is suitable for identification of modules for possible application of the principles of mass customization within the house-building sector. However, design and construction of infrastructural objects differ significantly from design and construction of a house. This method has been adapted to be suitable for an infrastructural object. The adaptation has been made in a structured way, by application of the method for a viaduct. The design for variety method of is part of the method of Vanessa Veenstra and is applied in this research. The method analyses the sensitivity to change of the various components and by this identifies if a component is suitable to standardise or to modularize. Adaptations to the method were made. To give more accurate results, the table for the coupling indexes has been divided into two tables. One table considers the direct constructive coupling-relations, and another table considers the parametrical relations. For the GVI a chance of occurrence was added, here the likelihood that a certain circumstance will occur was graded with 1, 2 or 3. These values functioned as a multiplication factor, resulting in GVI*factor. In addition, the values that have to be assigned are 1, 3, 6 and 9, instead of 1 till 9. This should make it easier to decide what value to assign and it is thought to result in more clear results. The adaptations of the method resulted in a new method for infrastructural objects to identify components that are suitable for application of standardisation or modularization.

A deconstruction of a viaduct was made; the various functions and components were identified. Based on the deconstruction, a viaduct seems to be a relatively simple object. However, by filling in the tables and reviewing the values assigned, it became clear that a viaduct is highly complex. The components had a high degree of coupling and high GVI-values. This implies that the design of a viaduct currently is integral and that a viaduct is highly sensitive to uncontrollable factors, as changes in time and locational circumstances. The high GVI-values were remarkable because the design of a viaduct has stayed relatively the same within the past 50 years. However, it turned out that the high value is mainly caused by the locational circumstances and the requirements of the client that differ significantly within in every project. Therefore, it is not surprising that experts consider every viaduct as unique. The locational circumstances are unique, and the client demands a unique solution. However, although their unique circumstances, also a lot of aspects are comparable. The repetition that is present in the various situations should be used by the application of the principles of standardisation and modularization.

When the tables had to be filled in, the structural engineers had to ask themselves the following question: if a change in external situation (GVI) or component X (internal situation) occurs, will change in component Y be required, and how big are the influence and change required? The structural engineers found it very complicated to give a clear answer to this question. The effect of a specific change is different in every situation occurring and depends on a lot of aspects. In addition, there are many relations between the different components. Therefore, no "unambiguous" answer can be given. Within this research, it has been chosen to identify the coupling relationships and their perceived index values, but no description why certain values have been assigned was documented. However, although full descriptions of why certain values are assigned have not been documented, an estimation about the coupling of components and the sensitivity of the components to the change in other components or external factors are made. This already provides great insights into the architecture of a viaduct.

When the filled in tables were analyse, no direct relation was identified between the values assigned by the five structural engineers. From this data, no clear conclusions could be derived directly. However, this can be explained by the fact that the structural engineers all have their own perception of what a certain value means and have a different level of experience with a viaduct. To account for the different perceptions, the values are ranked. From these values, a clear pattern and conformity could be identified. The outcome of the structural engineers individually

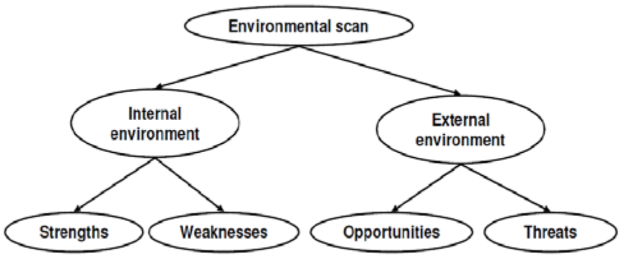
A correlation between the CI-R and CI-S values and the place of a component in a viaduct was identified. The components of the superstructure (higher located components) had significantly higher CI-S values and lower CI-R values than the components of the substructure (lower located components). This can be explained by the top-down design approach that is used for a viaduct. This also gives an explanation why the non-structural components of a viaduct had relatively low coupling indexes. The non-structural components are not essential for the functioning of a viaduct, considering the main function: p*rovide overpass for different levels of the infrastructural system to facilitate unobstructed traffic flow/facilitate conflict free crossing.* The non-structural components are added to make viaduct safer and to provide more comfort for the people crossing the viaduct. Because the non-structural components are not essential for the functioning of a viaduct, are designed base on the constructive parts and some of these components are already standardised by RWS, these are not considered further in the analysis of the results.

To increase the reliability of this research, a session was held with all the structural engineers together to discuss and agree on values assigned. The results of the tables filled in by the structural engineers individually and the result of the session have been combined into one table. Based on the ranking, the components were categorised into low, medium and high. The values have been reviewed based on criteria identified by the researcher. It was founded that almost all components were suitable to standardise or to modularize. Most components were identified suitable to modularize. This results from the high GVI-values, that is caused by the high sensitivity to locational circumstances and different requirements of the client. Therefore, sufficient flexibility is needed.

However, the outcome derived from the tables is not leading. Going through the entire process provide new insights that can be used for the application of the principles of standardisation and modularization, and can contribute to the creation of new innovative ideas. The outcome is a starting point and should be further analysed and discussed when a design for a modular viaduct is made. In addition, the method developed can be used by BAM Infra for other infrastructural objects.

6.1.3 Discussion of result – Reflection on advice given by SWOT-analysis

At the beginning of this research, it was thought that the technical part of how a standardised interface could be developed for a viaduct would be the most challenging factor. However, in this research, it is found that to fully benefit from the implementation of the principles of standardisation and modularization; a lot more is required than the development of a standardised interface. It requires various changes in the way of working on the company level. Besides, changes on the level of the construction industry are needed as well. In the synthesis, chapter five, the advice for BAM Infra was already discussed. Within this section of the discussion, an SWOT-analysis based on the framework given in figure 6—1 will be presented to identify the strengths, weaknesses, opportunities and threats for implementation of the principles of standardisation and modularization by the advice given in section 5.2.



6—1 SWOT-analysis framework, derived from Grant (2002)

6.1.3.1 *Strengths, weaknesses, opportunities and threats*

Internal	*Strengths – General for the company for the implementation of the principles of standardisation and modularization.*	*Weaknesses – General for the company for the implementation of the principles of standardisation and modularization.*
	• *Extensive experience with complex projects* • *Consensus of other company in the infrastructural sector of the construction industry.* • *A lot of knowledge and expertise in-house:* *BAM Infra is a large company, and therefore have expertise in a lot of different disciplines.* • *Investment costs and risks can be shared* *For the implementation of new concepts the investments costs and risks can be shared by the different departments of BAM Infra*	• *Culture* *Although a lot of experts are open to the new approach, a significant group remains sceptical and are not willing to change. A mind-shift of these experts is needed.* • *Insufficient knowledge management:* *No clear database and no structured method of documenting projects are present* • *Large company: Inertia* • *Reorganisation:* *There is still friction between the different department and BAM Infra. Not all departments are willing to share their best practices. Although, BAM Infra has become one company, the working as individual companies is still present* • *Inefficient information transmission between the tender, design and realisation phases.* • *Insufficient application of feedback loops* *The application of feedback loops is insufficient and clearly documenting these loops for continuous optimisation and innovation is limited.*
	Strengths – Implementation of standardisation and modularization, and the development of a configurator.	*Weaknesses – Implementation of standardisation and modularization, and the development of a configurator.*
	• *Speed up tender and design phase* *Fast development of multiple alternatives and quick comparison of these alternatives. By combining and reuse of different modular designs, the tender and design phase can be speed up.* • *More flexibility in design* *Application of a standardised interface can result in more flexibility in design. By this, the company will be able to meet the various requirements of the client in an effective and efficient way. By combining standardisation and modularization, the concept still provides sufficient flexibility. However, when only standardisation would be applied, the concept will become to star and will not be suitable for different situations.* • *Continuously improvement and innovation of products and processes* *Accumulative learning takes place, and the principles of standardisation and modularization make step by step innovation possible* • *Reduce complexity* *The complexity of the total design can be reduced by breaking up the total design in discrete pieces: modules. Complex design can be divided into multiple small problems. These design problems can be solved individually: only have to deal with one (relatively few) problem(s)/issue(s) at the same time. In addition, reduces the complexity of communication, different disciplines than can communicate with one another only through standardised interfaces within a standardised architecture.* • *Autonomously data exchange; requires less communication.* *Less communication between the different disciplines or parties involved is required. The interfaces are standardised, and data is exchanged autonomously. The different disciplines can work more individually.* • *Deliver customised solutions for relatively low price.*	• *Development of a configurator is complex; it needs a lot of initial effort, and constant updating is required.* *- Development of ICT-tool* *- Collecting of data in a structured way for development of database* *- The ICT-tools cannot be too complex, has to be easy to use by the experts.* *- Has to be updated regularly/ model need to be revised.* • *Difficult to identify the most optimal solution* *The best solution will be different in the various situations occurring. A lot of factors are of influence.* • *Balance standardisation and flexibility* *Friction between standardisation and flexibility should be balanced. (see section XXX)* • *No experience with specific software* *Experts of BAM do not have experience with the ICT-programs that are required and/or facilitate the implementation of the principles.* • *Not sufficient clearly structured data available* *To develop a configurator sufficient data about current projects is required. The data needs to be collected in a structured way, this takes time.* • *Limits to the level of detail provided by the configurator.* • *The model can become too complex: simplicity is essential.* • *Experts can be sceptical about using the configurator* *Experts can be sceptical about using the configurator. The configurator should be of added value. Otherwise, experts will not use the tool.* • *Not sufficient time for development of product platform or other innovation within a project*

		Greater flexibility in product design, and efficiency in product development and manufacturing: *The end product can vary in shape and have different functions while the design and production of components and modules within a product family can be shared.*	*Development of a product platform requires a relatively long time. This time is not always available in a project. The development of a product platform has to be spread over different projects and needs to be developed future step by step.* • *The way BAM Infra is organised can significantly hamper innovation*
External		*Opportunities - Implementation of standardisation and modularization, and the development of a configurator.*	*Threats - Implementation of standardisation and modularization, and development of a configurator.*
		• *New contract forms: new procurement method and more integrated contracts (See Appendix A.21)* • *Digitalization of the construction industry. (see section 6.1.3.2)* o *Digital design by increasing maturity of BIM* o *Atomised production process of components* o *Application of sensors within infrastructural objects, to monitor various aspects.* • *Cooperation with other companies within the industry* o *Develop ideas together: co-creation and co-production (requires long-term relationships)* o *Platforms provide new opportunities for the architectural/engineering company: a specific module can be offered to the market in forms of BIM object.* o *Other companies can develop products that are conform the standardised interface individually and without BAM Infra having to give away their design.* • *A new way of thinking: awareness of the current situation.* *Various clients are aware that the different parties in the construction industry are constantly "re-inventing the wheel". They want to cooperate to change this approach: Supply chain cooperation and moving from full customization towards more mass customization (De-customization).* • *The new company structure supports a project transcending approach.* • *LEAN approach: less waste* *Application of the principles of standardisation and modularization is a LEAN approach: fewer waists.* o *Increase efficiency and effectiveness of product and process* o *Save time, costs: not fully design from scratch (constantly reinventing the wheel)* • *Demand for constructing in a sustainability way is increasing.* *The demand for building demountable, and reuse of materials or reuse of components is increasing. Modular design can be very beneficial considering these aspects.* • *Products in the construction industry have relatively long life cycles:* *In general products in the construction industry have relatively long life cycles, this implies that a new developed product platform/innovation or configurator will also have a long lifecycle.* • *Reduced safety risks on-site* *Project team on-site will get more experienced with the standardised way of how different components are connected. Due to this repetition in the assembly process, the different assembly processes can be optimised, and safety risks can be reduced.*	• *Not sufficient repetition* *Not enough projects to apply the product platform. However, based on the current market conditions and several major projects that are coming up in 2017, the number of viaducts that will have to be built the coming years is considered as sufficient.* • *General risk of innovation: no return on investment* *Always risk that innovation will not be a success or the risk that other competitors copy the concept.* • *Not sufficient freedom in design* *There are too many constraints, requirements and regulations. Almost everything is already decided on, or it is not possible to innovate or application of a standardised concept, due to these restrictions.* • *Not trust between the different parties* *There is not sufficient trust between the different parties in the construction industry. However, cooperation is essential.* • *Clients demand customization* *A client wants a unique design. The new approach will not directly be accepted by the client.* • *Boundaries/Limitations considering technical possibilities.* • *Standardised interface can become obsolete* *The standardised interface can become obsolete by the various developments in the market. The standardised interface can be adapted to the changing market and should be robust but flexible, to cope with these changes. However, it is always possible that the standardised interface is not flexible enough and will not be suitable any longer. But for a viaduct this most likely will not happen, the concept and way a viaduct is build has not changed (or only limited) in the past 50 years.* • *ICT limitations* o *No sufficient maturity of BIM-tools (software tools)* o *Lack of interoperability between various stakeholders and their heterogeneous enterprise information systems (EIS)* • *Future is unknown (see section 6.1.3.2)* *It is unknown how the market will develop, and what the market will demand in the future. There is a risk that the investment will not be earned back/be beneficial due to unforeseen changes in the market.* o *Governmental regulation* o *Demands and wishes of the client change over time* o *New technologies/innovations developed.*

Table 6—1 SWOT-analysis: implementation of the principles of standardisation and modularization, by the development of a database with a search engine, and the possible development of a configurator on the long-term.

The SWOT-analysis provides clear insight for BAM Infra about the implementation of the principles of standardisation and modularization by application of the advice formulated. The listed strengths, weaknesses, opportunities and threats have been identified during the research, and already been discussed within this report. The SWOT-analysis provides an overview

In this research, it was found that the implementation of the principles of standardisation has a promising future. Although the SWOT-analysis shows that BAM Infra has various opportunities for the implementation of the principles, there are also a significant amount of threads present. It is essential that BAM Infra is aware of the threats and opportunities when they decide to implement the principles. The management team eventually has to decide and will need to consider the three platform related trade-offs identified by Halman, Hofer and van Vuuren (Halman, Hofer, & van Vuuren, 2003). In addition, it is essential that current practices of the company will not be negatively influenced by the development of a standardised interface. The company still needs to be able to establish sufficient profit during the implementation. Therefore, gradual implementation in two phases is advised, as discussed in chapter five.

6.1.3.2 Reflection on advice given - the current market and situation within the company

Current market

It has to be noted that the advice given in chapter five, is formulated with the current developments of the market and the situation within the company into account. The current trends within the industry can be very fruitful for the implementation of the principles of standardisation and modularization, and thereby the development of a standardised interface. Below on several trends is elaborated, that are considered to have an impact on the solution proposed to BAM Infra.

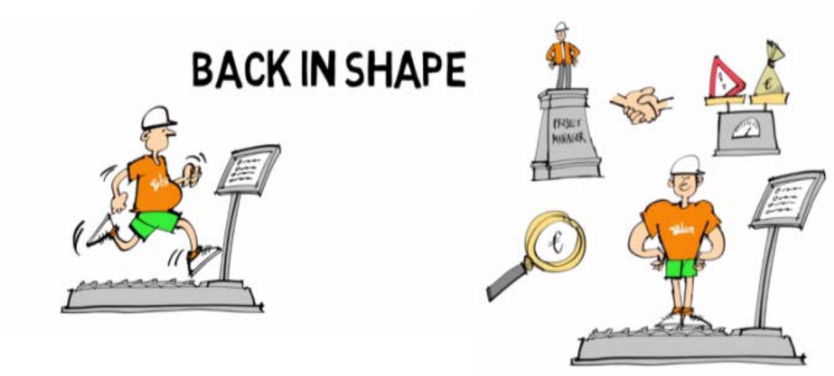
- *Digitalization of the construction industry*
  - *Digital design by increasing the maturity of BIM.*
    The ICT development, considering both hardware and software, can highly contribute to the digitalization of the construction industry. The BIM-model can become and attribute that contains all the knowledge and experience of a design and its components. Then BIM can be used by BAM Infra not only as a database containing all aspects of projects and exchange of drawings but also as a knowledge tool for simulations. Therefore, it is advised for BAM Infra to start documenting their current practices in a structured way, to be able to use the data when BIM is sufficiently mature.
  - *Atomised production process of components*
    Currently, the development of concrete components is made by application of a mould specially made for the specific project. The new technologies will make it possible to atomise the production processes. The production of steel beams is already partly atomised, and this technology is developed further. In addition, 3D printing is a trend that gives great possibilities for atomised production processes. A modular design could be very beneficial considering these trends.
  - *Application of sensors within infrastructural objects to monitor various aspects of the object.*
- *Increasing demand for building sustainable: design with possibilities for adaptation, building demountable, reuse of components or effective recycling.*
  The implementation of modularization is mainly derived from the use of repetition that occurs, by optimisation and innovation of product and process. However, a modular product platform can also be beneficial for sustainability aspects. With the usage of the modularization concept, products can be designed in such a way that they are easy to reuse and deconstruct. The possibilities that a modularization brings for adaptation, reuse, building demountable and effective deconstruction are not discussed in literature. However, in the house building and utilisation sector of the construction industry, they already apply the concept of lifecycle building. Lifecycle building is defined as: “the design of building materials, components, information systems, and management practices to create buildings that facilitate and anticipate future change to and eventual adaptation or dismantling for recovery of all systems, components, and materials” (Piepkorn, 2009). It is important to note that this concept of adaptation, building demountable, reuse of components and effective recycling is also suitable for the larger constructions in the infrastructural sector of the construction industry. The construction industry can make use of reconfigurable connections and modules, allowing it to be adapted to changed circumstances, and components can be reused, and the construction can be effectively deconstructed and recycled. Considering the reuse of components, this currently required tremendous effort to undo the steel pipe from the poured concrete. However, it shows it is possible and only needs to be further developed. In the project of knooppunt Hoevelaken, reuse of the beams of current structures is currently investigated.

Proposed solution fits within the current strategy of BAM Infra: from B to C

When the research was started the "back in shape" program that was launched in late 2014 was just finished. The goal of the program was to unlock the potential of all the individual working firms, by combining them and let them cooperate and share their knowledge and expertise. Reorganisation have taken place, and the program was successful; BAM was back in shape. Therefore, BAM was ready for the next step and a new strategy had to be developed. In later phases of this research, the new vision for BAM worldwide was formulated, the new strategic agenda of BAM Infra was presented: "Building the present, creating the future". Also stated as, moving from B to C. This strategy has been formulated based on three external forces that are shaping prospects for the construction industry. These are the following: 1) *Economic grow – Is considered to have a low but modest impact on construction volumes, 2) Sustainability and mega trends as urbanisation, and 3) Digitalisation – Is increasingly transforming the construction industry and the built environment.*

The experts of BAM Infra consider this strategy "moving from B to C" as not only be the builders of large projects but also be the creator of these projects. BAM Infra should become more an engineering firm, not only a contractor. This can be established by continuous learning from past projects and experiences, application of co-creation, working together within the Royal BAM Group, and connecting everything by the application of BIM.

Although the new strategy for 2020 was presented in later phases of this research, the proposed solution that has been investigated: the implementation of the principles of standardisation and modularization, does fit within the new strategy. The proposed solution demands sufficient maturity of BIM for successful implementation. BAM is currently the market leader when it comes to digitalisation in the construction industry. Therefore, it can be argued that application of the principles of standardisation and modularization will become possible, considering BIM, in the next couple of years .In addition, the application of the principles of standardisation and modularization with the goal of developing a standardised interface for some aspects contributes to the core values of BAM Infra: People, Planet and Profit. A description of these core values are given in Appendix A.23.



6—2 Illustration "Back in shape" program

PHASE SIX

Conclusion

7 CONCLUSION OF THIS RESEARCH

This chapter discusses the findings of this research. First, a summary of the answers to the research questions are given. Secondly, the main conclusion: answer to the main research question, is given. Hereafter, some potential directions and topics for follow-on research are suggested.

7.1 ANSWERING THE RESEARCH QUESTIONS

In this section, a summary of answers to the sub-questions of the research will be presented.

Sub-question 1 - What is already known in literature about the application of the principles of mass customization within the construction industry?

1. *What is the theoretical background of standardisation, modularization and a product platform? And what are the main insights that can be derived from literature?*

Within this research, the definition of modularity of Baldwin & Clark has been adopted. Modularity is considered as a strategy for organising complex products and processes efficiently. A modular system is composed of modules that are designed independently, but function as an integrated whole. (Baldwin & Clark, 2000) This implies that modularity has an effect on the complexity of the product design, but also has a significant effect on the processes related to the products. In addition, the viewpoint of Shilling is considered in this research. Here viewpoint is as follows: *Modularity is a general system concept, it is a continuum describing the degree to which a system can be separated and recombined, and it refers both to the tightness of coupling between elements and the degree to which the rules of the system enable the mixing and matching of components' capabilities* (Shilling & Paparone, 2005).

A product platform can be developed, to benefit from the principles of standardisation and modularization. A product platform is a set of subsystems and interfaces that form a common structure from which a stream of related products can be efficiently developed and produced (McGrath, 1995). Platform thinking is the process of identifying and exploring commonalities among firm's offerings, target markets, and the processes for creating and delivering offerings. The leading principle behind the platform concept is to balance the commonality potential and differentiation needs within a product family. The essence lays in the repetition that occurs. Based on the application of a platform, companies can create high-quality products at low cost, by systematically balancing an optimised solution between cost drivers and value proposition (Thuesen & Hvam, 2011).

2. *What benefits and disadvantages (risks) of implementation of the principles of the mass customization industry are there for firms?*

The perceived main advantage of modularization is that the end product can vary in shape and have different functions while the design and production of components and modules within a product family can be shared. In an ideal situation, the design is replaced by selecting an appropriate set of module variants from the product family. The key in the platform-driven approach is the sharing of components, modules and other assets across a family of products (Halman, Hofer, & van Vuuren, 2003). According to Hofer and Halman (2005) expected benefits of a product platform are:*1) Greater flexibility in product design, 2) Effectiveness in market positioning, and 3) Efficiency in product development and manufacturing.* (Hofer & Halman, 2005). These three benefits cover the main drivers for the implementation which are mentioned within literature, namely:

- *The increasing demands for cost and time reduction (higher demands of client)*
- *Increased competition, (the market is becoming more open and recession in the economy)*
- *Improvement in quality*
- *Reduction of the complexity of on-site construction.*
- *Increasing shortage of skilled workers in the construction industry.* (Gibb & Isack, 2003)

The main constraints perceived that are mentioned in literature are:

- *Product platform has limited lifetime*
- *Need to be managed and monitored*
- *Analysis of the future market (requires reliable forecast, need to understand the market's needs for the coming years),*
- *Initial costs for the platform development (Investment)*
- *High development time for the initial implementation of a product platform*
- *The development process will become more complex.*
- *Increased transportation logistics requirements*
- *Sacrificed benefits from conventional customization*
- *Owners and contractors capabilities*

3. *Are the principles of mass customization also applicable for the construction industry, considering the characteristics of a civil infrastructure project, and how can these be implemented?*

The principles of mass customization offers a great opportunity to improve project performance in the industrial projects. (Tatum, Vanegas, & Williams, 1987) (Song, Fagerlund, Haas, Tatum, & Vanegas, 2005) (Baldwin & Clark, 2000) (Sawhney, 1998) (Robertson & Ulrich, 1998). In addition, Gibb (2001) argued: *"Where the benefits of mass production can creatively be combined with systems that offer greater choice for the individual customer, provide improved control of the total construction process, and flexibility of assembly options."* (Gibb, 2001). Davies & Brady (2000) argue that companies that are active in the market of complex product systems can also benefit from repetition like the mass-production industry. They can improve their competitive position by learning from the initial project and developing the organisational capabilities to execute a greater number of similar projects: "economies of repetition", by putting in place organisational changes, routines and learning processes to execute a growing number of similar bids or projects at lower cost and more effectively. (Davies & Brady, 2000).

Although the principles of mass customization are successful in various industries, it cannot immediately be concluded that this approach will be beneficial for the infrastructural sector. Multiple studies have been conducted considering how a product platform could be developed in implemented. The main conclusions that are drawn:

- The development of product platforms needs to be incremental and systematic, with a clear separation between the development of the platform and the production of the products. (Thuesen & Hvam, 2011)
- A generic product architecture (platform architecture) can be defined by using a top-down approach (Kudsk, Hvam, Thuesen, Gronvold, & Olsen, 2013)
- Describe a methodology for developing product platforms is based on the concept of identifying modules that are amenable to standardisation and distinguishing them from those that must accommodate customization. (Veenstra, Halman, & Voordijk, 2006)

4. *Which challenges, circumstances and perceived barriers make the implementation of the concepts of standardisation and modularization hard to accomplish in infrastructural projects in the construction industry?*

Industrialisation has major potential for the construction industry. However, the principles of standardisation and modularization are not yet applied within the infrastructural sector. Several reasons why these principles are not successfully applied in the infrastructural sector of the construction industry are identified, some are listed below:

- *Construction companies have always struggled to solve the conflict between uniformity and variation* (Gibb, 2001).
- *Demand for flexibility is the cause of the fact that standardisation is not applied broadly or not even applied at a small scale.* (Larsson, Eriksson, Olofsson, & Simonsson, 2014).
- *The use of modularity is limited by demanding coordination requirements and limitations to interface standardisation.* (Ernst, 2005).
- *There is less scope for routinized learning in CoPS because projects are inherently one-off or unique"* (Hobday, 1998).
- *No project exceeding approach: The greatest challenge is that maintaining capability represents is learning from project to project because there is a risk that learning will be dissipated and lost to future projects and the same mistakes will be repeated* (Winch, 2003).

Different barriers to the implementation of standardisation are identified. The identified barriers originate from the characteristics of the construction industry and lead to a higher level of complexity in projects. Main barriers identified are the following.

- *Fragmentation and subcontracting,*
- *Procurement method and a strong focus on lowest price.*
- *Conservative industry culture.*
- *Adherence to traditional management concepts,*
- *Financial issues: new solutions and methods increase risks.*
- *Lack of top management commitment and support.*
- *Design and construction dichotomy,*
- *Lack of adequate awareness and understanding of standardisation method.*
- *Lack of customer focused and process-based performance measurement systems*,
- *Rules regarding plans, norms and rules of governmental organisations.*

In addition, two reasons for the reluctance to industrialise bridges are frequently mentioned within the industry: 1) Architects want to put their unique mark on each bridge, and because they enter early in the project they set constraints on production. 2) Clients are often conservative, i.e. reluctant to use new product options, as the application of proved techniques decrease risks of failure. These factors are hindering the implementation of more predefined specifications, and more time efficient production methods.

5. *What factors are considered to be essential for successful implementation of the concept of standardisation and modularization, referring to a product platform?*

By literature review several aspects are identified that are essential for successful implementation of the concept of standardisation and modularization, these are listed below:

- *Learning curve needs to be established:*
  - Winch (2003) learning from project to project, because there is a 'risk that learning will be dissipated and lost to future projects and the same mistakes will be repeated (Winch, 2003).
- *Constant optimisation of products and processes.*
  - When the platform is implemented, this has to be managed and monitored, and updated if needed. Also, optimisation of the platform should be established and new product development must be pursued on a continuous basis. (Jensen, 2014)
- *Standardise both product and process*
  - Ballard and Howell emphasise that industrialisation can be beneficial and that product and process design can be standardised for standard products, while for non-standard products they consider it to be necessary to standardise procedures for planning and to manage the design and installation of unique facilities. By this, they can benefit of the repetition that occurs. The companies will get more experienced, and a learning curve is established, this facilitates the constant optimisation of product and processes. (Ballard & Howell, 1998)
- *Knowledge and experience need to become embedded in the organisation practices.*
  - Davies and Brady (2000) emphasise that central to obtaining economies of repetition are the organisational capabilities, routines and processes. The growing stock of knowledge and experience need to becomes embodied in routines, procedures and IT tools of the organisation (Davies & Brady, 2000).
- *Cultural change/mind-shift is required*
  - Cortney and Winch (2003) argue that this also requires cultural and attitudinal changes. (Courtney & Winch, 2003). It is essential that a mind-shift occurs, as identifying similarities among projects instead of merely their uniqueness is the first step towards increased industrialisation.
- *Still, sufficient variation needs to be given: customised* solutions
  - While the parts can be standardised, the whole must provide variation: customised solutions from standardised components. Gibb (2001)
  - The commonality potential and differentiation needs have to be balanced.
- *Should be established together: the whole industry needs to adapt to the new approach*
  - The implementation of the principles of standardisation and modularization should be established together, with the whole industry.
- *Communication is essential*
  - Within various researches, it has been concluded that the flow of information and constraints between different domains (customer, engineer, production, etc.) is important for the successful implementation of a product platform (Jensen, 2014) (Jiao, Simpson, & Siddique, 2007). Communication is an essential factor. However, the communication within the current industry is not optimal and needs to be improved. Application of the principles of standardisation will greatly simplify coordination within companies as between companies. (Schilling, Toward a general modular systems theory and its application to interfirm product modularity, 2000). The standard interface facilitates effective information exchange. (Jansson, 2013) The standard interface can be combined with Building Information Modelling; this is argued to be a good tool that should be used to improve communication (Choi, 2014) (Jensen, Olofsson, & Lessing, 2015)

Sub-question 2 - Which components of a viaduct, can be identified that are suitable for standardisation and/or modularization?

1. *Is there potential for the implementation of the principles of mass customization in the current market of the infrastructural sector of the construction industry, considering the main characteristics of infrastructural projects?*

Before it has been investigated if a viaduct is suitable for the implementation of the principles of standardisation and modularization, first an analysis considering the current construction industry and the company BAM Infra is established to identify whether or not there is potential for the implementation of mass customization within the industry and BAM Infra. Based on several characteristics of infrastructural projects that have been identified by Hobday (Hobday, 1998), other opinions that have been argued in the literature review, and insights gained from interviews and discussions with experts of BAM Infra, it is analysed if the viewpoint and situation sketched within literature is applicable to the current situation in the construction industry and more specific for BAM Infra. The conclusion drawn was that there is still a lot of unused potential and space for improvement by implementing the principles of mass customization within the construction industry. Therefore, it is interesting to investigate if the principles of standardisation and modularization can be implemented within the infrastructural sector of the construction industry.

2. *What is a general design of a viaduct? (considering main practices in the Netherlands)*

This research is focused on the development of viaducts from prefabricated parts. Construction of a viaduct by an in-situ processes (pouring of concrete), is not suitable for modularization and therefore will not be reviewed. This is concluded because by the application of the pouring of concrete no modular connections (referring to the concept of Lego) can be established. In addition, different studies that have been executed considering the comparison of in-situ and prefabricated viaducts, and have concluded that prefabrication is the most suitable alternative to apply in the current situation in the Dutch construction industry (different criteria were considered) (BAM Civiel, 2013) (Bakker, 2014) (Gangaram-Panday, 2012). Furthermore, the general design in this research is based on the mainly practised method. In the Netherlands around 70% of bridges and viaducts are constructed with a prefabricated deck (TU Delft). In this research a viaduct is divided in five categories: foundation, substructure, superstructure, bearings, expansion joints and approach slab, and non-structural components.

3. *What practices, related to standardisation and modularization, in viaduct development have been recently established by BAM Infra?*

In section 3.4, the in-house research of a reference viaduct, the project of the N33, the project of the A12, the project of the N261 and the tender of the N18 are discussed. In these projects, some form of standardisation has been applied. The N261 is a project that is seen as an example of how BAM Infra should work in all their projects. In addition, it can be stated that application of the principles of standardisation has high potential. However, the principles of modularization are not yet applied within these projects. Within the interviews and meetings with various experts of BAM Infra, it has been questioned if they think the principles of modularization could also be applied by BAM Infra, and if the application of the principles is technically feasible and will be beneficial. The experts were positive. However, there are always constraints. It is not likely that it will be possible within the current contract forms.

4. *How can it be identified whether or not the application of the principles of standardisation and modularization for objects in the civil infrastructure sector are suitable? And which components of a viaduct can be identified to be suitable for standardisation and modularization?*

Within this research, the approach of Vanessa Veenstra has been used as a guideline to identify components that are suitable for standardisation or modularization. An extensive case study of a viaduct has been conducted. Five structural engineers of BAM Infra are questioned to fill in tables about the General Variety and the Coupling Indexes. Based on these tables, an advice can be given which components are suitable/interesting for the application of the principles of standardisation and modularization. Four outcomes are considered: interesting to standardise, standardise parametrical, modularize or where no clear conclusion can be drawn the project team should decide which approach is the most suitable. To establish a modular architecture, a standard interface needs to be developed. The outcome of the method shows that a viaduct is suitable for the application of the principles of standardisation and modularization. Most components, seven, were identified to modularize. Four were identified to standardise, four need to be further analysed, and two are advised to standardise parametrical.

Sub-question 3 - How can the principles of standardisation and modularization be implemented, within the current strategy of BAM Infra?

1. *What lessons can be learned from the successes and failures of already established initiatives/projects considering the principles of standardisation and modularization, from within the company BAM?*

Various initiatives of the Royal BAM Group have been reviewed. It has been investigated why these initiatives were successful and why were they were not successful. The lessons learned from these initiatives are summarised below:

- *Be true to the concept* - The five pillars of the W&R-concept, contribute to the success and have to be followed at all times.
- *Fixed design* - The concept will be successful when at least 70% is standardised. Demanding variety comes at high(er) costs.
- *Repetition* - Make use of the repetition considering both product and process.
- *Optimise* - Continuously optimise product and process. But do this by planning evaluation-moments at front. Do not optimise within a current project, apply the optimisation within new projects.
- *Work together* - Co-production can be very beneficial: “the whole is greater than the sum”.
- *Keep end-user in mind* - During the development of a new tool or design, keep the end-user in mind.
- *Process and product need to be aligned* – Process and product have to be standardised to benefit from the concept fully. As process and product are interrelated.
- *The reference should still offer sufficient variety - A* significant amount of variation is needed. Otherwise, the solution will not fit the various situation.

- *Standard is not always the best option* – sometimes it is better to design a product from scratch because too much adaptation of the reference design is required.
- *Clear flowcharts need to be developed* – Clear flowcharts needs to be developed with the trade-offs, to prevent the project team from "reinventing the wheel".
- *Sufficient room for innovation* – Sufficient freedom to think future than current practices, think "out of the box" is essential.
- *Diverse project-team* – In a diverse project team, the different members will complement each other.
- *Have one share vision* - It is important to work on the concept together with a shared vision and clear goals in mind.
- *Create support* - It is essential to explain to experts why certain steps are taken and how these can contribute.
- *Regular evaluation*s - Regularly evaluate projects, and learn from these projects for projects in the future.
- *Everybody's idea counts* - Everybody has a different view on current practices and can make a suggestion for improvement.
- *A small change can have a large impact.* - The changes can be in all the different levels and processes.

2. *What are the first steps to take, to benefit from the principles of standardisation and modularization, and to eventually establish a product platform for a viaduct?*

A new approach is needed for BAM Infra to benefit from the principles of standardisation and modularization in the construction industry. For standardisation and modularization to be of value in the construction industry, the development method is required to cope with the complexity involved. The construction companies will have to change their way of working. Different factors have an effect on if the new way of working, that benefits from the repetition that occurs, will be successful. Criteria that a new approach should have for the successful application of standardisation and modularization have been formulated. These are the following.

- *Establish a learning curve: constant feedback loops*
- *Client = King (meet the demand and wishes of the client)*
- *Continuously adapting and improving product and processes*
- *Clear trade-offs need to be made: only standardise and/or modularize elements that are suitable, and are of benefit.*
- *Clear communication and transparent information exchange.*
- *Project team should work autonomously (mainly design phase)*
- *Flexibility is needed: right balance is essential*
- *Early involvement of all disciplines*
- *Provide a protocol of which steps should be taken going through the different phases (more detailed design and realisation phase)*

In addition, the main changes in the market that are needed for implementing and to fully benefit from the new approach are listed.

- *More freedom in design: functional project description (reduce complexity)*
- *New way of working: movement from market pull towards market push*

3. *How can the principles of standardisation and modularization be implemented and what are important points to note and steps to take, to be able to benefit from the principles and to provide continuous optimisation and innovation?*

For BAM Infra it is essential to be aware that they cannot implement the principles of standardisation and modularization all by their selves. It requires effort from all parties within the industry and cooperation is needed. Although the industry is mainly sceptical, there are various companies that are open for this new way of working, and even several clients (municipalities and provinces) are promoting the approach. A platform for all parties involved in the infrastructural sector has been one of the recent initiatives. The various parties together are trying to find ways to implement the principles of mass customization in the infrastructural sector. It is advice that BAM Infra joints this platform. It would be a good strategy to invest in the application of standardisation and modularization within the companies and within the current market. Cooperation of the various parties involved in the infrastructural sector is essential, and will highly contribute to shift from the current market-pull towards a more market-push mechanism.

Main points that need to be considered by BAM Infra if they want to implement the principles of standardisation and modularization are identified, these are the following:

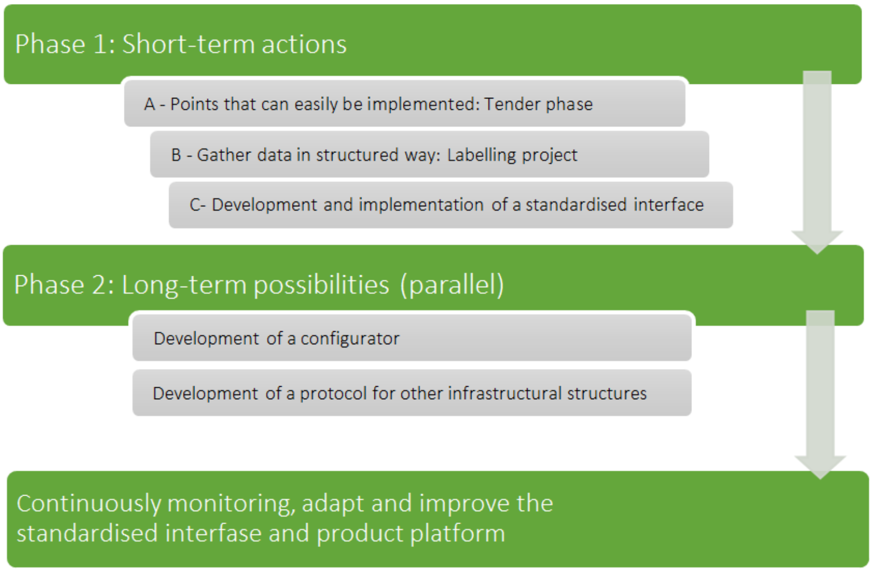
- *Balance standardisation with flexibility*
- *Application of the method developed*
- *Knowledge management is vital: gather data in structured way*
- *Feedback loops are essential for optimisation*
- *A mechanism has to be developed to apply the principles based on the data gathered (configurator)*
- *Provide protocol: steps to take*

- *Create support and change the way people analyse problems and design solutions*
- *Development of a standardised interface independently of the tenders or projects.*
- *Possible for employees to suggest improvement: collect ideas*
- *Cooperation is essential: within and outside BAM Infra*
- *Trade-offs need to be made: management team eventually has to decide*

In addition, other points that will have influence on the possible implementation of the principles of standardisation and modularization that lay out-side the company are identified, these are the following:

- *Requires effort from all parties in the construction industry, and a mind-shift is needed*
- *Data is not the only constraint: Maturity of BIM*
- *Future is unknown: conduct market analysis on a regular basis*

Within this research, it is advised that BAM Infra implements the principles in two phases: short-term actions and long-term possibilities, see figure 7—1. These steps consider to first change the current processes in the tender phase. Secondly, gather data in a structured way by application of a labelling system. A database can be developed where the knowledge and expertise can be shared in an effective and efficient way. The various projects should be documented and labelled, and an overview of the projects should be given. Thirdly, based on the data collected and appointing a research and development team, a standardised interface can be developed and implemented. However, application of a labelling system transfer knowledge and experiences for a project to other projects. A database and search engine can be developed, and eventually by application of the standardised interface and data collected a configurator can be developed. The database, search engine and configurator should be updated regularly; this will facilitate the continuous optimisation and innovation of the practices of BAM Infra. The database, search engine and configurator will contribute to working project-exceeding. Therefore, the long-term possibilities contain the development of a configurator, and in parallel the company can development a protocol for application of the principles of standardisation and modularization for other infrastructural structures, based on the experience they gained going through the advised steps for a viaduct. By application of these steps BAM Infra will be able to benefit from the principles of standardisation and modularization now and in the future.



7—1 Implementation of the principles of standardisation and modularization in two phases

7.2 ANSWERING MAIN RESEARCH QUESTION

In this section, the main research question as stated in section 1.5 is answered.

As presented in the first chapter of this research, the construction industry has become a highly competitive and complex market. The companies within the construction industry are constantly struggling between the power of flexibility given by project management of complex systems and the efficiency of using standardisation of product and process (Jansson, Johnsson, & Jensen, 2013). This is also applicable for BAM Infra; it is essential for BAM Infra to deliver variability (different circumstances) in an economical way. The following problem statement has been formulated: *The company BAM Infra misses out on opportunities for the application of the principles of standardisation and modularization in the design and realisation phases of construction projects.* A potential solution has been proposed: *Implementing the principles of mass customization, by application of the principles of standardisation and modularization.* This has been investigated for a viaduct and has been a strategic choice made by the management of BAM Infra. This has resulted in the main research question:

What are the opportunities/possibilities for BAM Infra to apply the principles of standardisation and modularization for viaducts?

This research has analysed the technical feasibility of the application of the principles of standardisation and modularization for a viaduct and investigated the possible implementation of the principles within BAM Infra. Therefore, this research is two-fold; two conclusions can be derived from the research conducted.

Technical feasibility – Identification of components suitable for standardisation or modularization
Based on this research , it can be concluded that it is technically feasible to develop a viaduct composed out of standardised and modularized components by applying a standardised interface. The general design for a viaduct was analysed, and the design phase turned out to be highly complex. Therefore, it will be complex to develop a standardised interface and develop a new way of connecting components. Within this research, a method for identification of components that are suitable to standardise or to modularize of infrastructural objects was developed; this was based on the method of Vanessa Veenstra. The method developed was applied to a viaduct. Various components of a viaduct were identified as suitable for standardisation or modularization. The method has provided new insights into the possibilities for application of the principles of standardisation and modularization. The outcome should be seen as a starting point for possible implementation and can contribute to the creation of new innovative ideas. It is advisable to use the method within the company. The method provides great insights into the external and internal aspects that influence the design of a viaduct, considering locational circumstances, changes over time and the change that is required in components when another component in the design is changed. By going through the steps provided in the method, the experts will experience that there are possibilities for the application of the principles of standardisation and modularization within infrastructural objects.

Implementation of the principles of standardisation and modularization within BAM Infra
From this research, the conclusion is drawn that, although the high complexity, the implementation of the principles of mass customization, standardisation and modularization, within the infrastructural sector of the construction industry has a very promising future. There are a lot of opportunities and possibilities for construction firms to benefit from the application of these principles. The principles of mass customization can be employed to increase the effectiveness and efficiency of project and processes. Designs can be pre-engineered, and a constant process of optimisation can occur. However, there are also many constraints for the implementation on the level of the total construction industry, as on the level of the current situation at BAM Infra.

To benefit from the principles of standardisation and modularization, the way the current construction industry works has to change. This requires effort from all parties involved, and a mind-shift is needed. Within this research, the assumption is made that the current construction industry will change from a responsive pull market towards a more pro-active push market. Several developments can be observed affirming this assumption. Therefore, it is essential that BAM Infra already starts investing in this new approach, to be able to benefit from the change of the market situation when the described change will occur. If BAM Infra wants to implement the principles of standardisation, it advised to implement this gradually in two phases. The steps that need to be taken within these phases, considering short-term actions and long-term possibilities are formulated. New processes will need to be implemented, data needs to be collected in a structured way and a standardised interface needs to be developed. The lessons learned, criteria for a new approach and main points to consider identified in the research need to be taken into consideration when BAM Infra will implement the principles of standardisation and modularization.

Although the current circumstances in the construction industry hamper the implementation of standardisation and modularization, the main constraints identified for the implementation come from within the company. To successfully implement the principles the current way of working will have to change significantly. Processes need to be adapted, and clear protocols and databases need to be developed. However, the main barrier perceived is that the employees are sceptical. People within the company need to be convinced, they need to accept the new approaches and should change their way of thinking. Making people aware, providing clear protocols, constant feedback loops, application of trade-off matrixes and decision models, and effective and efficient knowledge management are identified as essential factors for BAM Infra to implement the principles of standardisation and modularization. By application of the principles, BAM Infra will be able to work in a more project-exceeding and facilitates continuously optimization of products and processes in an effective way, to stay competitive within the dynamic market of the construction industry. By implementation of the principles, BAM Infra will be able to cope with the increasing complexity and competition currently present.

7.3 Suggestions for further research

Suggestions for further study seem relevant from a scientific, practical and social viewpoint. The implementation of standardisation and modularization within the infrastructural sector can be very beneficial for all parties involved; it has great potential. During the conduction of this research complementary research topics have been found. However, these aspects are related to the research but lay outside the scope of this research. Therefore, below a list of recommendations for further research is presented.

- *Development of a labelling system*
  Develop the proposed idea of a labelling system further, so that BAM Infra can document their current practices in a structured way. With the visions that the data can be reviewed within five year times. Based on the data insights can be drawn for the development of a configurator for viaducts.
- *Development of a configurator*
  As proposed within five years the development of a configurator should be possible based on the data collected by the labelling system. A proposed further study is to investigate how a configurator can be developed that makes BAM Infra more effective and efficient than their competitors (Note that a modular interface will be needed for the development of a configurator).
- *Balance the standardisation versus flexibility.*
  How can the different platforms be balanced regarding standardisation and flexibility, with regards to the application of the developed concept within new projects? Constant trade-offs considering standardisation versus flexibility need to be made.
- *Develop design of modular viaduct further*
  The standardisation and modularization of a viaduct will need to be developed in more detail. This research only gives a global view and provides suggestion for elements that could be standardised and/or modularized. No technical detail design is made.
- *Investigate the costs and benefits*
  Within this research, the assumption is made that the implementation of standardisation and modularization eventually will lower the costs for a contractor. However, more research needs to be conducted considering the eventually cost and benefits of the approach. More detailed and specific research about the actual cost and benefits is recommended.
- *What are the main barriers and how can these be overcome?*
  Within this research it is suggested that the implementation of standardisation and modularization can only be successful when all parties in the industry contribute to the concept, it needs to be established together. Therefore, it would be interesting to conduct more research about current barriers and how these barriers can be overcome by the cooperation of the various parties within the industry. (Considering aspects as regulations, functional requirements, etc.)
- *Research from the perspective of the client (RWS)*
  This research is conducted from the perspective of a contractor. However, it would be interesting to perform a research from the perspective of the client, mainly RWS. Contractors experience barrier for the implementation due to restrictions of RWS. But although RWS maybe will be aware of the barriers perceived, they will also experience limitation for them to change their way of working. By combining the research conducted and the suggested research valuable conclusion can be drawn. Also, possible an approach for the implementation of the principles of standardisation and modularization, which will benefit both parties can be developed
- *Understanding the cultural change required*
  Understanding the cultural change needed to enable the application of the principles of standardisation and modularization in the construction industry. How can these cultural barriers be overcome, to successfully apply the principles of standardisation and modularization?
- *Communication by application of an interface*
  The maturity of Building Information Modelling has significantly increased the last ten years. These developments have and will change the construction industry. It is argued that BIM will facilitate the implementation of standardisation and modularization. Different parties can effectively share an interface. The interface provides indirect communication, and possible conflicts can be identified. Therefore, further research should be conducted how an interface can be shared with different parties involved, based on the technical aspect of the development of a shared interface. But also research about how an interface can be shared in an effective and efficient way, considering the management and the human factor present.

- *Knowledge management: investigate how this could be improved*
  A method for labelling of the projects has been proposed in this research. However, knowledge management is not in the scope of this research. Apart from the development of a labelling system, further elaboration is suggested on how to obtain the gained insights and provide effective knowledge transfer from project to project.
- *Workout workshop proposed*
  In the advice given to BAM Infra, it is proposed to develop a workshop to raise awareness and give the experts insights into how they can apply the principles of standardisation and modularization in practice. Therefore, in further research, this could be worked out in more detail.
- *How can configurator support the different design phases?*
  It would be valuable to investigate how mass customization in construction can be supported by product configurators at different phase (tender phase, design phase, construction phase) and in addition to this at different specification levels (Sketch-design, end-design)?
- *Come up with evidence to convince people*
  Within literature as well as within BAM Infra, some people remain sceptical about the implementation of standardisation and modularization within the infrastructural sector. A mind-shift is needed. Therefore it is important to come up with evidence that the principles of standardisation and modularization can be an effective tool to stay competitive. People need to be convinced; otherwise, the approach will not be implemented.
- *Investigating if building demountable and reuse of components is possible and preferred.*
  Within this research, it is argued that the application of the principles of standardisation and modularization has great potential to design structures that are demountable and even can be reused. However, it should be investigated if this is possible considering technical feasibility and implementation and if this will be beneficial.
- *Development of a click-system*
  The researcher has asked in the survey and during the various interviews if it is possible to make less use of the pouring of concrete to make a connection and if a "click"-system can be developed. The respondents and interviewees answers were mainly positive. However, currently, a "click"-system for the various components of a viaduct has not been applied. It would be interesting to investigate the possibilities for the development and implementation of a "click-system".

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APPENDICES

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C.11 Combined results and conclusion

A. APPENDICES - REPORT

A.1 External and Internal developments

It is important to analyse the context, to understand the problem perceived, and to propose a possible solution. In this section, the current external and internal developments are discussed.

A.1.1 External developments (cannot be affected by BAM Infra)

The construction industry has always been seen as a constant market, up until now. Infrastructural projects become larger and more complex (Pavez, Gonzalez, & Alarcon, 2014). The construction industry has become a rapid-changing and dynamic market (Bertelsen, 2003). A summary of the external developments within the construction industry is given below.

- *Increased competition: low economy*
  Due to the recession (negative economic grow), the competition within the industry has increased. It has become essential for construction companies to be highly effective and efficient. Delivering projects that meet market demands by meeting all the requirements of the client is not sufficient anymore. To stay competitive construction companies need to offer products that meet the demands of the market better than their competitors. In addition, the procurement is by best value procurement, based on EMVI criteria. (Gibb & Isack, 2003) (Larsson, Eriksson, Olofsson, & Simonsson, 2014)
- *Fast changing dynamic market: uncertainty*
  The architectural, engineering and construction industry is experiencing a paradigm shift to meet new market requirements from clients (Azhar, 2011). The infrastructural sector has become a fast-changing dynamic market (Bertelsen, 2003). This fast changing dynamic market results in a high level of uncertainty. Uncertainty mainly about the current market demands and about what will be demanded in the nearby future, about the activities of competitors and the regulations that are constantly changing (Halman, Hofer, & van Vuuren, 2003) (Hobday, 1998).
- *New contract forms*
  The construction industry has moved from dealing with traditional contracts to increasingly using of Design and Build contracts and is currently moving towards DBFM(O) contracts, Design-Build-Finance-Maintain-Operate. These new contract forms, mainly DBFM(O), require a different way of working. Construction companies have to consider the total life-cycle of construction works, as they are also responsible for the later stages of the constructed object. It is essential that trade-offs are made between certain options, as this can significantly affect other stages in the total life-cycle. For example, choosing a higher quality product which is more expensive in the initial phase can result in fewer maintenance costs in the later phases. (Larsson, Eriksson, Olofsson, & Simonsson, 2014)
- *Functional specification: Increased design freedom and responsibilities*
  The construction industry is moving from complete specification of the total design towards functional specification of requirements. When traditional contracts were still the norm, Rijkswaterstaat fully specified the total design and handed the specified design to an engineering firm for consultation and further development. When the design was finished, a contractor was asked to construct the project. New contract forms have changed this process. The design is no longer completely specified; only functional requirements are listed. The functional requirements give the contractor more freedom in the development of the design, but it also increases their responsibilities (BAM, 2016).
- *Procurement is based on EMVI-criteria.*
  Procurement is no longer only linked to lowest price; construction companies can also score on EMVI-criteria. When EMVI-criteria are met, a discount budget will be drawn from the stated price. In essence, it ensures that the company that offers the best price to quality relationship within a certain budget scale is assigned the contract. This is called best value procurement. (Jensen, 2014) (Sarhan & Fox, 2013) (Blismas, Pendelbury, Gibb, & Pasquire, 2005)
- *Increase and constant changing regulations*
  The experts of BAM Infra have argued that although they have more freedom due to the new contract forms, they are still restricted by a high degree of regulation. The regulation hinders innovation. It has even been suggested by experts of BAM Infra that due to the high number of regulations, less time remains and limited solution space is available for customising and delivering more of what the client demands, and creating higher value for the client. (BAM, 2016)
- *Higher demands of clients and other stakeholders*
  Clients are becoming more demanding. They demand fast building times, high quality and the demand for customization is increasing. Some clients even demand “future proof” objects that are flexible to adapt to changing circumstances. (Azhar, 2011) In addition, projects have to be realised without causing hindrance to the surrounding areas, considering both construction and demolition phases. Furthermore, the demand for sustainability is increasing. The objects need to be built in a sustainable way with the use of sustainable materials. (Gibb & Isack, 2003) (BAM, 2016)

- *Sustainability is becoming more important*
  Clients are becoming increasingly aware of the need to develop projects in a sustainable way. New constructions need to be designed taking the future circumstances in consideration. Constructions need to be constructed out of materials that have a low impact on the environment. The client is now also starting to place requirements on the demolition, reuse and recycling of the components. (BAM, 2016)
- *Increasing maturity of BIM-appliances and other ICT software*
  The maturity and application of BIM is increasing. Building Information Modelling is a representation of the development and application of a computer related model, which considers both processes and products. "BIM facilitates a more integrated design and construction process that results in better quality at lower cost and with reduced project duration" (Eastman, Techols, Sacka, & Liston, 2008). The application of BIM is considered a major opportunity for the construction industry. (Jansson, 2013) (Choi, 2014) (Persson, Malmgeren, & Johnsson, 2009) (Jensen, Olofsson, & Lessing, 2015) (McGraw-Hill Construction, 2011)
- *New technologies*
  Projects are increasing in complexity. The development of new technologies and innovations highly contributes to the increasing complexity of projects.
- *Lack of innovation in the construction industry compared to other industries.*
  Compared to other industries, there is relatively limited innovation within the construction industry. This is mainly because previously there were no incentives for companies to innovate. However, due to the market shift that has occurred, innovating has become possible and more attractive. The need and freedom to innovate have increased.

A.1.2 Internal developments (processes that can be affected within BAM Infra)

BAM Infra has already adapted its practices to the changing market of the construction industry. However, there is still room for improvement, and the management team wants to implement a new approach for the entire company. The internal developments listed below are identified by reviewing data and having conversations with various experts of BAM Infra (BAM, 2016).

- *Re-organisation of the company structure*
  The reorganisation of the company structure has had a significant impact on how the employees of BAM Infra operate. The organisation has become less fragmented. More integration between the different departments and disciplines has been established. BAM Infra started working in a more integral manner in their multidisciplinary projects. The various members of the project team all work together from one location, during all the different phases of the project. Before the reorganisation, the different disciplines were not integrated. They mainly operated independently. However, the new approach demands that the project team work from one location and have regular meetings. The reorganisation has resulted in increased communication and cooperation between the different staff members.
- *The management of BAM Infra wants to adopt a new approach for the entire company.*
  To stay competitive and have a perspective for the future, the management team of BAM Infra wants to implement a new approach. After the reorganisation, the so-called "back in shape" program has been launched. This program is very successful. BAM Infra is back in shape. However, to stay in shape, referring to delivering projects in and effective and efficient way and to stay competitive in the market, a new approach is needed.
- Profit margins are not sufficient.
  Compared to other construction companies, BAM Infra is doing well in the infrastructural sector. However, the profits margins that are established are not sufficient for the continuity of the company. The company would like to grow and become more stable. Therefore, a new strategy is being implemented gradually, and new markets are being entered. This will make the company less sensitive to the fluctuations of the circumstances within the industry. (The company is currently working on gravity-based-foundations of windmills near the British coast. BAM Infra has recently won a tender for the design and construction of a tunnel located on the sea-bed. This tunnel will connect Denmark and Germany, and this will become the largest traffic tunnel in the world.
- Ageing of the staff within the company
  Within an organisation, it is important to have the right balance between senior and junior staff. The senior employees have a lot of experience and knowledge. The junior employees have less experience but have more knowledge about new practices, are eager, and have an open mindset which allows them to think "out of the box". The combination of senior and junior staff, with different backgrounds, is considered to be a good approach for companies to follow, for BAM Infra as well. Within BAM Infra, the average age of the employees is relatively high. BAM Infra is aware of this and tries to improve the balance of senior and junior staff.
- Experts' perspective;
  Within BAM Infra, both proponents and opponents of a new way of working within the company are present. Based on the interviews conducted and the survey, it can be concluded that majority of the experts is positive about the implementation of the principles of mass customization within their company. However, there are also opponents. Some experts are sceptical. They argue that the old way of working, which they have followed for a long time, is a good approach. Although the experts are mainly positive about the implementation the principles of mass customization

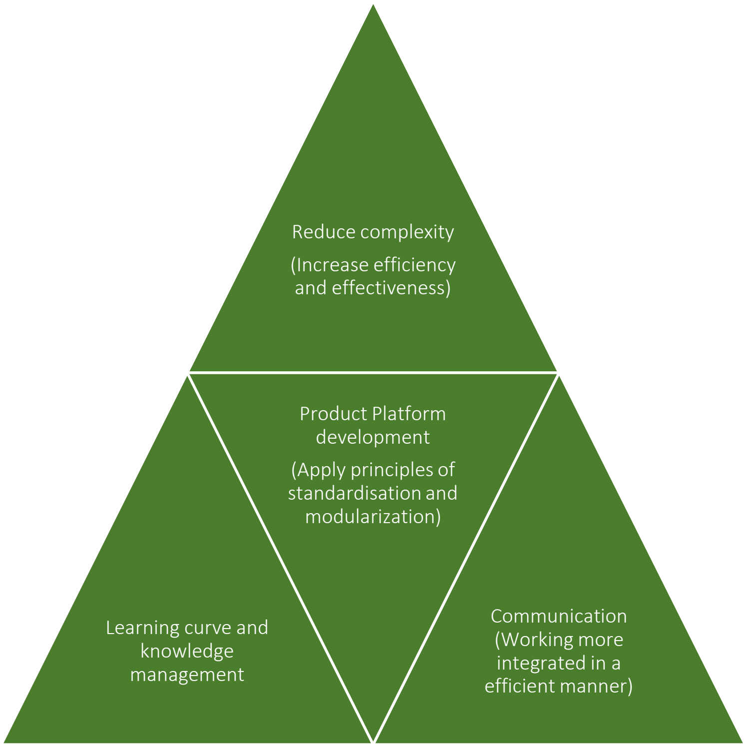
within the company, the experts argue that it will not be easy to implement this within the company. It is complex, and people are resistant to change.

- More awareness of the essence of sharing knowledge
  The various employees of BAM Infra are becoming increasing aware of the essence of sharing knowledge within the organisation. In-house they are currently developing a platform known as: "Who can I phone? This platform has been developed with the aim of providing a database for experts where they can look up who has been involved in certain projects and/or are specialists in a certain area. They can then contact each other to share knowledge and experiences, which can be applied in new projects

A.2 THREE CORE ASPECTS

Within this thesis three core aspects have been identified by the researcher herself. They are identified based on literature review, observations and interviews conducted. The three core aspects are visualised in figure A-1, the aspects identified are:
- *Reduce complexity (increase efficiency and effectiveness)*
- *Learning curve and knowledge management*
- *Communication (Working more integrated in an efficient manner)*

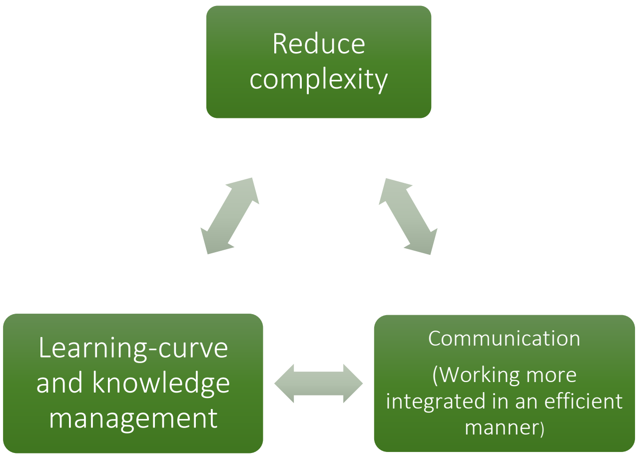
These three core aspects all revolve around: *Product platform development, by appliance of the principles of standardisation and modularization.*



A—1Three core aspects of this research

A.2.1 Relations between the three core aspects

In this research three core aspects are identified. These core aspects are related to each other, as illustrated in figure A-2.



A—2 Relations between the three core aspects

. Learning-curve and knowledge management

- “Reinventing the wheel.”

The problem of inefficiency of the construction industry is due to the constantly repeated routine design tasks without reusing past knowledge, causing unnecessary duplication of effort. (Azhar, 2011) This is also applicable for BAM Infra. They mostly design a new project from scratch, and therefore the company does not make use or limited use of the repetition of product and processes that occur. They are constantly “reinventing the wheel”. When the experts start on a new project, they rely on their own knowledge and experience they have gained during their studies and working. Moreover, only limited interaction to share knowledge and ideas takes place. The knowledge in this way stay located at the individual employee and is sometimes shared with the new project team. Most of the time a design is made from scratch, with only using the knowledge of the project team. The project teams are in this way constantly “reinventing the wheel”.

- Knowledge is not transferred/documented to the total organisation

No internal database where the documentation (drawings, decisions made, process) of projects can be shared. There is no database that the experts of BAM Infra can consolidate for possible solutions, ideas and innovations that can be applicable for a project they are working on currently. It is vital for BAM Infra to revise and improve their current policy on knowledge management.

- Work project-based.

Currently, BAM Infra works product-based. The innovation of both products and processes that are specially developed for a certain project are not review, applied or developed future in other projects. The knowledge stays with the experts, who take this knowledge to their next project, but the knowledge stays with the experts as no database is established. The ideal would be to work on a more project-exceeding level. The experience, lessons learned and designs can be useful for the new projects.

- No feedback loop (validation + verification) is applied.

BAM Infra does apply the System Engineering (SE) principle of validation and verification. However, the validation and verification are limited. The validation and verification at the end of building phase are conducted by the project leader. However, it would be more valuable if the analyses would be conducted within all the different disciplines that have worked on the project. Currently, this is not the case. At the end of the design phases and construction phases, the projects are being limited reviewed on how it has developed (process, time, and failure). Although, the protocol does describe that an evaluation had to be conducted during all different phases and most important at the end of the project. This evaluation is not always conducted properly. When projects are finished, the experts of BAM just continue to a new project. However, this leaves no time for evaluation and proper documentation of the project, considering both processes and delivered products. Although the evaluation of projects is limited, more important, the conducted evaluation of the project is mostly not transferred throughout the total organisation. The experts of BAM Infra get no or limited feedback about the project. The result is that the experts are not always aware of what faults are made, and the same mistakes are made to the next project. This also applies to the aspects that when well, if the experts are aware that certain processes or techniques have been successful, they will apply this approach also in future projects. By not establishing this feedback-loop, BAM Infra misses out on opportunities to optimise and benefit of lessons learned from already realised projects.

2. No clear communication and framework for development and construction.

- Limited cooperation + integration between disciplines within BAM Infra (fragmentation).

Although the organisation structure has been changed and the company is now working in a more integrated manner, still fragmentation in the organisation’s way of working and structure is present.

- Essential to work more integrated, but this need to be established in an efficient and effective manner.

Currently, there is a lack of integration between the different disciplines. This needs improvement. Efficient and effective communication within current projects and development is needed. However, this can be complex because everything is interrelated, considering both processes and products.

- Limited co-production

BAM Infra does already cooperate with a small group of suppliers (preferred suppliers), which they have worked with before. However, limited co-production takes place. Letting suppliers co-produce can give BAM Infra a step ahead of the market, as capacities, resources and expertise’s can be combined; the whole is greater than the sum”.

3. Complexity, of both process and product

- Every project is different; all object are unique.

Every project is “unique”, as each project has to deal with various situations, considering location, requirements, budget, opinion of stakeholders, etc. Infrastructural projects are mainly constructed on locations where the space for the construction is limited. In addition, the new construction will have a significant impact on the surrounding, and most of the times the infrastructure has to keep functioning. These factors make the projects more complex. The solution space is smaller, as there are more restrictions and points to consider.

- Higher demands of client

The demands of the clients are increasing. In the traditional contracts, the client handed over a design to the construction company. However, currently requirements are functionally specified, and the construction company has to design his own solution for the situation. This makes it easier for clients to be more demanding. The clients want projects to be established in a sustainable way, should be constructed within a limited amount of time, should be of high quality, and only limited hindrance is

accepted. In addition, the client demands a level of customisation and this all within time and budget.
- Need to consider the total-life-cycle.
BAM Infra needs to consider the total-life-cycle because the responsibilities of the contractors have increased due to DBFM(O) contracts. Construction companies have to find an optimum within the design, construction and maintenance in the use phase. Choosing a more expensive material can result in low cost in the total-life-cycle, as less maintenance is required.
- Many stakeholders
Infrastructural projects have to deal with many stakeholders with diverse interests, as the projects are relatively large and will have an influence on the surrounding area. This means that a lot of people and businesses are affected by the new construction. Therefore, design has to be made which takes all these viewpoints into account. For example, a new highway with a length of 100 km has to be constructed. Many people, people living in the area and the local businesses, will be influenced by the implementation of the highway. In addition, the rules and requirements of the province need to be considered. When the highway goes from the North of the Netherlands to the South, the highway will go through different provinces and municipalities and will have to meet their different requirements and rules.
- Complexity of the civil constructions (technical)
Civil constructions are complex in a technical manner, as many factors are of influence and interrelated with each other. This makes it hard to innovate.

A.2.2 Proposed solution that needs to be investigated, in response to the three core aspects

In this research, the vision is that the implementation of the principles standardisation and modularization is and efficient and effective approach to decrease complexity, establish a learning curve and provide clear communication. This will be elaborated on below:

1. A learning curve can be established
- Reuse of design of already realised projects.
The design of different projects can be re-used and adapted to the new situation. By reuse of the main concept, principles and design of components, much time can be saved in the design phase.
- Optimization
Optimisation of current practices can be established on the level of process, and the product-level. The products and processes can be optimised by an iterative process. This optimization will contribute to increasing the quality of the processes and products. By reuse of designs, a significant amount of time can be saved in the design phase. In addition, the actual construction on the side can be speeded up; the prefabricated modules only need to be assembled, and the construction team will have experiences with this "reused"-design. When products and processes are optimised, this will result in faster design and construction, and the quality of both product and process will increase.
- Work on a project exceeding level.
It is important that the innovation developed for a certain project can also be applied in other projects. The ideas and knowledge generated for a project need to be shared in the organisation. Knowledge management is essential to work project-exceeding. Innovation can be applied and even improved within new projects.
- Implementation of a feedback-loop (validation + verification).
BAM Infra should improve and expand their current practices of the appliance of System Engineering, consider validation and verification. Reviewing the different phases of the project gives BAM Infra a great opportunity to learn and optimise their practices. It is important that projects will be reviewed. The different disciplines within the project team need to review the design and construction process, considering what went well and what went wrong, where points of improvement and which objects or process are risky and need to be monitored in future projects.

2. Provides clear framework
- Provides a clear framework
The implementation of a product platform can be highly effective, as it guides the different disciplines and visualises the solution space. The solution space functions as a framework. It provides clear boundary conditions, in which the different disciplines have to work. Additionally, less communication is needed, and design can be made without the need to work together tightly. The implementation of the principles of standardisation and modularization contributes to the design process as components can be adapted, or updated without affecting other parts of the total design.
- Possible to gain knowledge interdisciplinary within own organisation
A platform makes sharing of designs and ideas between the different disciplines easier.
- Increases the possibilities to cooperate with other companies.
BAM Infra can share their knowledge and expertise by cooperation with other companies, and vice versa. They can work on the same product, within the framework as they need to consider the boundary conditions. Working together can have benefits that out-compete concurrent: "The whole is greater than the sum of parts", and risks can be shared. Jacobs et al. (2007), points out that the implementation of a product platform, one of the positive outcomes of a product platform is the development of closer commercial ties with suppliers as a result of increased integration (Jacobs, Vickery, & Droge, 2007).

3. Reduce complexity

Divide the design/problem in small subsystems (from integral to a more modular architecture)

The process of innovation can be simplified, by dividing the design into subcomponents. This reduces the complexity because the problem is divided various smaller problems, which can be solved independently from other problems and components.

Easier to innovate

A modular architecture has fewer dependencies relationship between components. Therefore, it is easier to innovate, as the changes within the module do not have an effect on the other modules. A modular design is more flexible in comparision to an integral design. The design can be better adapted to different circumstances, due to fewer dependencies/coupling relations.

Develop a configurator: Mix and Match

When principles of standardisation and modularization have been implemented, BAM Infra could consider the development of a configurator. Here, a reference design can be adapted to the specific situation, this is an easy and efficient way to make multiple design options and review/compare them, as a decision have to be made.

4. Additional benefits

Build in a more sustainable way

The implementation of the principles of standardisation and modularization can result in an increase of sustainability within project and processes. Sustainability is one of the key points of RWS. Currently, RWS specify that the different elements of construction have to be easy to deconstruct, recycle and generate a limited amount of waste. In addition, limited hindrance during construction (assembly) and deconstructing is preferred. Modular design can have significant benefits for these aspects. A modular design has fewer dependencies between parts, and these parts are connected making use of a common interface. In the ideal situation, the different modules can be “clicked together”, and less or no pouring of concrete is needed. Moverover, this makes demolition and recycling easier. However, such techniques are not yet developed.

- Fast changing environment/market

The implementation of standardisation and modularization offers the possibility to shift/be flexible in changing circumstances in the dynamic market of the construction industry. As explained before, a reference design can be adapted. Adaptation of the structures of this reference design is easier than when an integral design is applied, due to less coupling between the parts. In addition, standardisation and modularization result in more “future proof”-constructions. As current construction objects can be easier adapted to the new circumstances (for example the objects can be expanded). In the design phase the possibility of adaptation already needs to be considered, to make it more flexible for adaptation in the future.

A.3 RESEARCH STRATEGY AND METHOD

Research strategy – Empirical research

This research is a qualitative research, theory and current practices are analysed and compared. Research tools that have been used are: conducting a literature review, analysing of documents (written and drawings), conducting many interviews, have discussions and conversations with various experts, and observation of current practices within the company BAM Infra and the construction industry.

This research is an empirical research. The word empirical within a research means that information is gained by observation or experiment. Within scientific research, all evidence must be empirical; this means it has to be based on evidence. When conducting an empirical research the why, whom, how and when needs to be discussed? The" why" establishes the need for the study, and generates a series of expected results, or hypotheses. The "who", considers how large the study will be, does it considers an entire population, or will only samples be collected. The "how", refers to the selection of variables to observe, and how to statistically analyse them. Moreover, the "when" establishes the need for the study. The objectives of empirical research are:
- Go beyond simply reporting observations
- Promote environment for improved understanding
- Combine extensive research with detailed case study
- Prove relevance of theory by working in a real world environment (context) (Empirical Research, 2009)

Based on the characteristics of empirical research, as listed above, an empirical research approach is considered to be suitable for this research.

To be more specific, in the first part of the empirical research an explorative research method has been applied. Exploratory research focus is on the discovery of ideas and insights and is best suited for the beginning research, for the development of a research plan. Exploratory Research is research conducted for a problem that has not been clearly defined. Exploratory research helps determine the best research design, data collection method and selection of subjects. Exploratory research often relies on techniques such as:
- Secondary research - such as reviewing available literature and/or data
- Qualitative approaches, such as informal discussions with consumers, experts, management or competitors
- More formal approaches through in-depth interviews, focus groups, projective methods, case studies or pilot studies

These techniques have been applied in this research.

It has to be pointed out that these phases illustrated in figure 1-5, in section 1.6.1, are listed in a systematic way, and has been the basis for conducting this research. However, this research remains an iterative process. This has also been mentioned by Verschuren and Doorewaard: "Within designing and conducting research there are continual movements back and forwards between the various stages of the research." (Verschuren & Doorewaard, 2010) In addition, Verschuren en Doorewaard stated that: "In terms of the design of the research, iteration means that the designer must constantly switch from the one part of the design to the other. Each time, he or she reconsiders the consequences that the provisional decision concerning the one part will have on each of the other parts of the design to be. That is, both the parts that are still to follow and the parts that have already been designed must be adapted if necessary. This process stops as soon as an adjustment does not have recognisable consequences for any of the other parts of the design. (Verschuren & Doorewaard, 2010)

Literature review – Method

In this research, at first, a literature review will be conducted. The theory will be analysed and compared with the current situation within the construction industry. For conducting the literature review, parameters are defined. This assures that the search process will be structured and restricted. The parameters that are used are listed below:

Parameter	Narrow search	Broad search
Language	*English*	*English and optional Dutch*
Industry	*Construction Industry: Civil and Infrastructural constructions*	*Construction industry*
Publication	*Last ten years*	*Last 30 years*
Literature type	*Articles, books and reports*	*Articles, books and reports*

To obtain the scientific literature that is relevant for this research, different sources have been reviewed.
Different search engines were used to search their database; Scopus, Web of Science and Google Scholar. These library databases have been used to find articles related to the research field, considering theory, analyses and review of current practices.

Key-words that are used for this research are:

- *Modular, modularity, modularization*
- *Viaduct, fly-over*
- *Construction industry, construction*
- *Product platform*
- *Mass customization*
- *Prefabrication*
- *Standard, standardisation,*
- *Concrete bridge, bridge*
- *Infrastructure projects, infrastructure, infra, infra sector*
- *Interface*
- *Industrialization*

The search fields that have been used are 'Article Title, Abstract, and Keywords'. This is the standard setting of the search engines of Scopus and Web of Science. Different combinations of keywords have been used to find relevant literature. The result of the search in the search engines was then analysed.

At first, the search was listed by date (sort on: Date). This approach was chosen because the development for a product platform, standardisation and modularization within the infrastructural sector of the construction industry have not been broadly analysed before. Moreover, currently, standardisation and modularization get more and more attention in literature. The relevance of the article was identified based on the title and in what kind of journal the article was published. When an article looked interesting, first the appendix was read, to decide if it could be useful and related to this research. When it was considered to be useful, the article was saved and printed out, to read the paper and make notes. Secondly, the same search was sorted by the number of citations of the article received (Sort on: cited by), as the perception is that articles that have been cited often are valuable articles to review. However, most of the searches, which were searched by sort on: "cited", gave a list of relatively old articles, as current writers use these articles for explaining the theory. When already sufficient theory was found, this search of "cited by" was skipped, because it mostly referred to articles about the theoretical background. Thirdly, the sort on: "relevance" has been used for the search of literature related to this research.

In addition, articles provided on the Blackboard organisation folder of "platform design" of the Department CME have been reviewed. In addition, the articles provide on Blackboard for the course industrialisation and innovation in the construction industry, given by Professor Dr. Ir. J.I.M. Halman at the University of Twente, have been reviewed. In addition, articles, books and reports that were suggested by Professor Dr.ir. J.I.M. Halman, have been reviewed.

The collection of articles that were considered to be useful for this research (referring to the articles obtained by search engines and documents from Blackboard) were reviewed in more detail. This gave the researcher new insights and new points to search on. It is important to note that the search remains an iterative process.

A.4 OPPORTUNITIES, CONCERNS AND RISKS PERCEIVED BASED ON REVIEW OF LITERATURE

A.4.1 Article 1: Choi - Links between Modularization Critical Success Factors and Project performance

In the article of Choi: *Links between Modularization Critical Success Factors and Project performance* (Choi, 2014). Modularization is defined as, a well-established technique which can improve the efficiency and productivity of the construction industry. The main value and benefits of modularization, disadvantages and impediment of modularization and success factors for a high level of modularization have been identified according to a review of various literature. These are listed below:

Main value and benefits of modularization	*Disadvantages and Impediments of Modularization*	*Success Factors for Higher Levels of Modularization*
Lower capital costs	*Cost Barrier*	*Early Consideration*
Improved scheduled performance	*Coordination Barrier*	*Alignment*
Increased productivity	*Engineer Design Barrier*	*New technology*
Increased safety performance	*Procurement Barrier*	*Design*
Reduced waste and less impact on the environment	*Owners and Contractors Capability*	*Standardisation*
Higher overall quality	*Culture (shift is needed)*	*Fabrication infrastructure*
Fewer site-based permits		*Improvement in Logistics*

A.4.2 Article 2: Kleuver - Industry and Project Enablers for Broader use of Modularization

Kleuver (2011) has listed the pros and cons of application of modularization specifically within infrastructural processes that have been identified by using CII PPMOF Tool Categories (Kleuver, 2011). The categories identified are; schedule, cost, labour, safety, site attributes, mechanical systems, project and contract types, design, transportation and lifting requirements and supplier capability.

Category	PROS	CONS
Schedule	*-Parallel schedule allows for simultaneous work* *-Shorter schedules*	*-Higher schedule risk*
Cost	*-Lower field costs (fewer workers, fewer accommodations needed)* *-Lower material transportation costs (if source is closer to Fab Shop than to end site)*	*-Higher engineering costs* *-Higher transportation costs* *-Higher overhead costs for planning*
Labour	*-Increased productivity due to improved working conditions* *-Cheaper wage rates in a distant fabrication shop* *-Closer to skilled workforce*	*-Extra labour needed (expert engineers, QA/QC engineers on Fab Shop and with suppliers)* *-Team organisation requirements higher* *-Union relations*
Safety	*-Increased safety due to improved working conditions* *-Covered working areas* *-Work performed on the ground as opposed to high up*	*-Higher risks during transportation*
Site Attributes	*-Less material storage necessary*	*-Site access (roads, obstacles, ports, etc..) might not allow for insertion of big modules*
Mechanical Systems	*-Standardisation medium/long term effects*	*-Earlier procurement poses high logistical complications* *-Mechanical systems cannot be bought at optimal time* *-Mechanical systems not always aligned with structural and other systems*
Project and Contract Types	*-Long term relationship with fabrication shop* *-Streamlining of suppliers, long-term contracts with suppliers (with standardisation)*	*-Risk allocation shifts*
Design	*-Standardisation medium/long term effects* *-More widespread use of 3D modelling: long term benefit*	*-Earlier design necessary* *-More complex design necessary* *-Interface management complex* *-More work to create new specs* *-More coordination between disciplines necessary* *-Less flexibility of design (freezing design)* *-Low supply of experts*

Transportation and Lifting Requirements	*-Shipping materials into one location, closer to source* *-Easier material management at fab shops (storage, receiving, routeing)* *-Crane requirements shifted from site to fab shop for assembly*	*-Double shipping* *-More complex requirements* *-Supply of heavy lift cranes not always assured* *-Modules sizes limited by crane sizes* *-Transport infrastructure (road capacities, bridge capacities, bridge clearances, port facilities, transport ships) not always matches requirements, impedes bigger modules to be built* *-Higher logistical workload* *-Earlier coordination and planning necessary*
Supplier Capability	*-Fabrication shops typically closer to supplier* *-Long term contract with fewer suppliers possible*	*-Higher requirements for suppliers (quality)* *-More coordination between procurement and supplier necessary* *-More QC/QA requirements and workload* *-Long lead purchases are riskier*

Table A—1 Modularization Pros & Cons list using CII PPMOF Tool Categories have been listed (Kleuver, 2011)

A.4.3 Article 3: O'Conner & O'Brien - Standardisation Strategy for Modular Industrial Plants

In the article; "Standardisation strategy for modular industrial plants", the considered main economic advantages and disadvantage of modular, standardised plant application are identified and listed below (O'Conner, O'Brien, & Choi, 2015).

<u>*Economic advantages of modular standardised plant application*</u>

Advantage	Examples of specific advantages
Design only once and reuse multiple times	*• Save costs of design and owner* *• More reliable early project cost estimates*
Design and procure in advance/acceleration responds to schedule needs	*• Ideal for schedule-critical projects* *• Long-lead items can be stocked. Fabrication can start and finish earlier* *• Less schedule risk since many sequences can be optimised and well understood* *• When nearly "shovel-ready" design documentation is needed*
Accelerated, parallel engineering for site adaptation	*• Engineering for needed site adaptation of standard design is less iterative and more parallel and, therefore, accelerated* *• Many "delta" engineering efforts can be anticipated and built into the standard design offerings* *• Fewer errors and iterations in such engineering, given better-defined design "boundary conditions*
Learning-curve benefits in fabrication	*• Quality and safety benefits* *• Productivity benefits* *• Containment of related risk/uncertainty*
Procurement discounts from volume or early commitment	*• Greater purchasing leverage via multi-purchase agreements* *• Early procurement is enabled, which may have the effect of kerbing cost escalation*
Construction material management cost saving	*Reduced material/component inventory* *• Smaller construction warehouse/storage* *• Fewer frequent material/component outages*
Learning-curve benefits in module installation/site-construction	*• Quality and safety benefits* *• Productivity benefits from familiar design and installation* *• Field schedule improvement due to optimised activity sequencing* *• Containment of related risk/uncertainty*
Learning-curve benefits in commissioning/start-up (planning and execution)	*• Quality and safety benefits* *• Productivity benefits* *• Higher levels of pre-commissioning possible* *• Containment of related risk/uncertainty* *• Less training required*
Learning-curve benefits in operations and maintenance (given clients with multiple plants)	*• Quality and safety benefits* *• Productivity benefits* *• Containment of related risk/uncertainty* *• Operations/maintenance staff substitutability*
Operation and maintenance material management cost savings	*• Reduced operations/maintenance material inventory* *• Smaller warehouse/storage for operations and maintenance* *• Fewer and less frequent spare-part outages*

Table A—2 Economic advantages of modular, standardised plant application, derived from O'Conner et al (2015)

Economic disadvantages of modular standardised plant application

Disadvantages	*Examples of specific disadvantages*
Cost of assessing market and establishing scope	*• Cost of conducting planning study* *• Need to understand relative value or importance of accelerated schedule to customer/operator.* *• Need to understand what technical trade-offs the customer/operator is willing to concede* *• Need to understand regional (i.e., geographical) considerations/constraints/design variations and associated specific needs for regional flexibility within the framework of standard design* *• Need to recognise lifecycle limitations of standard design*
Cost of establishing design standard	*• Added cost of designing standard plant/unit and incorporating into the design the necessary amount of planned flexibility* *• Associated overhead/finance cost since there may be no assurance that added design costs will be 100% recoverable or usable without major subsequent changes*
Sacrificed benefits from conventional customization	*• Cost of inefficient interfaces/relationships between existing brownfield and new standard greenfield components* *• May require added construction materials (i.e., larger, conservative components)* *• May increase energy consumption from facility operations* *• Elimination of some unique operations/maintenance plant preferences*

Table A—3 Economic disadvantages of modular standardise plan application, derived from O'Conner et al (2015)

A.4.4 Article 4: Halman, Hofer & van Vuuren - Platform driven development of product families: Linking theory with practice.

The article starts with pointing out that firms in most industries increasingly using platform-based approach to reducing complexity and better leverage investment in product design, manufacturing and marketing. This helps them to manage the complexity of offering greater product variety. Halman, Hofer and van Vuuren state that the key to this approach is the sharing of components, modules and other assets across a family of products. (Halman, Hofer, & van Vuuren, 2003)

Considering the implementation of a product platform different advantages, disadvantages and risks have been identified by Halman et al. (2003), by conducting a case study with three distinct technology driven companies, namely ASML, SKIL and SDI (Halman, Hofer, & van Vuuren, 2003). The results have been listed below, and a concluding table is given; table 9-13.

Advantages
The expected advantages for product family development as indicated by the companies are listed below

ASML: Developed platform-based product families for its whole product range, by reuse of basic modules. They had two main reasons for changing to a family development approach. (1) A stable platform makes it easier to come up with newer modules and to ramp up volumes, and (2) from an engineering point of view, it is unaffordable to design a new machine from scratch every time a change in a local part of the machine is needed.
Expected advantages:

- Efficiency in the development process, considering volume, costs and maintenance.
- Higher flexibility in the assembly and advantages for service and maintaining the machines.
- Shorter time-to-market and shorter ramp-up times.
- Improved learning curves during training, increases the effectiveness.

Skil: This company has very high commonality within applications and high commonality across all products. Efficient use of resources and reducing time to market were seen as the main goal from an engineering and manufacturing perspective.
Expected advantages:

- Efficient use of resources, considering cost, time and high variety (by reusing existing components instead of developing everything new for every new product).
- Reducing time-to- market.
- Effectiveness will increase because a product platform results in a strong brand identity.
- The development of different brand segments clearly distinctive product families help the consumer to compare and choose between different products.

SDI: The starting-point for platform driven product families was the development of "general-purpose modules". They have chosen a modular design to speed up the process and reduce the costs. A range of products is defined based on a similar underlying technology, during design and development the focus is on keeping as many modules the same among the different applications.

Expected advantages:

- A product platform makes it possible to derive a variety of machines from the same building blocks.
- Cost efficiency in the product development process (maximise profit, keeping development budget the same).
- Time-to-market reduction.
- More efficient training program: "once you understand one product, you understand them all".

In the article, Halman et al. (2003) conclude that compared to the broad differences regarding the product applications and market structures found in the case study's, the reasons and expected benefits from building platform-based product families fall basically into three different categories:

(1) Enhancing the flexibility in product design
(2) Increasing efficiency in product development and realisation
(3) Improving effectiveness in communication and market positioning

<u>*Disadvantages and risks:*</u>

A product platform, by applying the concepts of standardisation and modularization, is not without risks. Product family development is more strategic and long term in nature, focusing less on singular opportunities than on single product development. Product families require a strong platform on which follow-on products can be built effectively and efficiently, and these platforms need to be renewed in time to be able to meet changing customers' demands. Product families have a limited lifetime that needs to be managed. Therefore, decisions have to be made about when to start a new family, which products to launch and in which order, when to move on to an extended or new platform and consequently to a new product family, and where best to allocate scarce resources (Halman, Hofer, & van Vuuren, 2003).

The three companies also share their view considering risk associated with product family development. This has been summarised in table A-4: Perceived risks related to platform-based product family development (Halman, Hofer, & van Vuuren, 2003)

	ASML	*Skil*	*SDI*
Risks	*-Development time and cost of platform*	*-High cost and time for integration of existing elements*	*-Development time and cost to meet specifications of all target markets*
	-Rigidity in design		
	-Restrictions on the integration of new technologies	*-Platform development becomes easily a goal in itself*	*-Development process becomes more complex*
	-Incorrect forecast of future user needs	*-Mistakes made in the beginning have a high impact*	*-Restrictions for all market segments*
	-Change from one platform to another	*-Failure to forecast customer needs correctly*	*-Selecting the right platform*

Table A—4 Perceived risks related to platform-based product family development, derived from Halman et al. (2003).

ASML state that, the platform development might lead to restrictions on the use of new technologies in later stages of the product family life cycle, to rigidity in the design when many choices have to be made at a very early stage, and the failure to correctly forecast future user's needs. Skil considers that the main risks lay in forecasting of future customer needs, the integration of existing elements, and the high impact of mistakes early in the development phase. SDI considers the major challenge of developing product families, lies in the correct choice of the platform. The major risks encountered are the restriction for different market segments, and the high initial cost and time for platform development.

Table A-5 : ASML, Skil, SDI - Main reasons and considered benefits and risks for following a family approach gives an overview of the risks and problems facing platform and product family development, as perceived by the three companies. The most risks are considered to encounter by;

- *Need for decision early in product life cycle*
- *The analysis of the future market*
- *The high initial investment for platform development.*

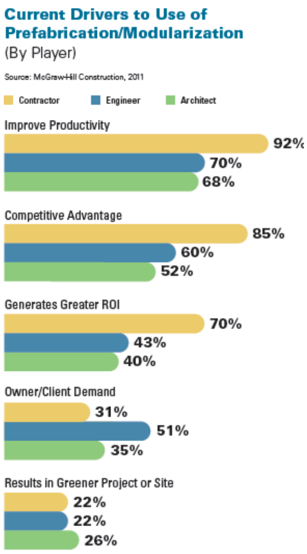
	ASML	Skil	SDI
Main reason	*- Volume* *- Costs*	*- Costs* *- Time* *- Styling (Branding)*	*-Able to be active in two markets with one budget*
Benefits	*- Efficiency* *- Time to market* *- Assembly* *- Service* *- Maintenance* *- Training* *- Learning-curve*	*- Improve learning* *- Efficient use of resources* *- Shelf of products*	*- Less work, time and costs.* *- Maximise profit in two businesses.* *- Easier to explain (communication and design)*
Risks	*- Get platform to work* *- Development time and costs of the platform* *- Restrictions one the use of new technologies* *- Rigidity (non-flexible) design* *- Incorrect forecast of future user needs*	*- Failure to forecast customer needs correctly* *- The process of developing families, as a goal in itself*	*- Development time and costs to meet specification of both markets* *- Development process becomes more complex* *- Selecting the right platform (make correct choice)*

Table A—5 ASML, Skil, SDI - Main reasons and considered benefits and risks for following a family approach, derived from Halman et al. (2003)

A.4.5 Article 5: McGraw-Hill: Prefabrication and Modularization: Increasing Productivity in the Construction Industry

McGraw-Hill Construction has investigated if prefabrication and modularization contributed to the Productivity in the Construction Industry (McGraw-Hill Construction, 2011). This is done by the conducting of a survey with contractors, engineers and architects. The most important conclusions that have been drawn are discussed below.

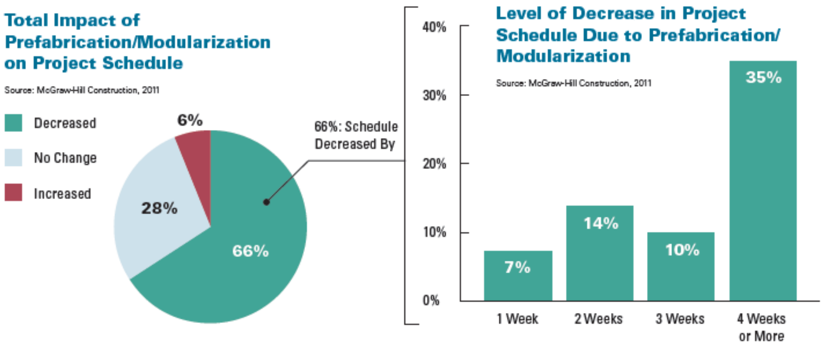
<u>Main drivers</u>
The most important driver of current usage of prefabrication and modularization has been indicated by the survey. The result of the survey shows that the ability to improve productivity is considered to be the main driver. The result has been given below, in figure 10-11. Other drivers that have been identified are; competitive advantage, generates a greater return on investment, the owner and client demands and the fact that it ought to result in greener projects and site conditions.



A—3 Current drivers to use of prefabrication/modularization, derived from McGraw-Hill Construction (2011)

In total 82% of the responders considers productivity as the main driver. Within this study, elements of productivity improvement included: improved project schedule, reduced cost and budgets, site safety and quality, referring to green building and waste reduction.

Impact on project schedule

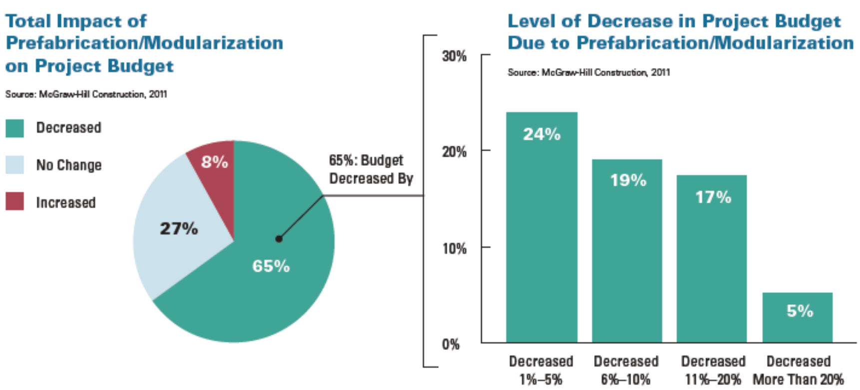


A—4 Impact of prefabrication/modularization on project schedule, derived from McGraw-Hill Construction (2011)

The experience with applying of prefabrication and modularization within projects result in reduced project schedule. Two-thirds of firms who currently use prefabrication/modularization experience reduced project schedule with 35%. Prefabrication and Modularization can yield time-saving through the ability to conduct work simultaneously onsite and off-site. As the production of the prefabricated modules is done off-site, the assembly of the prefabricated modules will require less time compared to full on-site development. Also, it is important to note that this approach will result in less hindrance on-site. This is mainly and advantage for infrastructural projects, where the roads in the surrounding area need to keep functioning, or can only be blocked for a limited time-period. By using prefabricated modules, the building time can be increased significantly, and the new object can be used almost directly after assembly.

Impact on project budget

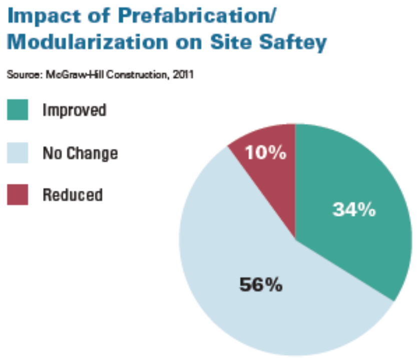
The profit margins within the construction industry are often very low. The result is that even a relatively small reduction in cost will have a significant impact on the profits of the construction firms. In literature, it has been argued that prefabricated modules are more expensive than the development of the construction on-site. Considering direct costs, this is true. However, when analysing the total costs of construction projects, the appliance of modularization and prefabrication result in lower total costs. In general, most savings are due to secondary issues. These secondary issues are for example reduced reliance on expensive onsite labour, ability to avoid overtime pay and other unexpected labour costs, and the ability to reduce onsite resources required. Additionally, traditional practices are mostly not delivered on time and within budget, due to change orders during the construction process. The report, therefore, states that: *Even when prefabrication appears to be slightly more expensive at the outset, the avoidance of unexpected costs during the process is valuable, especially for owners with inflexible budgets like those in the public sectors. This reliability increases in value when combined with the guaranteed, high-quality workmanship also offered by prefabrication/modularization* (McGraw-Hill Construction, 2011).



A—5 Impact of prefabrication/modularization on project budget, derived from McGraw-Hill Construction (2011)

Impact on site safety

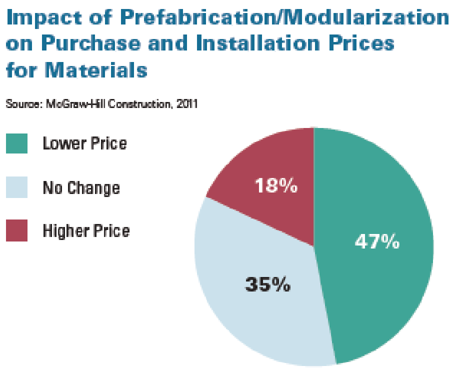
Within the conducted survey, one-third of the survey respondents (34%) find that they have seen site safety improve as a result of using prefabrication and modularization. However, also 10% of the respondents are of the opinion that safety decreased onsite. Their viewpoint is that prefabricated pieces are frequently large, and the approach to their installation needs to be carefully considered to avoid a negative impact on overall site safety.



A—6 Impact of prefabrication/modularization on site safety, derived from McGraw-Hill Construction (2011)

Impact on purchase and installation costs

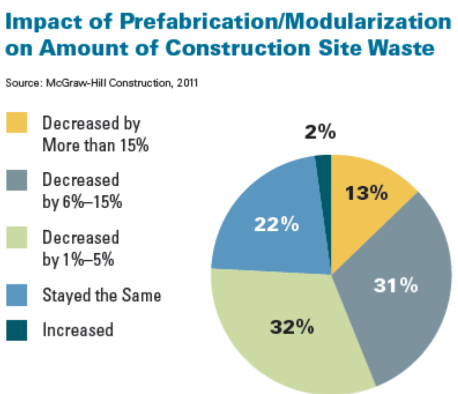
Considering the impact on purchase and installation costs, it has been found that 47% of the respondents who currently make use of prefabrication and modularization, the combined purchase price and installation cost for prefabricated components are lower than the regular purchase and installation of materials onsite. This outcome implies that making use of prefabricated modular components is less expensive than traditional development on-site. While the direct material cost of prefabricated modular components is greater, the total costs of materials and installation are reduced.



A—7 Impact of prefabrication/modularization on purchase and installation prices for materials, derived from McGraw-Hill Construction (2011)

Impact on construction waste

The result of the survey is that 76% of current users report that prefabrication/modularization decreases the amount of their construction site waste, with 41% reporting decreases of 5% or more. The report highlighted that not only are these gains for environmentally beneficial, but they also are financially beneficial, with less waste translating to cost savings and higher ROI.



A—8 Impact of prefabrication/modularization on amount of construction site waste, derived from McGraw-Hill Construction (2011)

A.4.6 **Article 6: Jameson - Is modularization right for your project?**

The article of Jameson (2007) starts with a critical view towards modularization. He states that following about modularization; *"In the right hands, it can be a very effective tool, decreasing costs and shortening schedules while minimising risk. In the wrong hands, it can add complexity and chaos".* In his article, he discusses the question that contractors can ask themselves: is modularization is right for your project? Although modularization has many benefits, the relative advantages compared to stick-built construction need to be considered. (Jameson, 2007)

The article of Jameson considers modularization within plant design and engineering, and the focus is mainly on the off-site production of modules versus a stick-build process on-site. Money is pointed out as the main driver to apply the concept of modularity. The potential value of modularization lies in:

- *Labour costs* - Differing in different circumstances, the cost of production off-site instead of on-site are considered to be lower. This is because they are more dependent on the circumstances on site and the weather. Moreover, facilitations for the workers need to be arranged. In addition, not at all locations, there will be sufficient labour rates, as plants are mostly developed in remote areas.
- *Productivity* - Due to the controlled environment of within the factory off-site, the productivity is higher in comparison to the on-site production as weather circumstances can have a great impact on the progress.
- *Equipment* - Jameson states that in contradiction of what is mostly assumed, modularization can allow for shorter durations of the need for large cranes and other equipment in the field. However, proper planning is essential.
- *Safety*- Shifting work into a controlled factory environment, generally benefits the overall safety risks of a project.
- *Reduction of peak workloads*
  In projects where limited local labour is available, producing large modules off-site can be very efficient. Here the workload can be shared on the different locations, on-site and off-site.
- *Schedule* - Production of modules can already start before the side is ready or the permitting that is needed have been given. Also, the assembly of the modules will demand less time than when the plant would be produced on site.

Although modularization can have significant benefits, still the trade-offs between modular ways of working or a traditional stick-built process need to be considered. Jameson states that for every project the suitability of a modular approach needs to be reviewed.

Within the article, it has to be highlighted that considering modularization for plant design has potential mainly due to limiting and difficult circumstances on-site and the fact that not always sufficient skilled labour is available in the nearby region. Off-site production of modules here is a good solution, as the modules can be fabricated in a controlled environment, resulting in higher quality, an increasing of safety for the builders and can have significant benefits for the schedule. As modules are prefabricated off-site, there will be less workload on-site, so less need for labour on-site and less facilitating infrastructure is required. Although this sounds very promising, it still needs to be pointed out that there are also limits. As the transport and shipping will put constraints on the size of the modules. Moreover, it can be argued if there will be sufficient heavy-lift equipment available. As pointed out by Jameson at the beginning of his article, the concept of modularization is not easy to apply. It can be an effective tool, but can also result in increasing complexity and chaos.

A.5 OPPORTUNITIES IDENTIFIED BASED ON REVIEW OF LITERATURE.

Opportunities						
Article	1	2	3	4	5	6
Time and Schedule						
Increasing efficiency in product development (shorter development time, by design by reference, design only once and reuse existing designs, parallel design and use of standardisation)		X	X	X	X	
Significantly increase the speed of a new product launch (Reducing time to market)				X		
Improve schedule performance: Less time for the construction phase is needed. Many sequences can be optimized and are well understood, and prefabricated modules are used.	X	X	X	X	X	X
Cost reduction						
Cost efficiency in the product development process (re-use of component design)	X	X	X	X	X	X
Less failure costs due to experience (repetition and learning-curve)			X	X	X	
Economies of scale can be obtained (Volume)				X	X	
Procurement discount from volume or early commitment			X			
Lower field costs (less facilities on-site needed)		X				X
Increased productivity						
More experience with the process and the product: increased efficiency		X	X	X	X	X
Increased working conditions (in factory and on-site)		X	X	X	X	X
Higher quality						
Higher product performance, constant process of optimization (iterative process, accumulated learning)	X		X	X	X	X
Increased safety						
Increased safety performance (within a factory and assembly on-site)	X	X	X	X	X	X
Reduce waste and less impact on the environment						
Reduce waste	X				X	
Efficient use of resources			X	X	X	X
Less impact and hindrance on the surrounding area	X				X	X
Less material storage on site necessary		X			X	X
Less permits needed						
Reduce site based permits	X				X	X
Common interface (platform) result in better cooperation and communication (within the companies and between companies)						
Long term relationship with fabrication shop and suppliers. By establishing more projects with another company, the cooperation will become better as they know the way the companies work.		X				
Better communication (due to one interface by usage of BIM) + Easier to explain		X	X		X	
Accumulated learning						
Improve learning curves, in all phases of the projects. (Design, fabrication, commissioning and start-up, planning and execution, operation and maintenance etc.)			X	X	X	
Efficient training program could be developed + and less training was required			X	X		
Opportunities related to the total life-cycle						
Advantages related to service and maintenance			X	X		
Higher flexibility in the assembly and advantages for service and maintaining the machines				X		
Improving effectiveness in communication and marker positioning: Strong brand identify				X		

Table A—6 Opportunities identified based on review of literature

A.6 Concerns and risks perceived based on review of literature

Concerns and risks perceived						
Article	1	2	3	4	5	6
Platform must be managed and updated						
Product platform has limited life-time		X	X	X		
Need to be managed and monitored	X	X		X	X	
Analysis of the future market (requires reliable forecast, need to understand the market needs for the coming years)		X	X	X		
New product development must be pursued on a continuous basis. (As long-term success and survival requires continuing innovation and renewal)				X		
High initial costs						
High initial costs for the platform development (Investment)	X	X	X	X	X	
High development time						
High development time for the initial implementation of a product platform	X	X		X	X	
Coordination Barriers:						
More coordination between disciplines needed		X			X	X
Currently lack of communication and collaboration (disciplines within organisation and different suppliers)	X				X	
New field, no proven strategy. There is limited research done on successful strategies to manage the risks and problems related to platform and product family development and implementation + firms are not familiar with the process.	X			X	X	
Different perspectives in the firm, on the development and use of the product platform. Problem may arise over different time frames, jargon, goals and assumptions, as platform development requires multifunctional groups.	X			X		
Engineer Design barrier						
Difficult to balance between commonality and distinctiveness.				X		
Development process becomes more complex		X		X	X	X
May result in over-design of low-end variants in a firm's product family to enable subsystem sharing with profitability.	X			X		
Restriction on the integration of new technologies. Creating barriers to architectural innovation.			X			
Increased transportation logistics requirements (Limits to the scale of the modules, due to transport and assembly on site.)	X	X			X	X
Less flexibility of design (early design is necessary, freezing design, rigidity)		X				
Additional concerns, uncertainties and barriers identified by companies						
Procurement barrier (functional specifications)	X					
Cultural shift is needed	X					
Sacrificed benefits from conventional customization			X		X	X
Increasing regulations (limited freedom, limited incentives for innovation)					X	
Architect does not apply the principles of standardisation and modularization in their design process.					X	
The clients does not want standardise/modularized structures. (they want unique structures)					X	
Owners and contractors capabilities For example: not sufficient work capital for the transportation and lifting requirements, and limited number of providers of prefabricated elements	X	X			X	X

Table A—7 Concerns and risks perceived bas on review of literature

A.7 CoPS VS MASS PRODUCTION

	CoPS project organizations	*Mass production industries*
Product characteristics	*Complex component interfaces*	*Simple interfaces*
	High unit cost	*Low unit cost*
	Product cycles last decades	*Short product life cycles*
	Many skill / knowledge inputs	*Fewer skill / knowledge inputs*
	Tailored components	*Standardised components*
	Upstream capital goods	*Downstream consumption goods*
	Hierarchical/systemic	*Simple architectures*
Production characteristics	*Project based*	*High volume, large batch*
	Systems integration	*Design for manufacture*
	Scale-intensive, mass production not relevant	*Incremental process, cost control central*
Innovation processes	*User-producer driven*	*Supplier driven*
	Highly flexible, craft based	*Formalized, codified*
	Innovation and diffusion collapsed	*Innovation and diffusion separate*
	Innovation paths agreed ex-ante among suppliers and users	*Innovation path mediated by market selection*
	People embodied knowhow	*Machinery embodied knowhow*
Competitive strategies and innovation coordination	*Focus on product design and development*	*Focus on economies of scale/cost minimization*
	Organic	*Mechanistic*
	Systems integration competencies	*Volume production competition*
	Management of multi-firm alliances in temporary projects	*Focus on single firm (lean production)*
Industrial coordination and evolution	*Elaborate networks*	*Large firm/supply chain structure*
	Project-based multi-firm alliances	*Single firm as mass producer*
	Temporary multi-firm alliances for innovation and production	*Alliances usually for R&D or asset exchange*
	Long term stability at integrator level	*Dominant design signals industry shakeout*
Market characteristics	*Duopolistic structure*	*Many buyers and sellers*
	Few large transactions	*Large numbers of transactions*
	Business to business	*Business to consumer*
	Administered markets	*Regular market mechanisms*
	Institutionalized/politicized	*Traded*
	Heavily regulated/controlled	*Minimal regulation*
	Negotiated prices	*Market prices*
	Partially contested	*Highly competitive*

Table A—8 Differences in characteristics of CoPS project organization versus mass production industries, derived from Hobday (1998)

A.8 CHARACTERISTICS OF CoPS – HOBDAY

The listed characteristics of CoPS that have been identified by Hobday, are derived from the report: Research challenges on complex product systems innovation (Ren & Yeo, 2007).

Elements	Characteristics CoPS
Unit cost/financial scale of project	The unit cost and financial scale of CoPS project is usually large. It has important financial contributions to both CoPS suppliers and customers.
Product volume	CoPS are produced in one-off projects or small batches. CoPS are never mass produced, product life cycles can extend over decades and decisions to invest may take months or years in pre-project study and planning.
Project life cycle concept	CoPS normally involve a series of phases including pre-production bidding, conceptual and detailed design, fabrication, assembly, delivery and installation, testing and commissioning, handing over, cost-production innovation/renovation, maintenance, servicing and sometimes, decommissioning. The project implementation is from conceptual design to product or system delivery.
Need for objective trade-off and optimization	Since CoPS may involve a large number of stakeholders and each stakeholder has different objectives and priorities, there is a need for trade-off among different objectives, such as cost, schedule, quality, safety, and so on.
Degree of technological novelty	CoPS usually involve a certain degree of technological novelty and innovation.
Product architectures	CoPS are made up of many customized, interconnected control units, sub-systems and components. As a result, the degree of system hierarchy is comparatively high, architectures are rather elaborate. This is demonstrated by a large Work Breakdown Structure (WBS) and Product Breakdown Structure (PBS). Furthermore, the interdependence of system components is high.
Degree of customization	CoPS designs are tailored for specific customer requirements. They involve a high degree of customization, either in the system level or components level.
Quantity of alternative component design paths	Within the architecture of CoPS, many alternative design routes for particular components may exist, and what appears to be incremental evolution at the systems performance level can mask substantial discontinuities at the component level. In CoPS, the problem of narrowing design choice can be daunting, especially under conditions of rapid technological change, unclear user requirements and multiple, customized components.
Feedback loops from later to earlier stages	There may be substantial feedback loops from later to earlier production stages which require alterations to overall system architectures or to the design of specific components.
Breadth of knowledge and skills	One dimension of CoPS complexity is the variety of distinct knowledge and skill bases which need to be integrated into the final product. In modern aircraft, for example, a wide variety of skills embracing new materials, software technologies, fluid mechanics and communication systems need to be mastered.
Degree of embedded software	While many CoPS are traditional industrial goods and systems, one relatively new factor is the degree of embedded software and IT now prevalent. as becoming a core element of CoPS, embedded software development has proved to be an uncertain, risk-intensive development activity.
High level of coordination effort	The production of CoPS is often beyond the technical and managerial span of control of a single firm, and collaboration is frequently a major part of the PM process.
High level of user involvement	The intensity of (lead) user involvement is high. Sometimes, a user is unclear precisely what need to be supplied. Or the user may make changes in requirements as the project unfolds.
Suppliers' involvement	The intensity of suppliers' involvement can further complicate coordination difficulties. The larger the number of firms involved in product definition, design, and manufacture, the more complex the coordination task.
Intensity of regulatory involvement	The intensity of regulatory involvement can shape the path of CoPS innovation. Regulations may be needed for safety purposes (e.g. as in aircraft and buildings), interfacing standards (e.g., as in telecommunications) and other reasons. In some industries, regulators take an intense interest in new products, approving design innovations, verifying production methods and adding new criteria to system validation and accreditation.

Table A—9 Characteristics of CoPS that identified by Hobday

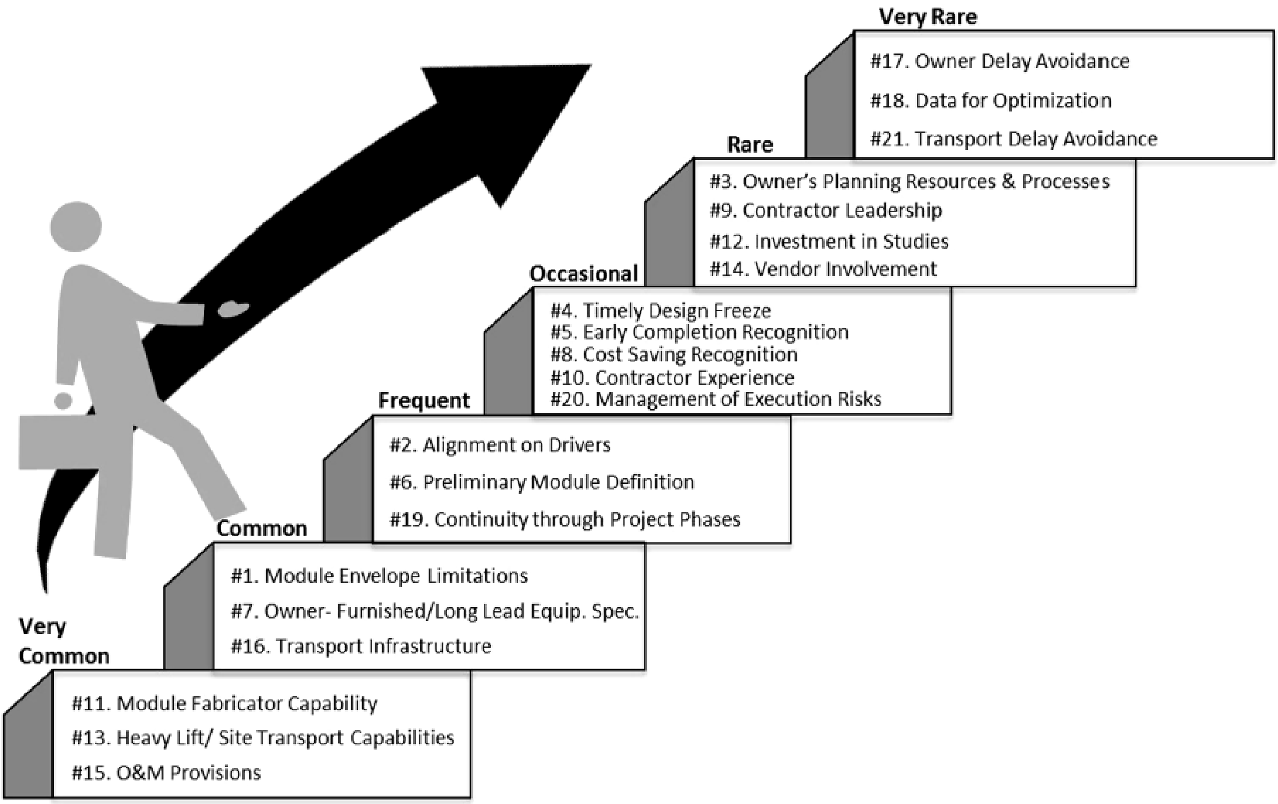
A.9 Critical success factors

Below the CSF are listed based on their impact score of the survey conducted by the Construction Industry Institute (O'Conner, O'Brien, & Choi, 2014)*.*

1. **Module envelope limitations** (Impact score 3.83):
   Preliminary transportation evaluation should result in understanding module envelope limitations.
2. **Alignment on drivers** (Impact score 3.79):
   Owner, consultants, and critical stakeholders should be aligned on important project drivers as early as possible in order to establish the foundation for a modular approach.
3. **Owner's planning resources and processes** (Impact factor 3.58):
   As a potentially viable option to conventional stick building, early modular feasibility analysis is supported by owner's front-end planning and decision support systems, work processes, and team resources support. Owner "comfort zones" are not limited to the stick-built approach.
4. **Timely Design Freeze** (Impact score: 3.58):
   Owner & Contractor are disciplined enough to effectively implement timely staged design freezes so that modularization can proceed as planned.
5. **Completion recognition** (Impact score: 3.42):
   Modularization business case should recognize and incorporate the economic benefits from early project completion that result from modularization, and those resulting from minimal site presence and reduction of risk of schedule overrun.
6. **Preliminary module definition** (impact score: 3.42):
   Front-end planners and designers need to know how to effectively define scope of modules in a timely fashion.
7. **Owners-furnished/ long lead equipment specifications** (impact score 3.42):
   Owner-furnished and long-lead equipment (OFE) specification and delivery lead time should support a Modular approach.
8. **Cost savings recognition** (Impact score: 3.42):
   Modularization business case should incorporate all cost savings that can accrue from the modular approach. Project teams should avoid the knee-jerk misperception that modularization always has a net cost increase.
9. **Contractor leadership** (Impact score: 3.39):
   Front-end Contractor(s) should be proactive - supporting the Modular approach on a timely basis and prompting Owner support, when owner has yet to initiate.
10. **Contractor experience** (Impact score: 3.37):
    Contractors (supporting all phases) have sufficient previous project experience with the modular approach.
11. **Module fabricator capability** (Impact score: 3.37):
    Available, well-equipped Module-Fabricators have adequate craft, skilled in high-quality/tight-tolerance Modular fabrication.
12. **Investment in studies** (Impact score: 3.32):
    Owner should be willing to invest in early studies into Modularization opportunities in order to capture full benefit.
13. **Heavy lift/site transport capabilities** (Impact score: 3.32):
    Needed heavy lift/site transport equipment and associated planning/execution skills are available and cost-competitive.
14. **Vendor involvement** (Impact score: 3.28):
    OEMs and technology partners need to be integrated into the modularized solution process in order to maximize related beneficial opportunities.
15. **O&M provisions** (Impact score: 3.26):
    Module detailed designs should incorporate and maintain established O&M space/access needs.
16. **Transport Infrastructure** (Impact score: 3.22):
    Needed local transport infrastructure is available or can be upgraded/modified in a timely fashion while remaining cost-competitive.
17. **Owner delay avoidance** (Impact score: 3.16):
    Owner has sufficient resources and discipline to be able to avoid delays in commitments on commercial contracts, technical scope, and finance matters.
18. **Data for optimization** (Impact score 3.05):
    Owner and Pre-FEED/FEED contractor(s) need to have management tools/data to determine the optimal extent of modularization, i.e., maximum NPV (that considers early revenue streams) vs. %Modularization (the portion of original site-based work hours)
19. **Continuity through project phases** (Impact score: 3.00):
    Disconnects should be avoided in any contractual transition between Assessment, Selection, Basic Design, or Detailed Design phases; their impacts can be amplified with Modularization.

20. Management of execution risks (Impact score: 3.00):
    Project risk managers need to be prepared to deal with any risks shifted from the field to engineering/procurement functions.
21. Transport delay avoidance (Impact score: 3.00):
    Environmental factors such as hurricanes, frozen seas, or lack of permafrost, in conjunction with fabrication shop schedules, do not result in any significant project delay.

In the illustration below, figure A-9, the frequency and impact of the 21 CSF are shown. (O'Conner, O'Brien, & Choi, 2014)



A—9 CSF frequency and impact, derived from O'Conner et al (2014)

A.10 COMPLEXITY IN CONSTRUCTION PROJECTS

Hofer and Halman (2005), argue that for many firms it is a challenge to manage the complexity of offering greater product variety (Hofer & Halman, 2005). However, the complexity of the construction industry keeps increasing (Jensen, Olofsson, Smiding, & Gerth, 2014) (Gibb, 2001). In reaction to cope with this increased complexity and increasing demands, firms in many industries are considering platform based development.

As the implementation of a product platform is used to handle the complexity that occurs, it is important to know what the actual meaning/interpretation of this complexity is. In the Cambridge dictionary, the degree of complexity is considered to be concerned with the amount of differing but interrelated parts. (Cambridge dictionary online, 2016). This implies that a project's complexity is defined by differentiation and interdependencies.

Gidado (1996) has done several interviews with experts that are working in the construction industry. The interviewees see a complex project as:

- Having a large number of different systems that need to be put together and/or that with a large number of interfaces between elements (this means there are many interdependencies between elements).
- When a project involves construction work on a confined site with access difficulty and requiring many trades to work in close proximity at the same time.
- Projects with a great deal of intricacy which is difficult to specify clearly how to achieve a desired goal or how long it would take.
- Projects that require a lot of detail about how it should be executed.
- Projects that require efficient coordinating, control and monitoring from the start to the finish.
- Projects that requires a logical link because a complex project usually encounters a series of revisions during construction and without interrelationships between activities it becomes very difficult to successfully update the program in the most efficient way. (Gidado, 1996)

Gidado (1996) identified that project complexity revolves around six main components, each made up of some intersecting factors and are listed below, and are listed on the ranking of the perceived complexity (Gidado, 1996):

- Organizational complexity
- Uncertainty
- Inherent complexity
- Overlap of construction elements
- Rigidity of sequence
- Number of trades

Wood and Gadibo (2006) suggest that there seem to be two perspectives of product complexity in the construction industry: the managerial perspective, this involves the planning of bringing together numerous parts of work to form workflow, and the operative and technological perspective, this involves the technical intricacies or difficulties of executing a complex production process (Wood & Gadibo, 2006).

In the article "project complexity in construction" of Wood and Gidabo (2007), a consensus has been made that although technical aspects of a project can greatly add to the complexity, it is, in fact, the organisational aspects which contribute more to the complexity of the project. While technical complexity is a definite factor in project complexity, it was felt that this was much easier to deal with than complex relationships and organisations. They identified that poor communication and poor use of information were seen as a significant factor contributing to the complexity of a project. Wood and Gidabo (2007), argue that project in the construction industry are very complex. A lot of different factors contribute to making a project complex. These factors can be manageable. However, it is when a combination of these factors are encountered that the project is perceived as complex. "Simply having a project that has a high degree of overlap between design and construction can be complex but manageable, however, when this is coupled with poor channels of communication and high interdependencies between roles the project becomes much more complex." (Wood & Gidabo, 2007)

From the survey and interviews conducted with experts in different fields of the construction industry, three main 'concerns' were identified.

- Firstly, the experts highlighted that it was important to understand the stakeholders' position in the project. Due to the different interest of different stakeholders, this has a great impact on the complexity of a project.
- Secondly, it was emphasised by industry experts that the need to have a clear and well-defined project brief and to understand the client's needs. They considered that it is important that the client has a clear idea of what they want, and need to communicate this to all parties that are involved in the project.

- Thirdly, it was identified that there is distinguish between managing projects and programs which include a number of projects, this has an obvious impact on the complexity. The complexity of the project, considering all different projects and programs, are much bigger. This because of the interaction between each of the projects. In addition, a relative conclusion of the research conducted by Wood and Gidabo (2007), is that the complexity needs to be identified at the earliest stage possible to be able to manage it appropriately. Identifying where the complexity lies in a project is identified as a critical factor to project success. (Wood & Gidabo, 2007)

Parnas (Parnas, 1972) argues that appliance of modularity in the construction industry, can be an effective approach to cope with the complexity; "Modular design structures are advocated as particularly useful when systems become so large and interdependencies between elements of the system so numerous that integrated design efforts become almost impossible" (Parnas, 1972). This implies that modular designs are a useful means of managing complexity.

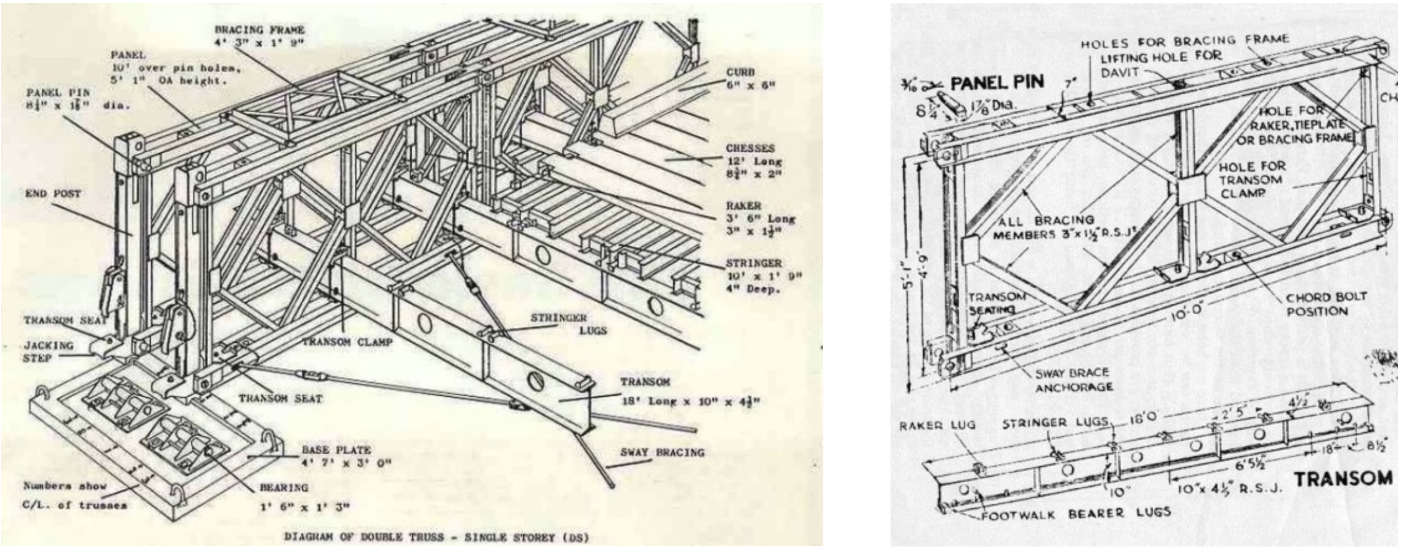
A.11 Application of the principles of standardisation and modularization in complex systems

Bailey bridge

The Bailey bridge is a modular structure. It is a pre-engineered solution with standard interchangeable components. The Bailey bridge was developed by the British Army during World War ll.

There were five basic considerations that were important for the design:

1. *Flexibility* – The Bailey bridge had to be a solution for any situation. Therefore flexibility in design was required. Flexibility was built in with the ability to create variable length spans, floating configurations and be able to be strengthened in-situ if needed.
2. *Materials* - All parts were made from readily available materials, in this case steel.
3. *Interoperability (exchangeable)* - All parts were manufactured by standard engineering practices and companies which precluded extremely fine tolerances, the tolerance and consistency must be sufficient to enable interoperability. Interoperability means that the different components of the bridge from different suppliers should be combined without any problems occurring or adaptations needed to be made.
4. *Transportation* - All parts were designed within certain dimensions, this for easy transportation. Parts could not be larger than the size possible for transport, could not weight more than 600 pounds, and the components needed to fit in a regular truck.
5. *Simple to construct* – The Bailey bridge should relatively simple to construct. The idea is that everybody should be able to construct the bridge out of the modular parts, also if you do not have engineering experience. A clear guidebook was provided, that described which bridge was suitable for the specific situation and provided guidelines for constructing the bridge step-by-step. For the assembly of the different components, no heavy lifting machines were needed. The bridge was constructed by launching and jacking down the connected components (modules).



A—10 Bailey bridge - possible combination that can be made

The main advantages of the Bailey bridge perceive in literature are due to;
a*) Speed of construction* – All elements of the bridge are prefabricated and even stocked. This way the actual construction on-site is more an assembly process. The bridge can be constructed in a limited amount of time.
b) *Safety* – The bridge is made out of components that are easy to handle for the construction workers. Moreover, the Bailey bridge has proven to be a very robust bridge.
c) *Modular structure* – Because the bridge is modular, a lot of different variations can be made with the same components. The concept is very flexible, the components are interchangeable and can be combined in different ways. The modularity of the construction also means that the construction can be assembled relatively fast, but it is also possible to adapt the structure in later phases. The structure can be demounted, and the different components can be reused. The connections between components are mainly bolts and nuts.
d) *Interchangeability* – the different components are interchangeable.
e) Maintenance - Damaged parts can be easily and quickly replaced.

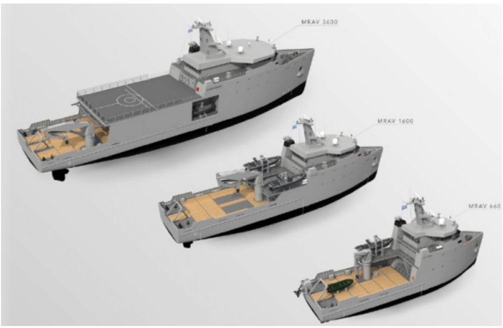
Shipyard Damen

The shipyard Damen applies the principles of mass customization already for a long time. As this has been beneficial, they currently still apply the principles of standardisation and modularization within their new vessel development. Based on its unique, standardised ship-design concept Damen can guarantee consistent quality. Damen's focus on standardisation, modular construction and keeping vessels in stock leads to short delivery times, low 'total cost of ownership', high resale values and reliable performance. Furthermore, Damen vessels are based on thorough R&D and proven technology.

A modular platform contributes to the success of the shipyard. Shipyard Damen explain within their brochures their vision and approach*: A modular platform is inherently flexible: this allows naval clients to better react to changes in the mission environment. Modularity also has implications on the cost of ownership; the lifetime of an individual vessel can be efficiently extended by upgrading capabilities with new equipment modules that are not integrated into the original design. The MRAV range is commercially built and also uses commercially available components. This is made possible because of the vessel's non-combatant role. Using robust commercial off-the-shelf equipment reduces the total cost of ownership without reducing the quality.* (Damen, 2016)

Their main points for their new vessels (family of vessels) are
a) Effective and efficient
b) Smooth role change through plug and play mission modules
c) OPS room offers centralised mission control and situational awareness
d) Potential for dual use by military and civilian operators.

One of Damen's key aims with this new range of vessels is to reduce the pressure on a navy's human and financial resources. The modularity of the mission modules plays a major part in the process. This is achieved by combining the capabilities of specialised ships in one ship by using add-on equipment modules. These can be fitted inside standard 10, 20 or 40-foot containers or have the footprint of a container. In figure A-11 an overview of the new family has been given. The vessels mainly build by combining the same components, the principles of standardisation and modularization are applied.



A—11 Product platform Damen MRAV - Modular

A.12 Projects where a form of standardisation and/or modularization has been applied

A.12.1 Projects where a form of standardisation and/or modularization has been applied: N33

N33			
Component of viaduct	*Standardised and/or modularized.*	*Realisation by in-situ or prefabricated elements.*	*Explanation*
Foundation			
Foundation pad (sloof)	-	*In-situ*	The foundation pad is constructed on site by pouring concrete. The dimensions of the foundation pad depend on the condition of the ground and the length of the span. In the N33 no standardised dimensions for the foundation pad have been applied.
Foundation piles	-	*Prefabricated*	Prefabricated foundation piles were applied, but the dimensions of the piles were not standardised over different structures. For every structure the suitable dimensions of the foundation piles were applied, the repetition was not specifically considered.
Substructure			
Intermediate wall/column (s)	-	*Prefabricated*	The intermediate column(s) are prefabricated. On-site the capping beams and the connection with the deck have been made by an in-situ process.
Abutment or bank seat (including foundation pad)	-	*In-situ*	Constructing an abutment or bankseat by an in-situ process is currently the main practices in the Netherlands.
Capping beam	-	*Prefabricated*	
Wing walls	*X*	*Prefabricated*	Standard dam walls (sheet piles) are applied
Superstructure – Core			
Deck	*X*	*Prefabricated*	One type of deck was chosen: inverse T-beams. No standardised dimensions have been applied. The beams with different lengths and dimensions were ordered at the supplier.
Edge beams	*X*	*Prefabricated*	For the edge beams one type was chosen. No standardise dimensions have been applied. The edge beams with different lengths and dimensions were ordered at the supplier.
Superstructure - Extensions			
Pavement: Asphalt	-	*In-situ*	The asphalt that is suitable for a specific road on a viaduct depends on the type of deck and the amount and load of traffic that is considered to cross over this viaduct. However, during the design phase, the asphalt is not a limiting factor. The choice for asphalt is taken in the last phase of the design and is mostly dependent on the planning of the project.
Edge element (finishing)	*X*	*Prefabricated*	The edge elements and the parapets are standardised. The client found it important that the entire highway had the same aesthetical appearance. See figure 3-29.
Parapets (pedestrian and traffic.	*X*	*Prefabricated*	The same as the edge elements.
Upstand (schampkan t)	-	*In-situ*	Upstand is basis always the same. However, within the N33 these have been designed for each viaduct individually. An upstand is a relatively simple component, therefore is possible that some of the upstands have the same design and dimensions. However, this was not specifically considered by the project team.
Safety guards (guard rail)	*X*	*Prefabricated*	Has to meet the requirements of RWS. The standard detail of RWS is applied.
Bearings, expansion joints and approach slab.			
Bearings	-	*Prefabricated*	Which type of bearings is suitable to be applied and the dimensions of these bearings, mainly dependent on the dimensions of the abutment/bank seat and the dimensions, type and weight of the beams for the deck applied. Because these were different for the various viaducts, no standardised bearing has been applied.
Expansion joints	*X*	*In-situ*	The expansion joints are constructed on-site. Different types and shapes that are prescribed and provided by RWS are applied.
Connection between	-	*In-situ*	

Approach slab	*X*	*Prefabricated*	One type of approach slab for all the different structures is applied. However, the dimensions and the amount of reinforcement rebar are considered for every viaduct individually.

A.12.2 Projects where a form of standardisation and/or modularization has been applied: A12

A12			
Component of viaduct	Some form of standardisation applied	Realisation by in-situ or prefabricated elements.	Explanation
Foundation			
Foundation pad (sloof)	*X* *Standardised*	*In-situ* *Mostly in- situ, but some (3) viaducts have prefabricated concrete pads*	In general, the foundation pads are made by an in-situ process. The width of the pad is the same for every pad, as this depends on the profile of the road. The length is not standard, this is different for every structure. It depends on dimensions of the viaduct and the specific locational circumstances. However, one type of mould is applied, as it is possible to scale the mould. A foundation pad is a relatively simple component to make. Within the project, it was important/ demanded by the client to maximise the availability of highway lanes during construction and limit the overall hindrance for the surrounding area. There were also incentives to finish the road earlier than required. To decrease the construction time of the total project, within three viaducts prefabricated pads have been applied. BAM Infra had no experience with prefabricated pads, and some problems occurred. During the design phase, the constraints in weight and dimensions for transportation of the elements were not considered. The pads were very heavy (expensive transport) and cast in rebar was not completely adapted to maximal dimensions for transport. The design had to be split into two parts. The pads needed to be constructed out of two prefabricated components to make transportation possible. The foundation sheet piles were prefabricated in two parts. The two prefabricated parts were transported to a yard nearby the construction site. At the yard, the two prefabricated parts were combined. A short prefabricated connection piece was applied to combine the two prefabricated parts. The connection between sheet pile and the pad was thus precast. After piling the other halves of the sheets, the whole precast foundation pads were transported to the construction site and installed on top of the sheet piles. Both parts of the sheet pile were welded together using a thick connecting steel plate to cope with tolerances. To make the structure stiff, the steel connections were poured with concrete. Constructing this connection is complex, and requires more attention than when the foundation pad is constructed by an in-situ process. The “natte knoop” is a weak point in the structure, this weak point is not present when the foundation pad is made by an in-situ process on site. By applying precast foundation pads for three viaducts, the total construction time was decreased with several weeks. However, this technical solution was very expensive. This investment in fast construction method (expensive construction) has eventually paid off due to substantial financial reward on the availability of the whole 30 km of the A12 highway within this specific contract.
Foundation piles	*X* *Standardised and Modularized (connection to pads)*	*Prefabricated*	In the project mainly prefabricated piles have been applied, mostly prefabricated piles that were rammed into the ground. However, for a small amount of structure, prefabricated piles that are screwed into the ground have been applied when building vibration-free or minimal hindrance was required. To save time the connection from the foundation piles to the foundation pads were all realised in the same way. Some form of modularization has been applied. The pile ends were not crushed, but their surface was only roughened. However, this was not suitable for all construction types and depends on the load. However, where it was feasible, this method is applied. The advantage of this method is that it saves time compared to fully dismantling the pile ends.
Substructure			
Intermediate wall/column(s)	-	*In - situ*	The choice between in-situ and prefabrication of an intermediate wall/column(s) is mainly based on: hindrance, time (vehicle lost hours and finishing of the project), and the amount of space available. Considering all these three categories, making use of prefabricated elements could be more attractive, but this is also more expensive. For the A12 the columns were made in-situ on site. The columns had a relatively simple shape (round). Therefore an in-situ process could be applied. For the columns, rebar (reinforced steel) cages were prefabricated and transported to the site. There the rebar cages were connected to the rebar of the foundation pad and foundation piles and the moulds placed around the cages. Hereafter, the moulds were poured with concrete. When the concrete was hardened, the moulds were taken away.
Abutment or bank seat	-	*In-situ*	The abutments or bank seats of the A12 were made by an in-situ process on site. The viaducts of the A12 are mainly integrated viaducts. No joints are present, and the

(including foundation pad)			connection between the components are made by pouring concrete. This is a special type of concrete that is more flexible than general concrete. The abutment of bank seat is cast together with the deck. This is a relative expensive connection (fast hardening mortar/glue is required), and precise casting is required for the fitting of components. The connections were all based on the same basic principles.
Capping beam	-	*In- situ*	The capping beams of the A12 could not be prefabricated, because of their shape and dimensions. The elements would become too long for transport and would become difficult to handle. Because the elements could not be prefabricated in one part, it became less interesting to apply a form of standardisation. If the capping beam would be constructed out of three prefabricated parts that had to be connected together on site, this would still require the casting of concrete to make the beam one stiff whole. In general, connecting prefabricated parts by casting/pouring of concrete (in Dutch: natte knoop) are more expensive, compared to construction by an in-situ process. Although the components are prefabricated, they still significantly amount of time is needed to combine the components by pouring concrete. Also, the components need to be dimensioned bigger and more reinforcement steel is required
Wing walls	-	*In-situ*	The function of the wing walls is to turn the ground. The amount of ground, and thereby the forces on the wing walls are different for all the viaducts. However, the differences that occurred were not significantly. For the wing walls, one type of mould could be applied that could be adapted/scaled to the specific situation. The wing walls all had different dimensions, but the design was the same. When this would be constructed out of prefabricated parts, it would have been possible to apply one type of wing wall, with around 4 or 5 different dimensions. However, within the A12 it was decided to construct the wing walls by an in-situ process.
Superstructure – Core			
Deck	*X* *Type was standardised*	*Prefabricated*	In this project the supplier Spanbeton was already involved at the beginning of the project, considering the design of the deck. Together with Spanbeton Bam Infra investigated some possible innovations to serve construction of the viaduct in more than one construction phase. A special type of deck beam was developed (“OQ”). This beam required no perpendicular post-tensioning. The connection between two decks was made only by application of concrete, instead of quite expensive and difficult post-tensioning couplings of regular type of beams (box beams). This innovation is only interesting when construction is divided in more than one phase. This is the case when a viaduct will be adapted, expanded or a totally new viaduct has to be realised, but the road cannot be shut down. Because of this innovation, one part of the viaduct can keep functioning, while the construction team are building or deconstructing the other part of the viaduct.
Edge beams	*X* *Type was standardised*	*Prefabricated*	The edge beams were all conformed to one basic design and could be easily connected to the deck. The span of the deck was the same in many cases, or the span of the deck was relatively similar. The edge beam needed to be scaled to the specific structure, but for the structures that were comparable, standard dimensions could be applied.
Superstructure - Extensions			
Pavement: Asphalt	-	*In-situ*	The asphalt that is suitable for a specific road on a viaduct depends on the type of deck and the amount and load of traffic that is considered to cross over this viaduct. However, during the design phase, the asphalt is not a limiting factor. The choice for asphalt is taken in the last phase of the design and is mostly dependent on the planning of the project.
Edge element (finishing)	*X* *Both standardised and modularized as much as possible*	*Prefabricated*	The edge elements(finishing) of the A12 is a concrete structure with prefabricated plates connected to this structure. The prefabricated plates have the appearance of brickwork. After the design was finished, the length and height of edge element were determined to maximise the number of standard elements for all viaducts with the same design for the edges. The architect, the project leader and other members of the project team together have analysed how one standard dimension that would be applicable for all structures could be established. Eventually, only 20 different dimensions of the edge elements were needed, before there were approximately 400 different dimensions required.
Parapets (pedestrian and traffic)	*X* *See edge element: Both standardised and modularized as much as possible*	*Prefabricated*	The parapets are combined with the edge element (finishing). The edge element also has the function of a parapet (See figure 3-31 and 3-32).

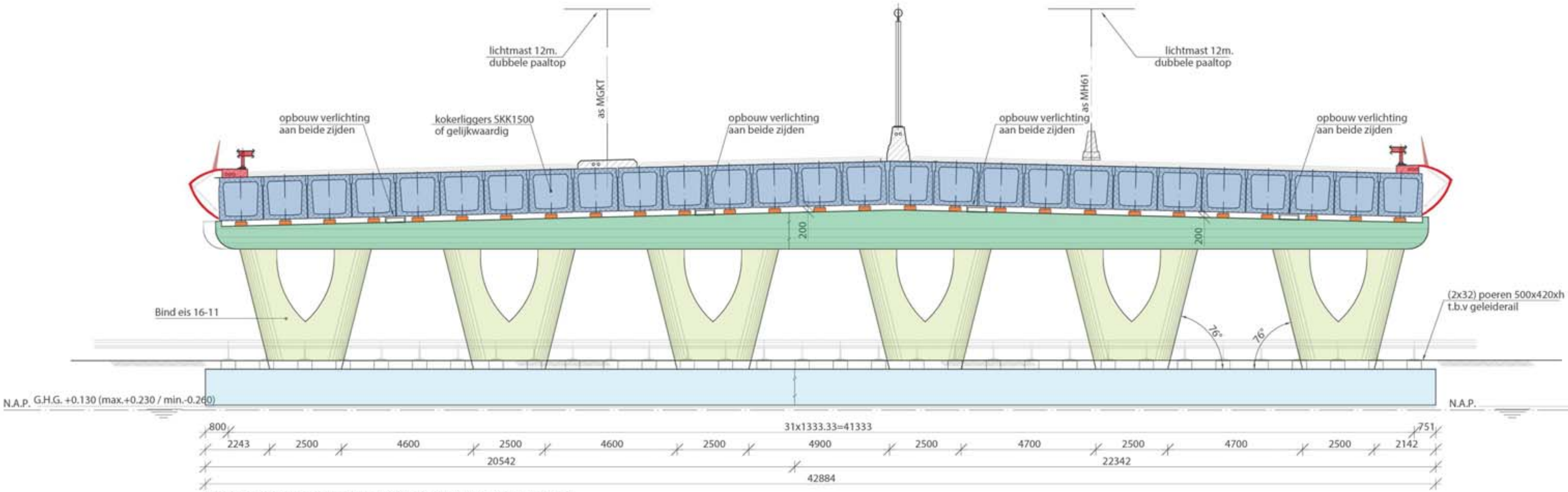
Upstand (schampkant)	*X* *Standard type and dimension ranges*	*In-situ*	Within the project of the A12, the upstand is made by an in-situ process and by this connected to the beams or edge beam of the deck. The cheapest solution is applied. Constructing the upstand by the connection of prefabricated components is considered to have no added value. The upstands need to have a very long length. However, this length cannot be transported. In addition, when the upstand would be made out of different parts the connection with the deck and between the different upstand still need to be cast by concrete. The casting of concrete needed and the fact that the structure still needs to hardened, eventually will not be significantly faster, compared to the application of the in-situ process. In addition, application of prefabricated parts is likely to be more expensive. Although no prefabrication was applied, the design (dimensions) is standardised in different dimension ranges.
Safety guards (guard rail)	*X* *Standardised*	*In-situ (concrete) Moreover, prefabricated standard design (RVS).*	On the viaducts of the A12, the general design for a safety guard that meet the requirements of RWS is applied only limited. The general design could only be applied when sufficient space was available. When there was not sufficient space on the viaduct, the standard solutions was not suitable. To make it possible to apply the general solution, the width of the viaduct has to be increased. However, this had a significant effect on the total project. The adaptation that had to be made would be very expensive, and not in all situations sufficient space was available to apply these changes. A special solution is designed for this specific situation. The function of blocking the vehicles, in this case, is realised by a barrier. This barrier is constructed by an in-situ process on site. Within the edge beams, steel cables were incorporated for the connection of the barrier. The barrier is constructed/placed against the edge element (finishing) and is situated on the edge beam. Against the edge element and on the edge beam a mould is placed around the steel pipes, and the mould is poured with concrete, this forms a rigid connection. For this specific solution, the shape and its dimensions were standardised. As explained, the concrete safety guards (barriers) were cast using edge element as back-end formwork. Length and type of front-end formwork were standardised to match the length of edge element. Prefabrication has been considered, but from a design point of view appeared to be no option, because of the high anchoring loads of the safety guards to the deck. A safety guard on a viaduct has to be able to handle the forces of the vehicles, without breaking or moving. No deformation or movement is accepted. Because a deformation or movement can have a significant amount of impact on the edge element connected to it. The element needs to stay in place. If deformation or movement occurs, this means that there is a big chance that the edge element will fall down on the underlying road. This in contradiction to safety guards on roads, these safety guards are designed with the idea that the safety guards or barriers have to move with the forces of the vehicle.
Bearings, expansion joints and approach slab.			
Bearings	-	-	No bearings are needed for an integral viaduct.
Expansion joints	-	-	Most viaducts within the A12 are integral viaducts, and therefore do not have expansion joints. Integral viaducts are applied to optimise the maintenance cycle (decrease costs). An integral viaduct requires a special approach slab and grid rebar in asphalt. Furthermore, deck and foundation of this type of viaduct are cast together to cope with expansion. The dynamic loads are led into the abutments and foundation. The result is that more rebar (reinforcement steel)in all the different elements needs to be applied. Moreover, the thickness of foundation sheet piles needs to be increased. This results in an increase of the initial costs, but this should lead to lower maintenance costs, and by this lower life cycle costs of the structure. As discussed before, the project of the A12 has a DBFM contract. This means that BAM Infra is also responsible for the maintenance. Therefore, BAM Infra has made a choice to apply integrated viaducts. The initial costs were higher, but this will be earned back by low maintenance costs in the first twenty years.
Connection between	*X* *Standardised: detail RWS*	*In-situ*	The connection between is realised by the pouring of concrete in the open hole. This is based on a detail provided by RWS and is the same in all projects.
Approach slab	*X* *Type was standardised, and a standard dimension is applied.*	*In-situ*	A specific type of slab that is suitable for an integral viaduct is applied. This type of approach slab (one piece, connected to abutment/deck with steel cables) has standard dimensions. The design was standardised for all the approach slabs within the project. However, the number of reinforcement cables still varied. Application of a prefabricated approach slab has been investigated. However, it was not the best option. The prefab pieces would still have to be cast together because the slab eventually has to be one solid piece. This is a time-consuming process, and more rebar will need to be applied to the components compared to when an approach slab is made by an in-situ process on site. In addition, the steel connection required would probably be more expensive.

A.12.3 Projects where a form of standardisation and/or modularization has been applied: N261

N261			
Component of viaduct	Some form of standardisation applied	Realisation by in-situ or prefabricated elements.	Explanation
Foundation			
Foundation pad (sloof)	*X*	*In-situ*	The foundation pads have been standardised. All the foundation pads are of the same dimensions. The foundation pads are constructed by an in-situ process at the construction site. Only one mould was needed. The same mould could be used for all foundation pads that needed to be constructed. In addition, because the foundation pads all had the same dimensions, this gave uniformity to the total design. An in-situ process was chosen because a foundation pad is a relatively simple component to compose and is robust. The process is relatively low in costs. Moreover, the chance of failure is relatively low because it is an already established method where BAM Infra has much experience with. Because the N261 was an entirely new road, the moulds did not cause hinder for the traffic.
Foundation piles	*X*	*Prefabricated*	For the foundation piles, prefabricated piles that are "heien" are applied. This is the most common and cheapest method to apply. On places where it was required to build vibration free (trillingsvrij), for example near gas pipelines or very close to houses where the building method could cause nuisance, prefabricated piles were applied, but here they were drilled into the ground. All piles have the same dimensions: 400x 400.
Substructure			
Intermediate wall/column (s)	*X*	*Prefabricated*	Within the project of the N261, a standard column has been designed. The project team has chosen to apply prefabricated concrete columns. The main reason for this was that the new road needed to be constructed between two other roads. The client demanded that these roads should not be affected by the building process, only limited hindrance for the road (lost vehicle hours) and the surrounding area was permitted. The columns have been prefabricated. This was mainly chosen because the prefabrication the columns could be realised relatively fast, compared to constructing the columns by an in-situ process on site. The prefabricated columns could be put in place during the night. During the night only a small part (one or two lanes) needed to be close. The road still was open for traffic and during the day no hindrance occurred for the road-users. During the design phase of the N261, the project team was a challenge to develop a design that could be realised within a small budget. The price with BAM Infra had won the contract was not realistic if the conventional method was applied. To be able to deliver the project for the procured price, a new innovative approach was needed. The total design of the project of the N261 has been designed with the idea in mind to benefit of possible repetition. Within the project, the columns of a viaduct all are the same in design and dimension. A V-shaped column was developed, that also could be turned around for an A-shaped column. For the project 34 V-shaped columns and 16 A-shaped columns have been prefabricated. To fabricate these columns, only two different moulds were needed. Almost in all structures of the N261 these V and A-shaped columns have been applied. The project team even developed a solution about how the standard dimensions could be applicable for all structures when a small slope (for drainage) had to be realised. Small concrete box structures were constructed to change the height of the total intermediate column structure, while the height of the standard columns could remain the same. However, for one structure it was not possible to be constructed out of the standardised column shape. A new design has been developed. Within this design again a standard was applied. The shape and dimensions of the three columns for this structure have been standardised. Because the columns were standardised, the three columns could be constructed by the application of one mould. Therefore, for the entire project, only three different moulds for the columns were needed.
Abutment or bank seat (including foundation pad)	*X*	*In-situ*	The abutments have been made uniform by standardisation of the dimensions and the location and way the reinforcement steel has been applied. The abutments have been constructed by an in-situ process on site. The in-situ process was suitable because an abutment is a relatively simple object to construct, it is a relatively cheap method and BAM already has plenty experience with this process.

			In addition, because the abutments were constructed for a new road that was in between two roads, applying moulds that need to support the structure until the concrete is hardened will not lead to hindrance.
Capping beam	*X*	*Prefabricated*	The choice to prefabricate the capping beam is based on the general vision and the circumstances within the project had to be realised. The road had to be developed between two roads, and the new road should be constructed within a limited time frame. In addition, the shape of the designed capping beams was complex (curved) and could not be made by an in-situ process. The complex shape of the capping beam could be realised by application of prefabrication. For the ten structures that needed to be realised, 31 capping beam have been prefabricated. The capping beams we are the same, they were standardised and therefore only one mould was needed. The steel mould could be used multiple times.
Wing walls	*X*	*In-situ*	The design of the wing walls has been standardised. The same shape has been applied for all the different structures. However, some variations in the dimensions occurred. This because all structures had different dimensions and different angels of crossing, making use of only one specific dimension was not possible. Prefabrication of the wing walls was mainly considered from the perspective that this would result in a decrease of the building time. Secondly, the locations where the wing walls had to be constructed were relatively complex locations to apply an in-situ process. Moreover, thirdly, it would not be possible or would become very difficult to construct the designed shape by the application of an in-situ process. However, the demanded shape of the wing walls could be realised by prefabrication. For the wing walls standardisation has been applied. Two standard types have been developed. The design is optimised and provides one uniform aesthetic appearance.
Superstructure – Core			
Deck	*X*	*Prefabricated*	Two types of decks have been applied. A deck constructed out of inverted T-beams and a deck constructed out of box beams. The project team selected the beams out of catalogues of suppliers of prefabricated concrete elements. Here the beams have already been standardised considering their dimensions. The span here is the most important factor.
Edge beams	-	-	No edge beams are applied. The edge elements were connected to the last normal beam of the deck.
Superstructure - Extensions			
Pavement: Asphalt	*X*	*In-situ*	One general asphalt layer has been applied for the N261
Edge element (finishing)	*X*	*Prefabricated*	The edge elements have been standardised. One standard has been designed that could be applied to all the different structures. This gives uniformity in the design, which was demanded by the client and the architect. The edge elements were all prefabricated with the same dimensions. The elements could be adapted to the different heights of the deck. The prefabricated elements could be accustomed to the specific height of the deck by changing the angle of the connection mechanism (scharnierend).
Parapets *(pedestrian and traffic)*	*X*	*Prefabricated*	The parapets have been standardised in their design and dimensions. They were connected to the edge elements.
Upstand *(schampkant)*	*X*	*In-situ*	For the upstand, standardised details have been applied. These details were based on the standard details provided by RWS. The upstands are constructed by an in-situ process. An in-situ process has been chosen, because it is a robust element and not highly complex. Therefore prefabrication will not be beneficial
Safety guards *(guard rail)*	*X*	*Prefabricated*	A safety guard is demanded by the RWS. Here the standard details of RWS for standard concrete bridge construction are applied.
Bearings, expansion joints and approach slab.			
Bearings	*X*	*Prefabricated*	For the viaducts that have been standardised, bearings of the same type with standard dimensions have been applied.
Expansion joints	*X*	*Combination of prefabrication and in-situ*	RWS provides standard details for expansion joint. Within the project of the N261, these standard details were applied for the design of the expansion joints. The road of the N261 all were of the same type (provincial roads), have to deal with the same forces and the same regulations. One type of expansion joint, therefore, could be applied to all the structures. However, the dimensions of the expansion joints could be different for the various structures.
Connection between	*X*	*In-situ*	The connection between is not a real joint, referring to an expansion joint. The connection between connects the approach slab with the abutment. The connection is established by pouring concrete. RWS had provided a standard detail

			for how this connection should be constructed. Within the N261 the standard detail design of RWS is applied.
Approach slab	*X*	*Prefabricated*	The approach slabs are prefabricated components. These prefabricated components have been ordered at the supplier RomijnBeton. The project team had to choose between the possible standardised dimensions that RomijnBeton offered.



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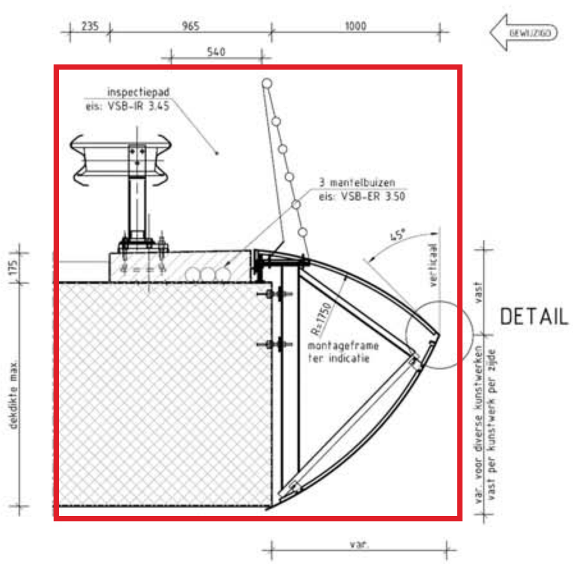

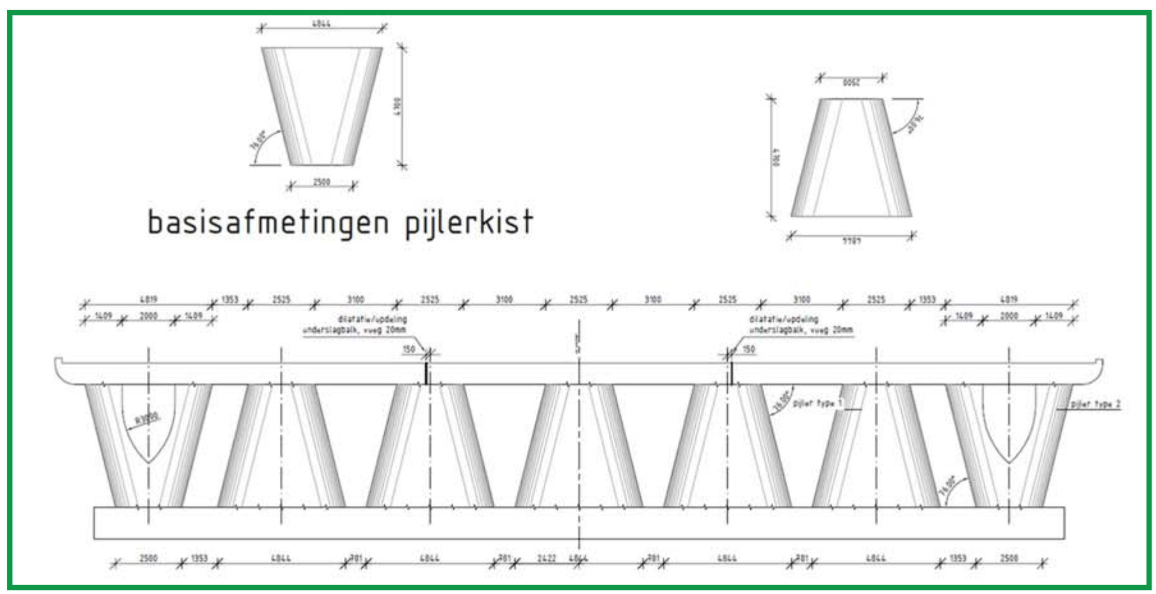

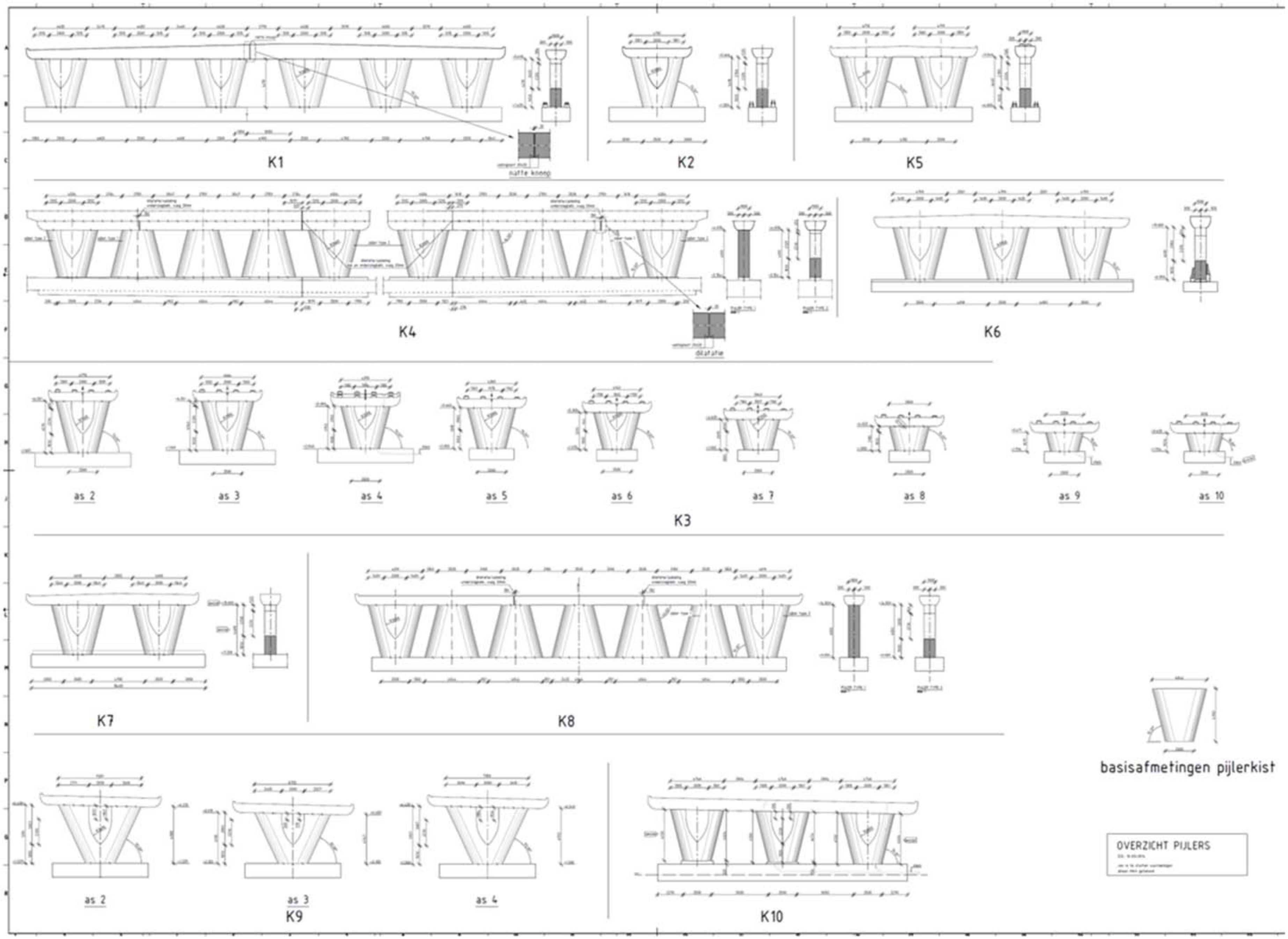

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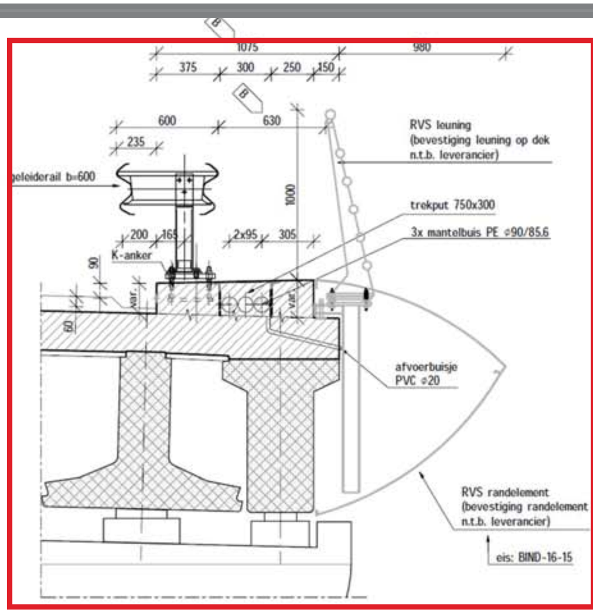
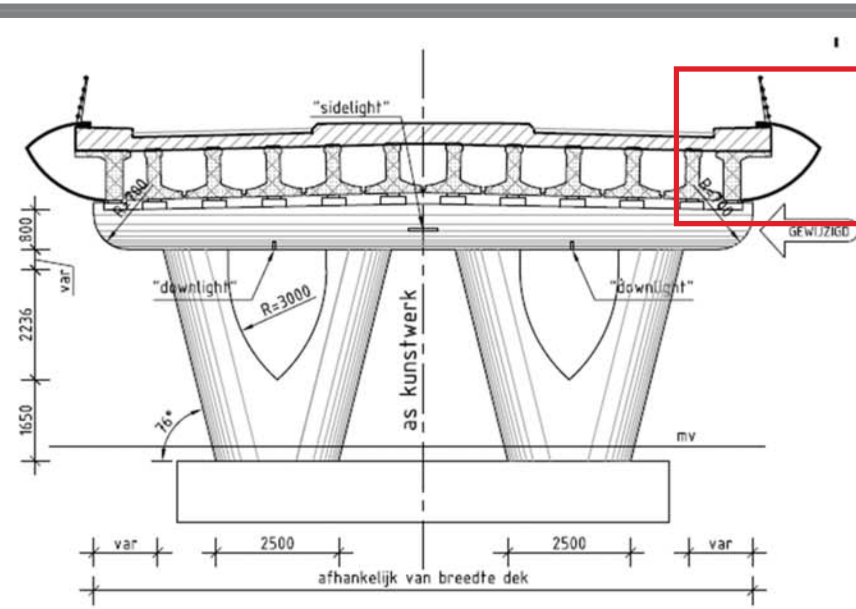
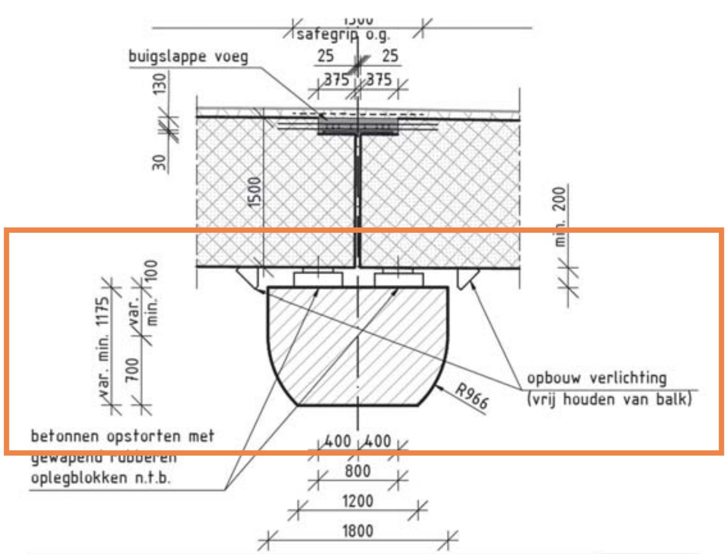
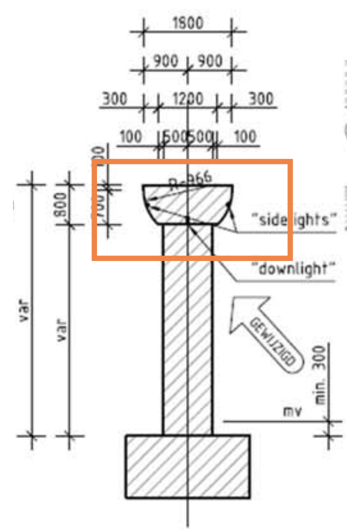
OVERZICHT PIJLERS









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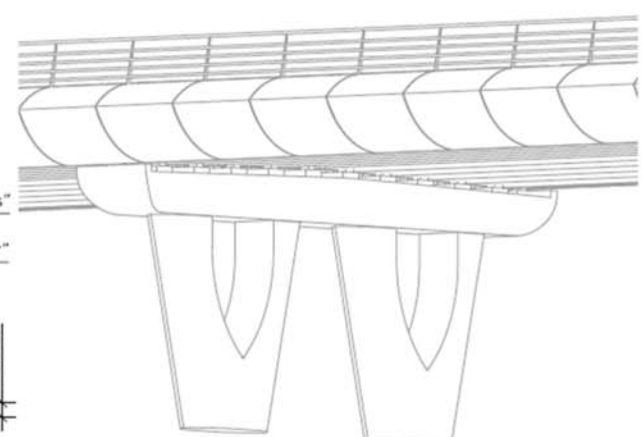
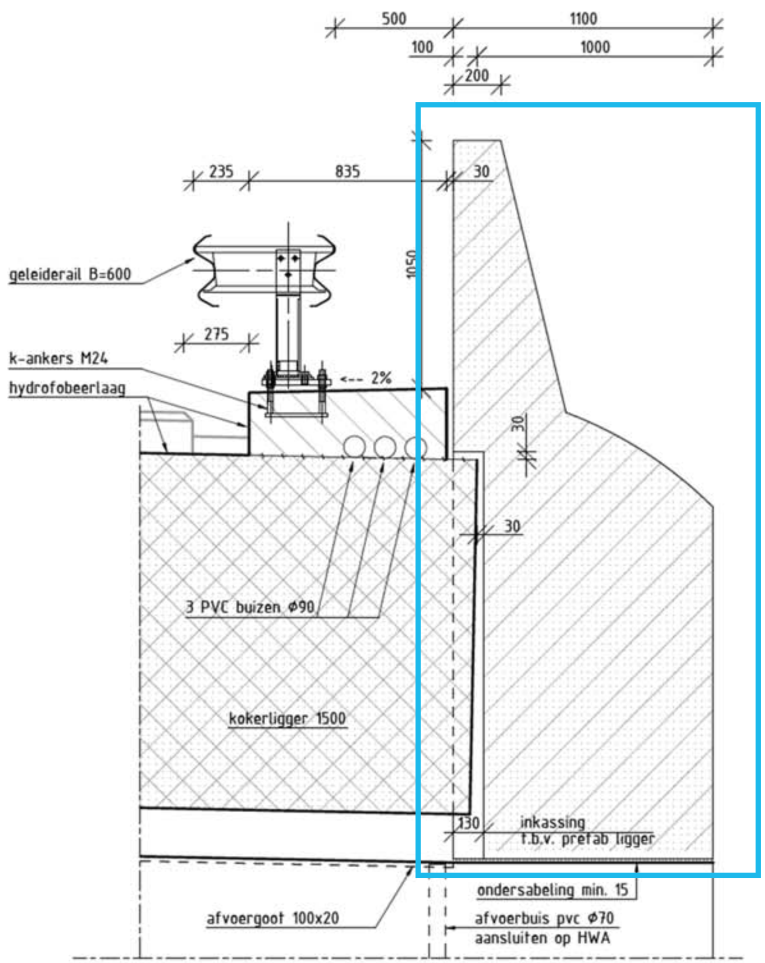


3D VIEW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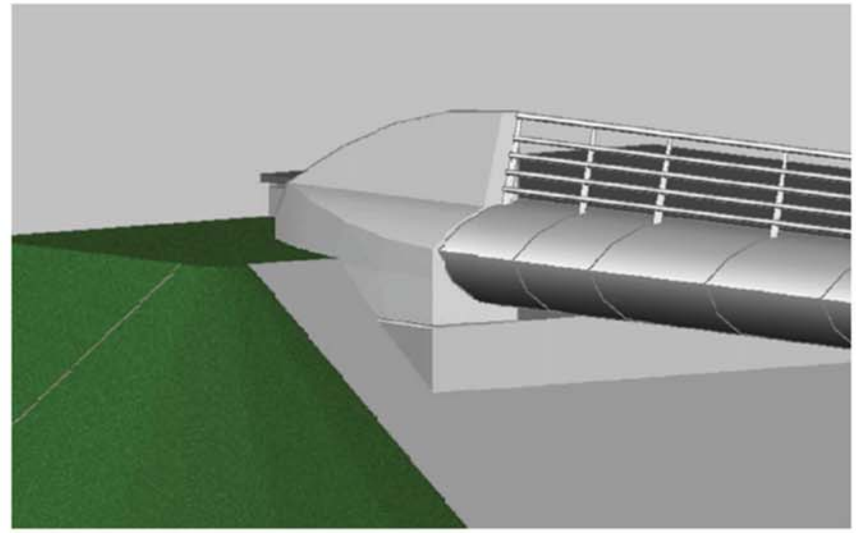

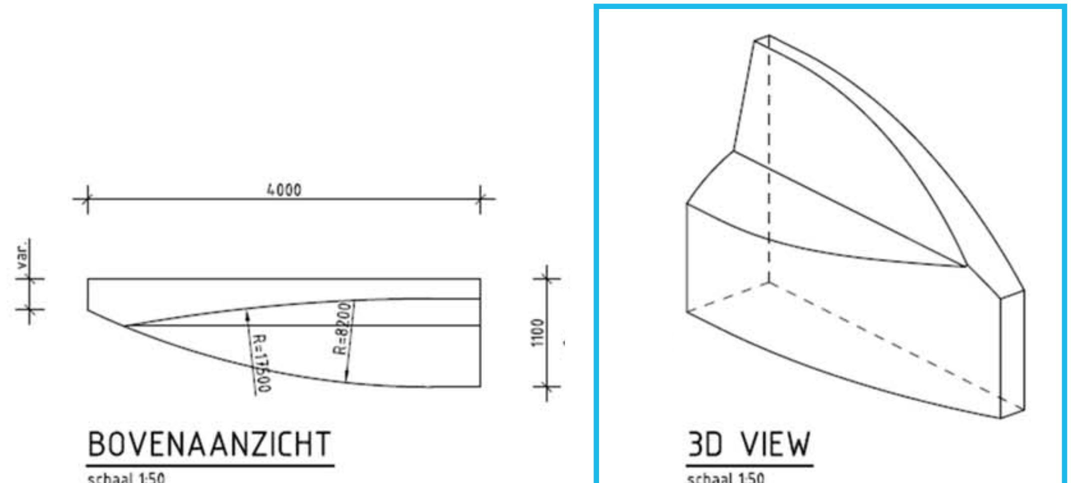
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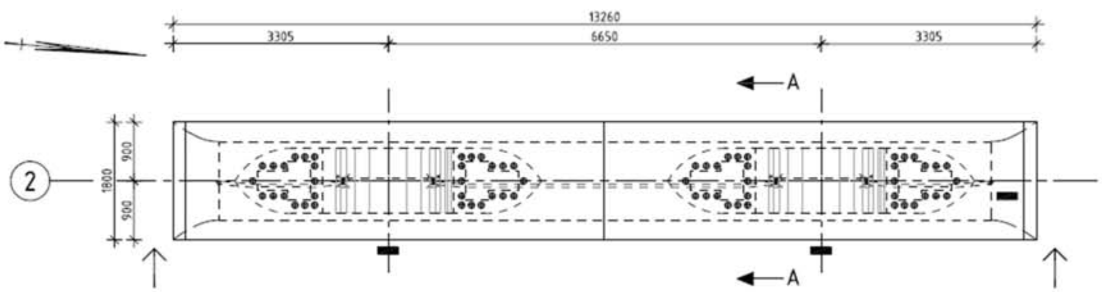
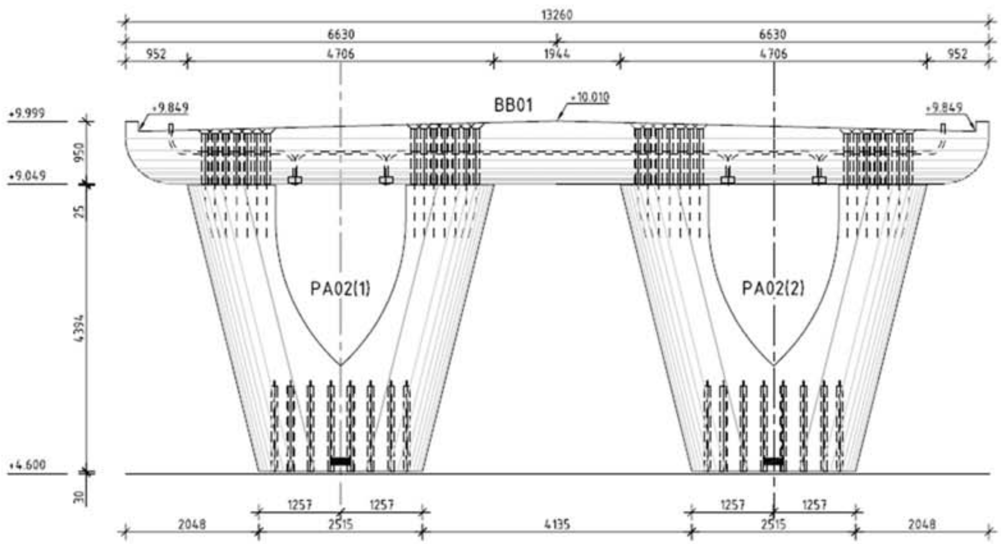
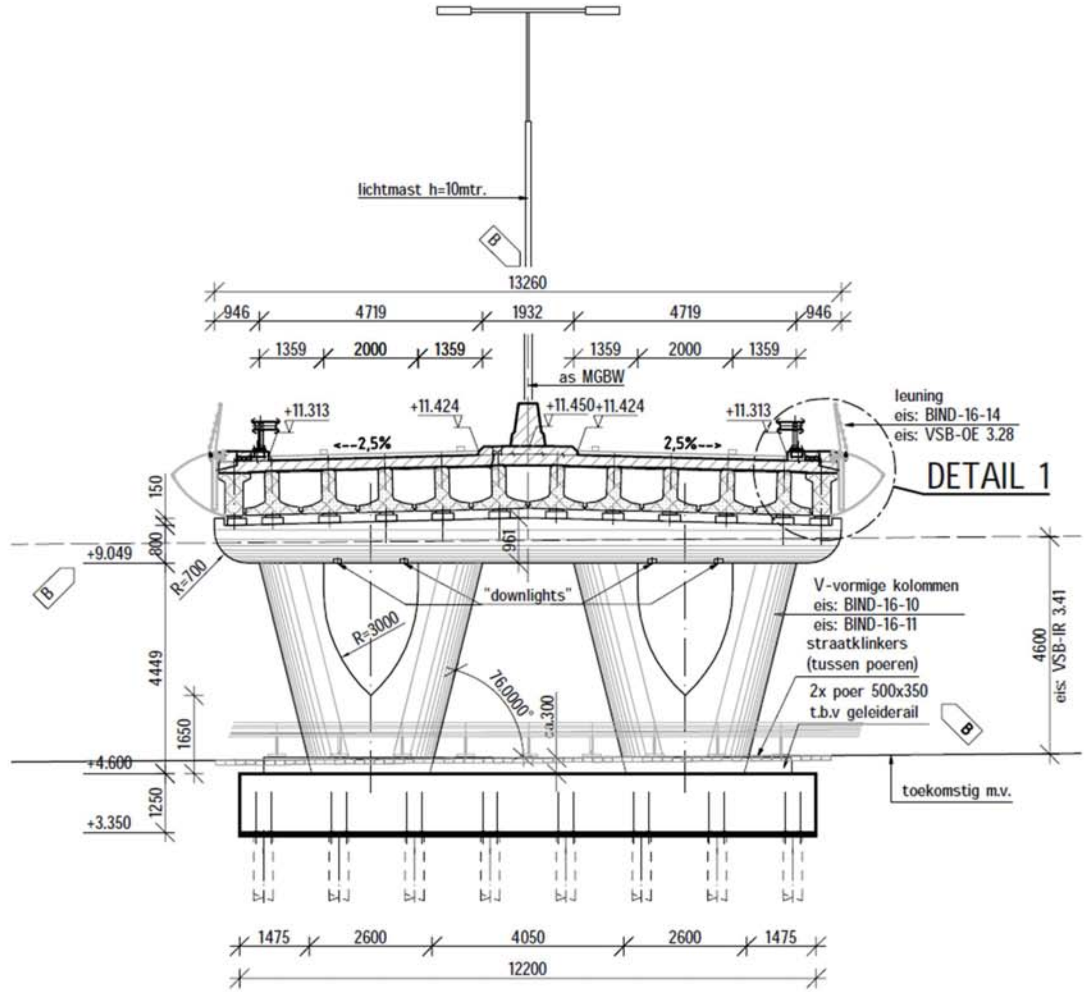


Bovenaanzicht KW5 steunpunt as 2
Schaal 1:60



Vooraanzicht KW5 steunpunt as 2
Schaal 1:60

Merkstippen kolommen aan Oostzijde!
(op 150 mm vanaf onderzijde kolom)



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A.12.4 Projects where a form of standardisation and/or modularization has been applied: In-house research: Reference viaduct

Reference viaduct			
Component of viaduct	Some form of standardisation applied	Realisation by in-situ or prefabricated elements.	Explanation
Foundation			
Foundation pad (sloof)	*X*	*In-situ*	In the research of the reference viaduct, it has been concluded that for the realisation of the intermediate columns rebar (reinforcement steel) should be applied. The rebar (reinforcement steel) should be continued from the foundation pad to the prefabricated capping beam. The rebar has to be spread over the entire length of the columns. This will have an influence on the foundation pad. The size of the foundation pad will be different for the various structures. However, the design should be the same in all situations and should be adapted parametrically (scaled) to the specific situation. A foundation pad is mostly constructed by an in-situ process. Constructing a foundation pad out of prefabricated components is possible, but because of the large dimensions of a foundation pad, this is usually not applied. The prefabricated components will be large and heavy. Therefore, difficulties occur with transportation and during assembly of the component. However, prefabricated foundation pads have been successfully applied within the project of the A12 –Lunetten-Veenendaal. For the A12 prefabricating some of the foundation pads were appropriate because it resulted in fewer lost-vehicle-hours. Prefabricating the foundation pads is not an optimal solution; the cost for transportation and assembly are significantly higher and dealing with deviations of the piles is more complex.
Foundation piles	*X*	*Prefabricated*	The foundation piles should be constructed under an angle of 5:1. The most optimal approach here is to apply spread footing (pile configuration – spreidstand), with two piles.
Substructure			
Intermediate wall/column(s)	*X*	*Prefabricated*	Prefabricated columns have been chosen as the most optimal solution for the reference design. Within the intermediate columns rebar (steel reinforcement cuttings) should be applied. The steel cuttings should be continued from the foundation pad to the prefabricated capping beam. The steel cutting has to be spread over the entire length of the columns. The building time and the minimising the hindrance have been the most important criteria for the decision made.
Abutment or bank seat (including foundation pad)	*X*	*In-situ*	Within the research of the reference viaduct, an abutment was chosen as the standard. Moreover, a reference for standard dimensions has been made. When a design is made these dimensions should be used as a starting point.
Capping beam	*X*	*Prefabricated*	For the reference viaduct, prefabricated capping beams were chosen as the standard. This was mainly based on the criteria for fast building time and the minimising hindrances.
Wing walls	-	-	The wing walls have not been investigated within the in-house research of a reference viaduct.
Superstructure – Core			
Deck	*X*	*Prefabricated*	The deck should be constructed out of box beams with straight edge beams. This conclusion has been drawn based on the research of Avinash Gangaram-Panday. Within the research, a different type of decks have been analysed, and trade-offs have been made. The outcome of the research was a flow diagram. The flow diagram can be applied to different projects, the most optimal solution for the specific situation can be determined.
Edge beams	*X*	*Prefabricated*	For the edge beam, the same principles as beams of the deck should be considered. In the case of a standard reference viaduct, box beams need to be applied.
Superstructure - Extensions			
Pavement: Asphalt	*X*	*In-situ*	One general asphalt layer has to be applied. This is not further investigated in the research, as this is the expertise of BAM Wegen (BAM Roads)
Edge element (finishing)	*X*	*Prefabricated*	The way the edge elements are connected and their general design are standardised. The general design is based on the standard details of RWS. The idea behind the standard detail is that the different architects can design their own finishing element while keeping the structure behind and the connection of the finishing element to the edge beam standard.

Parapets *(pedestrian and traffic)*	*X*	*Prefabricated*	The parapets have been standardised in their design and dimensions.
Upstand *(schampkant)*	*X*	*In-situ*	The upstand is standardised details, which are based on the standard details provided by RWS. Because it is a robust element and not highly complex, the upstands are constructed by an in-situ process. Prefabricating the upstand will not be beneficial.
Safety guards (guard rail)	*X*	*Prefabricated*	A safety guard is demanded by the RWS. The standard detail of RWS for standard concrete bridge construction is applied.
Bearings, expansion joints and approach slab.			
Bearings	-	*Prefabricated*	The type of bearings that need to be applied is not considered in this research. This had to be analysed in later phases. Unfortunately, the research was ended abruptly.
Expansion joints	*X*	*In-situ and prefabrication*	RWS provides standard details for expansion joint. These standard details should be applied in the reference viaduct.
Connection between	*X*	*In-situ*	RWS had provided a standard detail for how this connection should be constructed. Within research of the reference viaduct, the standard detail design of RWS is applied.
Approach slab	*X*	*Prefabricated*	The approach slabs are prefabricated components that are standardised by RWS. RWS also provides a standard detail for how the approach slab should be connected to the abutment or bank seat.

A.12.5 Projects where a form of standardisation and/or modularization has been applied: Tender of the N18

Tender of the N18			
Component of viaduct	Some form of standardisation applied	Realisation by in-situ or prefabricated elements.	Explanation
Foundation			
Foundation pad	*X*	*In-situ - but prefab would be further investigated when the contract was awarded.*	The entire design of all the intermediate columns was the same for every intermediate column. This made sure that all the columns had the same aesthetic appearance. To realise this, all the foundation pad had the same dimensions. In some cases, this means that the foundation pad was over-dimensioned. However, because of the repetition, this was less expensive than when foundation pads were developed specially for every column individually.
Foundation piles	*X*	*Prefabricated*	In all situations, the standard dimensions of the foundation's piles, square of 450 by 450, have been applied. This was the standard. However, in some situations different foundation methods that resulted in less noise hindrance for the surrounding area, were appropriate. For example, foundation piles that are screwed into the ground (schroefpalen), or foundation piles where a hole was drilled, where after the pile was drilled into the ground (boor palen).
Substructure			
Intermediate wall/column(s)	*X*	*In-situ - but prefab would be further investigated when the contract was awarded.*	In the entire design of the N18, the intermediate columns were the same for every structure. To realise uniformity in the design, all the intermediate columns had the same dimensions; a standard was chosen. This meant that in some cases, the columns were over-dimensioned. However, because of the repetition, applying one standard dimension was less expensive than when a column had to be developed specially for every structure individually.
Abutment or bank seat (including foundation pad)	*X*	*In-situ - but prefab would be further investigated when the contract was awarded.*	Full standardisation of abutment/bank seat is in most situations not possible. Much variation occurs, because of different heights of the deck and different angles of crossing. However, the detailing of the design has been standardised.
Capping beam	*X*	*In-situ - but prefab would be further investigated when the contract was awarded.*	As discussed before, the entire design of the intermediate columns was kept the same for all the different structures. The design of the capping beam in this design depends on part of the total structure of the intermediate column. Therefore, the capping beams were (automatically) standardised.
Wing walls	*X*	*In-situ - but prefab would be further investigated when the contract was awarded.*	The general shape and the detailing of the design for the wing walls were kept the same in all the different situations. However, still, many variations occurred, due to different heights of the deck and different angles of crossing.
Superstructure – Core			
Deck	*X*	*Prefabricated*	In most situations, the decks have been constructed out of prefabricated box beams. The dimensions of the beams have been divided into five different distances. This was to make the production of the parts easier, as more of the same beams with the same dimensions should then be fabricated. In addition, the dividing of the dimensions of the beams was with the idea that this could be beneficial because it increases the efficiency during the assemblage process on the construction site. Dividing the dimensions of the beams into five different distances meant that some of the beams had to be over-dimensioned. However, the costs of this over-dimensioning of the beams are relatively small and are easy won back by benefitting of the repetition within the production and assembly processes. When it was not possible to apply box beams, inverted T-beams are applied. However, this was required only for some of the structures.
Edge beams	*X*	*Prefabricated*	In the situations where a deck is constructed out of prefabricated box beams were

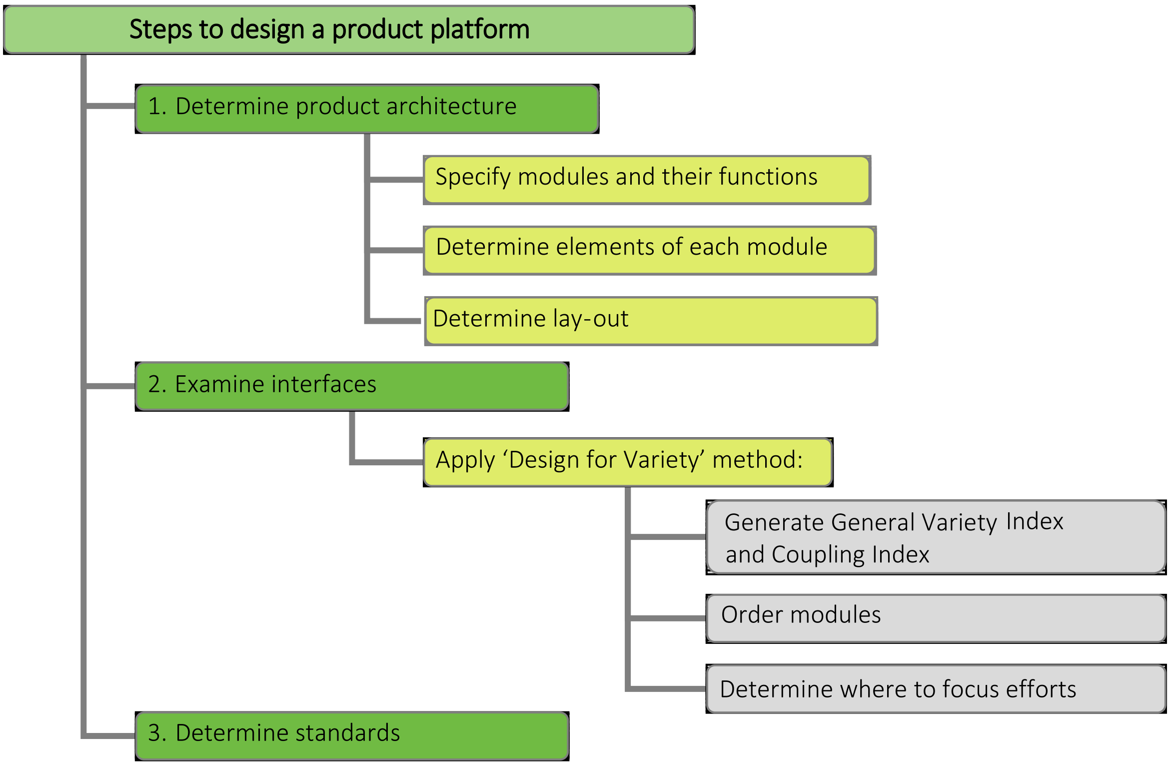
			applied, the same principles were applied to the edge beams. The dimensions of the edge beams are dependent on the height of the box beams. Although five different standardise lengths for the beams of the deck had been applied, the project team reduced the different deck heights to three standard heights. The result was that only three different upstand constructions were needed and only three different dimensions of the edge elements were required.
Superstructure - Extensions			
Pavement: Asphalt	*X*	*In situ*	Pavement is almost always standardised. The road-type for the viaducts is the same for all structures
Edge element (finishing)	*X*	*Prefabricated*	As discussed before, only three standardised height of the deck occurred within the different structures. The prefabricated edge elements all had the same design but were adjusted to the three standardised heights. Therefore, three different dimensions of the edge elements could be applied. By applying only three different deck heights, the project could benefit from the repetition that occurred.
Parapets (pedestrian and traffic)	*X*	*Prefabricated.*	The parapets applied were prefabricated. In the listed requirements, three different types/groups of parapets for the containment level were demanded. Three different standard designs were developed, that could be applied in the three different heights. The parapets are connected to the deck by an in-situ process.
Upstand (schampkant)	*X*	*Prefabricated*	The upstands are made out of prefabricated standardised elements. The connection/attachment to the deck is made by an in-situ process.
Safety guards (guard rail)	*X*	*Prefabrication.*	The standard design (considering the different types) conform the standard details of RWS has been applied. The safety guards are standard. They are the same for all infrastructural projects. Different dimensions are available, depending on the specific requirements listed a choice can be made between the different standardised designs of the components.
Bearings, expansion joints and approach slab.			
Bearings	*X*	*Prefabricated*	For the viaducts that have been standardised, also the same bearings could be applied within the design for the tender. When the project would have been rewarded, this would have been analysed further.
Expansion joints	*X*	*The combination of In-situ and prefabrication.*	The expansions joints are dependent on the type of covering layer that is applied on the deck. Depending on the type of covering layer, standard steel expansion joints or low-noise steel expansion joints are applied. The steal expansions are prefabricated and are connected to the deck by an in-situ process. Based on trade-off tables it could be analysed which approach would be the most optimal for the specific situation. Due to repetition within the different structures, a standard could be chosen.
Connection between	*X*	*In-situ*	The connection between are the same in every structure. Based on trade-off tables it could be analysed which approach would be the most optimal for the specific situation. Due to standardisation within the different structures, a standard could also be applied to this detail.
Approach slab	*X*	*Prefabricated*	The design of the approach slab is the same in all the different situations occurring. The actual dimensions are dependent on the width of structure and the load that the structure should be able to carry. Different standard dimensions have been applied, that fit the different standardised dimensions of the deck and meets the requirements listed.

A.14 PROTOCOL FOR DESIGNING PRODUCT PLATFORMS – VANESSA VEENSTRA

The protocol for designing product platforms, developed by Vanessa Veenstra is illustrated in A-12 (Veenstra, Halman, & Voordijk, 2006). The framework describes the basic elements that constitute a product platform and provides an essential start in the process of designing product platform. The protocol provides practical guidelines and decision rules to help companies develop and manage product platforms effectively. Within this protocol, three main phases can be distinguished. *1) Determine product architecture, 2) Examine interfaces and 3) Determine standards*.

Three main definitions are important:
- *Coupling-index:* A measure of the coupling among the components. It indicates the strength of coupling between the components in a product. The stronger the coupling between components, the more likely change in one will require a change in the other.
Coupling- index R (CI-R), is the coupling index-receiving, this indicates the strength (or impact) of the specifications that a component receives from other components. The coupling index S (CI-S), is the coupling index-supplying, this indicates the strength (or impact) of the specifications that a component supplies to other components.
- *Generational variability index (GVI):* Indicator of the amount of redesign required for a component to meet the future market requirements. The GVI is based on an estimate of the required changes in a component from external (non-controllable) factors.

It has to be point out that the GVI and CI-R give an indication of how many the components is expected to change. The CI-S is a measure of how likely those changes are to be passed on.



A—12 Protocol for designing product platforms, developed by Vanessa Veenstra (Veenstra, Halman, & Voordijk, 2006)

Phase 1) Determine the product architecture

First, the modules need to be specified by defining their respective functions. Secondly, the physical elements, by which module will fulfil its intended function, need to be determined. After these steps, elements can be coupled to the modules and a layout can be determined. This process of determining the architecture makes it possible to translate the functional requirements into technical specifications directly.

As illustrated in the figure 10-5 phase 1 is divided into three phases.
a) Specify modules and their functions
b) Determine elements of each module
c) Determine layout – The layout shows how the different components are coupled, and it is important to gain insight into how different components interact/ are related to each other.

Phase 2) Examine the interfaces
In phase 2, the design for Variety method of Martin & Ishii has to be applied. This is a step-by-step method for development of robust product platform architecture. The approach is a series of structured methodologies to help design teams reduce the impact of variety on the life-cycle costs of a product. The step-by-step method is considered to aids companies in developing a robust product platform architecture that results in reduced design effort and time-to-market for future generations of the product. This by using the concept of specification "flows" within a product development project (Martin & Ishii, 2002). The Design for Variety method consists out of three main steps:
A) Generate the "General Variety Index" (GVI) and the Coupling Index (CI).
The GVI indicates the amount of redesign effort is required for the future design of the product. The CI indicates the coupling among the product components. It gives an estimation of how components are influenced when a change in the design is made. The generations of the GVI is carried out in six steps: *1) Determine market needs, 2) Create a quality function deployment tables (QFD), 3) List expected changes in customers' requirements 4) Estimate engineering metric target values, 5) Create GVI tables and finally 6) Calculate the GVI.*

The process of the estimation of the Coupling Index is established by first conducting a list of specification flows between components, then the sensitivity to change of these components is estimated, and finally the calculation is made. This is carried out in six steps:
- *Step 1: Develop basic layout for product* – The layout of a product, show how the different components are coupled, referring to how the different components are connected and interact with each other.
- *Step 2: Draw control volumes around the components* – A group of components where one circle is drawn around, is a module. According to Martin & Ishii (2002), a control volume is a boundary around a system indicating the flows into and out of the system.
- *Step 3: List specification flows between components* – Specification flows are the design information that must be passed between designers to design their respective components. By this, the relationships between the different components are identified. The project team should analyse each control volume and list the CI-R, the specifications that they need to receive from each of the other modules. The CI-S, also needs to be identified, listing the specification that they expect to supply to each of the other control volumes.
- *Step 4: Build graphical representation of specification flows* – The outcome of step 3 is visualised. Although the visualisation gives great insight into how modules interact, this step can be very complex.
- *Step 5: Estimate sensitivity of components to change.* – The project team should review each specification, considering how much they are affected by small changes in the specification. The sensitivity of the modules has to be estimated. High sensitivity is when a small change in the specification requires a change in the components. Low sensitivity is when the specification need to be changed significantly (large change), to create a change in the components.
- *Step 6: Calculate the couplings-index* – The CI-R (coupling index return) and the CI-S (coupling index supply) together indicate how tightly coupled a component is. The coupling-indexes can then be listed in a table, to get a good overview. Additionally, it is suggested by Martin and Ishii (2002) to develop a graph. The graph will indicate how much a component is expected to change.

B) Ordering of the modules based on the result of the first step.
In this step, the GVI and CI are considered together, to get a better understanding of the influence of external factors and the way in which changes affect the product design. It gives insight in how to set up the platform that is the most resistance to external change. The insight can be drawn from a graph using the GVI and CI.

C) Determine where they need to focus their efforts on.
The ordering of modules in the second step will aid the design team to determine where they need to concentrate their effort: where to standardise and where to modularize. This step is considered as an important step because the design team aims at developing a product platform in a way that as much of the design is standardised and modularized across generations. The outcomes of the first steps are reviewed. Based on the definitions (Martin & Ishii, 2002) listed below, the different components are ranked, and it can be determined which components can be standardised or modularized to establish a well-working platform.

Standardised (GVI and CI–R related)
- Fully standardised: it is expected that the component will not change across generations.
  This implies that the GVI and CI–R are equal to zero.
- Partially standardised: the component is expected to require minor changes across generations.
  The higher the GVI and CI–R, the less standardised is the component.

Modularized (CI–S related)
- Fully modularized: the geometry, energy, material, or signal (GEMS) of the component can be changed to meet expected customer requirements without requiring other components to change.
  This implies that the CI–S of the component is zero.
- Partially modularized: changes in the GEMS of the component may require changes in other components.
  The higher the CI–S, the more changes expected, and thus the component is considered less modular.

Martin and Ishii have developed a table to give an overview of how they draw conclusions from the filled in tables. This table is given below.

Standardise	*GVI*	*CI-R*	*CI-S*
Fully	0	0	0
	0	0	>0
Modularize	*GVI*	*CI-R*	*CI-S*
Fully	>0	>0	0
Partly modularize, or not possible	>0	>0	>0

Table A—10 Interpretation data, table developed by Martin and Ishii (2006)

When the GVI, CI-R and CI-S are listed, the project team should analyse the outcome. First, the components with a high GVI needs to be considered. These components require high redesign efforts due to changing demand and requirements of the market. Veenstra et al. (2006) argue that while high CI-R components can also require high redesign efforts, the high GVI components generally will have a much greater impact on the redesign efforts. Hereafter, the CI-R and the CI-S need to be considered. The CI-S has a high potential for causing changes in other components. It is important to note that it is not always possible to standardise components, as products change over time to meet the changing circumstances and demands in the market. The parts that cannot be standardised should be modularized. The modules that still have a high GVI and CI-R are likely to change. The changes will have an impact on other components in the design and therefore will need to be modularized. Modularization is accomplished by reducing the CI-S of the components. (Veenstra, Halman, & Voordijk, 2006). The components that have a relatively low GVI-value are components that are though not to change significantly. The project team, therefore, needs to analyse the lower GVI-values in combination with the CI-R and CI-S values. These components can be interesting to standardise.

Phase 3) Determine the standards
In this last step of the protocol, the design rules that the modules should conform to are determined, and the standard is designed. Due to this standardisation of the design, the project team is able to develop a decoupled architecture: a product platform that will require less design effort for the follow-on products.

In addition, firms can also reduce or eliminated the GVI created by the specification flows. The GVI-value can be reduced by applying the approaches listed below:
1) Remove current components specifications
    a) Rearrange the mapping of functionality to components
    b) “Freeze” the specifications (is not allowed to be modified)
2)Reduce sensitivity of the components to changes in the specifications
    a) Reduce internal coupling
    b) Increase the “headroom” of the specification. The headroom can be increased by designing the product in a way that the components can absorb a large change in the specification before requiring redesign. (“Overdesign”)

Approach within this research
The steps to design a product platform developed by Vanessa Veenstra will be taken as a guideline in this research.

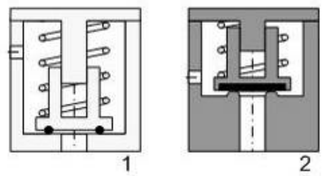
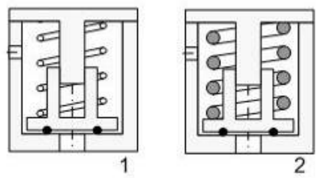
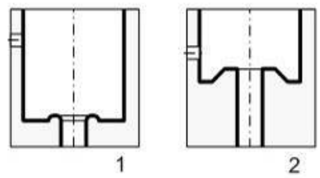
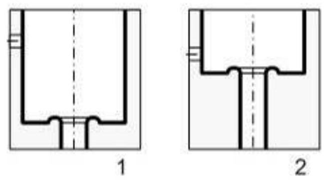
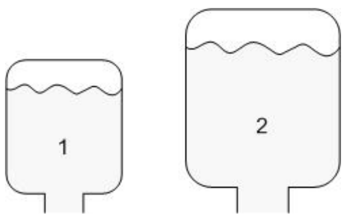
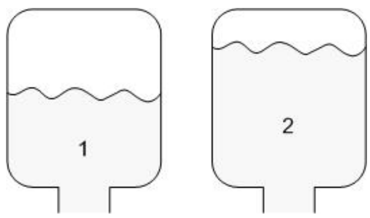
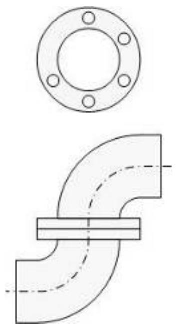
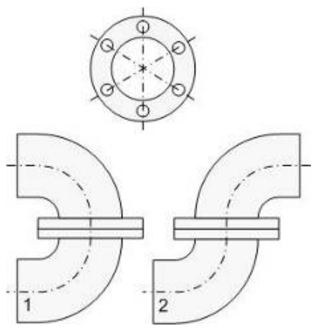
It has to be noticed that although companies understand the strategic reasons for applying the principles of mass customization, the process to implement this is not always clear. Martin and Ishii (Martin & Ishii, 2002) argue that issues arise concerning the definition of platform elements, such as modules and interfaces. Secondly, companies find it difficult to determine which elements they should standardise or modularized. Thirdly, they have difficulties with the design step to be taken. Martin and Ishii point out that in a very traditional organised industry, with often unique and complex projects and a large number of different, autonomous parties involved, applying the principles of the mass customization industry can be complicated.

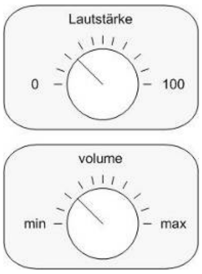
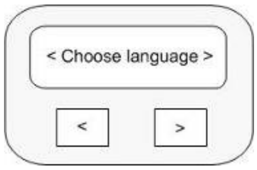
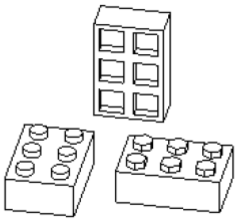
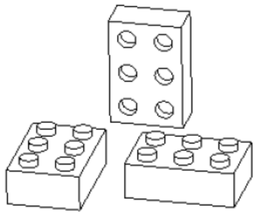
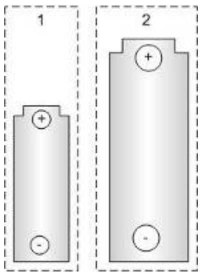
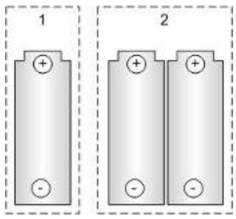
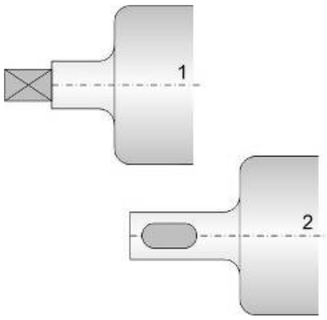
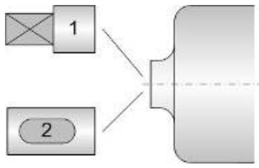
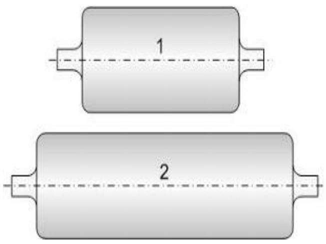
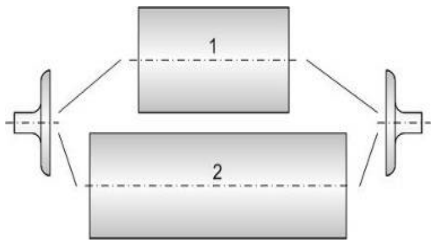
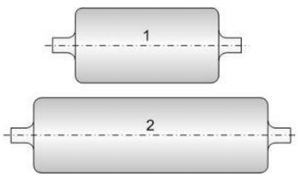
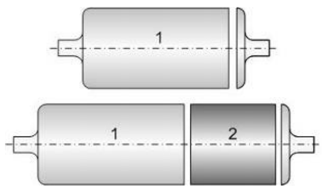
A.15 DIFFERENT GUIDELINES FOR DESIGN FOR VARIETY METHOD

In the article of Kipp and Krause (Kipp & Krause, 2008) different guidelines for application of the design for variety method are identified. The different guidelines are clustered into four categories. These guidelines can help the project team during the design phase. They give a clear overview of the possibilities to benefit from the repetition present in products.

- *Category A* - This category describes design approaches, which support an easy creation of product variants without affecting the product architecture.
- *Category B* – This category contains design approaches, which affect the product design as the product architecture directly. As a common basic principle, all these guidelines show possibilities how to divide components into standard and variant parts.
- *Category C* – This category includes basic principles, which should be considered in the development of product families' architectures. Idealised, the common intention of these guidelines is the design products consisting of totally independent modules, which together provide the overall function.
- *Category D* – This category describes the basic rules for the development and production of variant products. These rules do not affect the product design, none the less they should be considered while designing a product.

Guidelines for design for variety

Category	Guidelines	Unfavourable	Favourable
A	*Guidelines only affecting the design of a product*		
A1	Use as many common parts as possible to create product variants		
A2	Standardise design parameter of different variants (for example: geometry, material etc.)		
A3	Use overdesign to avoid product variants (e.g. tank size).		
A4	Use higher symmetry to generate geometric product variants (e.g. flange design).		

A5	Use software instead of hardware solutions to create product variants (e.g. language variants).		
A6	Design module interfaces compatible.		
B	**Guidelines concerning both design and architecture of the product**		
B1	Use parallel and serial configurations to create performance variants. (e.g. battery)		
B2	Decompose cost-intensive components with a huge amount of variants to standard and variant components (e.g. roll flange).		
B3	Use cut to fit modularity to create geometric variants (e.g. size variant of a roll).		
B4	Use additional elements to create geometric variants (e.g. size variant of a roll).		

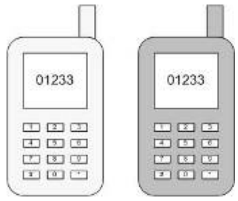
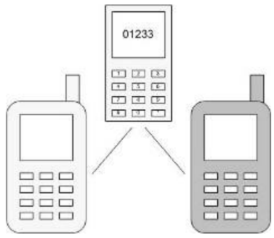
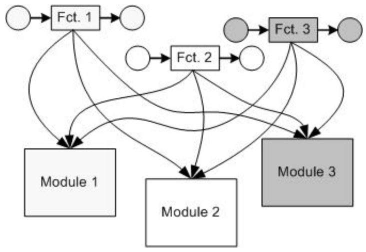
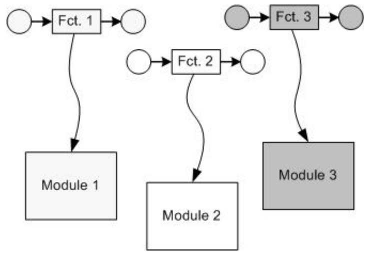
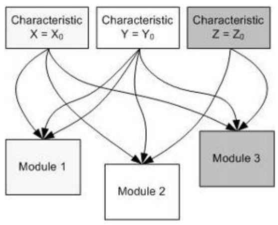
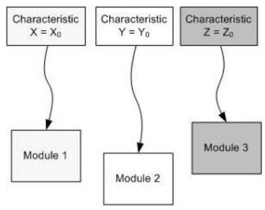
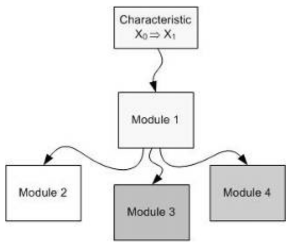
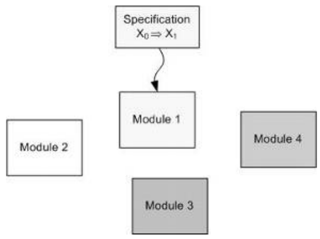
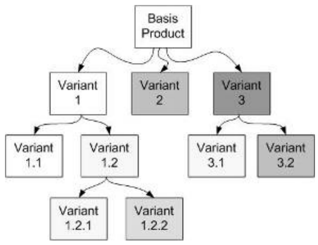
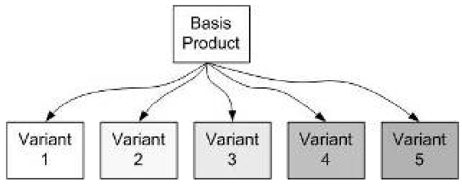
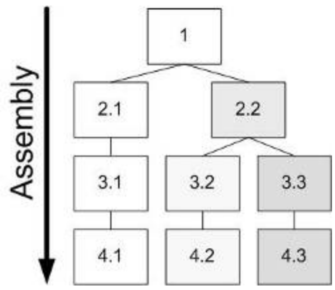
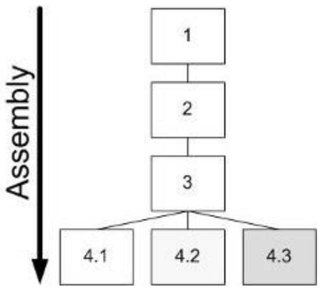
B5	Variant characteristics without any effect on the function should be isolated in new cost-efficient components (e.g. cell phone colour).		
C	***Guidelines concerning the product architecture***		
C1	Assign every function directly to one module of the product.		
C2	Assign every variant product characteristic directly to one module.		
C3	Changing one product characteristic should not effect more than one module.		
D	***Guidelines for the development and production of product variants***		
D1	Develop new product variants based on a non-order-related variant.		
D2	Product variety should be created at the end of the assembly process.		

Table A—11 Guidelines for design for variety, derived from Kipp en Krause (2008)

A.16 SESSION WITH CONSTRUCTORS: ALGEMEEN STAPPENPLAN

Uitleg afstudeeronderzoek
Binnen mijn afstudeeronderzoek onderzoek ik de toepassing mogelijkheden van de principes van mass customization, namelijk standaardisatie en modularisering, in de infrastructurele industrie. Hierbij kijk ik specifiek naar een viaduct.

Standaardisatie en modularisering
Bij standaardisatie en modularisering moet u zich het LEGO-concept voorstellen. Het ontwikkelen van een bouwwerk door het in elkaar zetten van standaard modulaire elementen heeft veel weg van de ideeën achter LEGO®. Standaard modulaire elementen kunnen namelijk worden gezien als de afzonderlijke LEGO-steentjes waarmee ontelbare combinaties kunnen worden gevormd, waarbij de connectie tussen de LEGO-steentjes vastligt (standaard interface). Men kan zelfs breder kijken door te stellen dat de LEGO-steentjes gemakkelijk uit elkaar te halen zijn en dan voor een nieuw LEGO-ontwerp gebruikt kunnen worden. Binnen een bouwproject is dit allemaal veel complexer, maar de ideeën zijn in de basis gelijk.

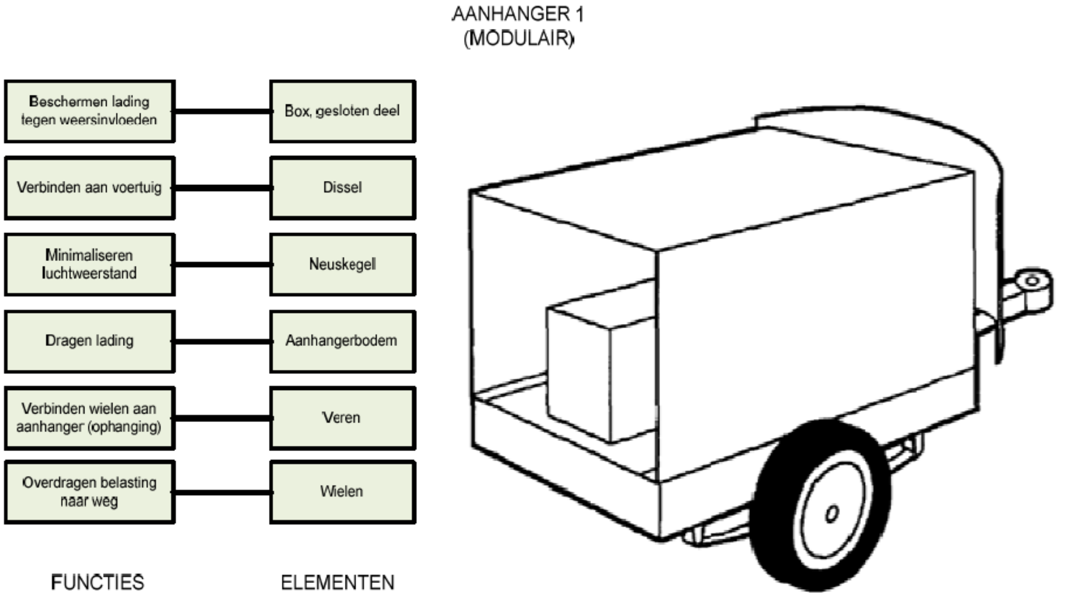
Ontwikkeling van product platform.
Het hogere doel van het toepassen van de standaardisatie en modulariseren is om uiteindelijk een product platform te ontwikkelen. Platform gedreven engineering binnen productontwikkelingsprocessen is gebaseerd op ‘platform denken’: het proces gericht op het identificeren en exploiteren van gemeenschappelijke kenmerken tussen de verschillende bouwkundige of infrastructurele objecten, producten en/of diensten, de beoogde doelgroepen en de realisatieprocessen. Dit door deze gemeenschappelijke kenmerken vast te leggen en het ontwerp hergebruikt kan worden om op efficiënte wijze nieuwe ontwerpen te kunnen ontwikkelen. De principes van standaardisatie en modularisering, die van toepassing zijn bij een product platform, zijn afkomstig uit de mass customization industry. Hier worden de principes gebruik om de markt te voorzien van voldoende variatie aan producten, in essentie zal standaardisatie en modularisering resulteren in hogere flexibiliteit. Dit is in tegenstelling wat men vaak verwacht als je over een standaard begint, maar juist door de interface (hoe zijn elementen gekoppeld) vast te leggen kunnen er snel vele verschillende varianten worden ontworpen. Daarnaast zal men een zekere mate van productstandaardisatie aan kunnen brengen in de ontwerpprocessen. Men kan gebruik maken van de repetitie die aanwezig is. Hierbij kan men op efficiënte wijze variatie aanbieden, die voldoen aan specifieke eisen van de verschillende klanten, voor relatief lage kosten.

Product platform word gedefinieerd als: een verzameling middelen (componenten, processen, kennis en personen) die worden gedeeld door meerdere producten. Voor het toepassen van product platforms is het noodzakelijk dat wordt uitgegaan van:

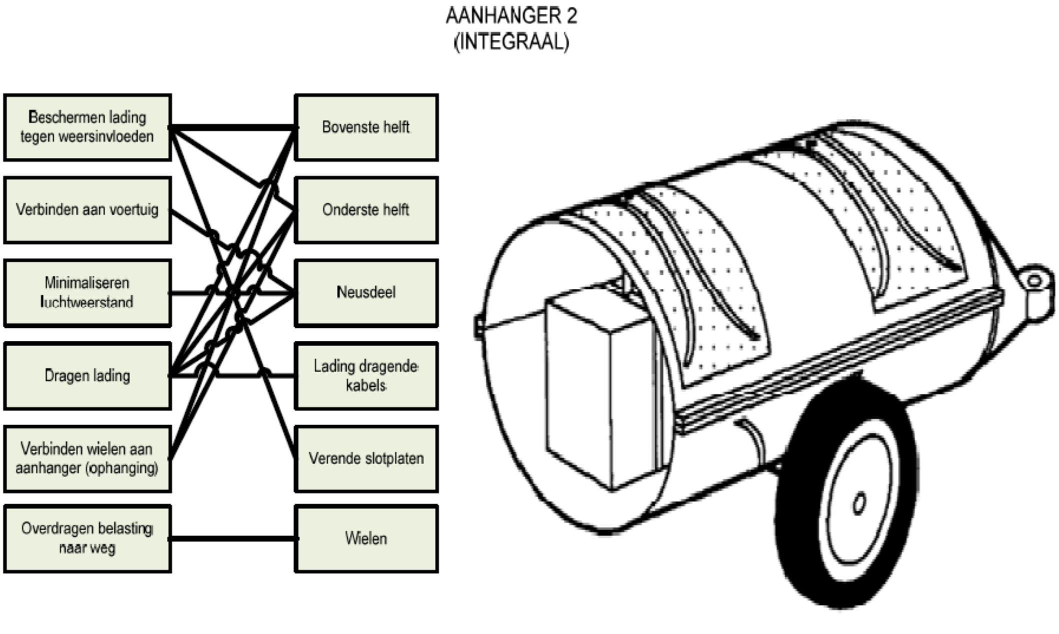
1. *Modulaire productarchitectuur* - Een modulaire opzet
2. *Interfaces* - Standaard interfaces zodat modulen gemakkelijk kunnen worden vervangen door verbeterde versies zonder dat het productontwerp wijzigt (hoe elementen aan elkaar vastzitten ligt vast)
3. *Standaarden* - Het gebruik van ontwerpregels.

Daarnaast moet de productarchitectuur
1. Zodanig modulair zijn dat subsystemen aan- en ontkoppeld kunnen worden.
2. Het platformdeel (subsystemen en/of raakvlakken) van de productarchitectuur zal als standaard aangemerkt worden.

In de figuren hierbeneden wordt een integrale aanhanger en een modularie aanhanger weergegeven. Het principe van modularisatie word hiermee relatief simpel gepresenteerd. De gedachte hierachter is dat als elementen slechts beperkte koppeling hebben met andere elementen (en hierbij functies) ,men door gebruikt te maken van een standaard interface (vastgelegd hoe elementen aan elkaar verbonden worden) deze elementen los van andere elementen kunnen ontwerpen en door ontwikkelen. Echter is volledige modulariseren van objecten vaak niet mogelijk en niet wenselijk. Men heeft hier dus te maken met verschillende gradaties van modulariteit.



A—13 Aanhanger modulair



A—14 Aanhanger integraal

Een goed voorbeeld van een productplatform binnen een organisatie, is de pax-kast van Ikea. In de basis zijn alle kasten hetzelfde, de kasten bestaan uit elementen van dezelfde afmetingen. De consument kan kiezen uit verschillende hoogtes en kleuren voor de basis bouw, verschillende kleuren en type deuren en verschillende handvaten. Daarnaast kan men de kast nog volledig naar eigen behoefte afstemmen doormiddel van zo als we wel zeggen “add-ons”. Men kan kiezen voor alleen planken in de kast, een kledingroede, maar kan ook lades toepassen etc. Alle elementen van de pax-kast zijn gemakkelijk aan elkaar te bevestigen en kunnen ook weer makkelijk uit elkaar gehaald worden. Dit is echt een proces van demonteren en niet van sloop. De kast kan dan ook gedemonteerd worden en op een andere locatie met bijvoorbeeld een andere indeling, weer in elkaar gezet worden. Daarnaast zijn de verschillende onderdelen uitwisselbaar met andere pax-kasten. Op deze wijze realiseert men klant specifieke oplossingen op efficiënte wijze.

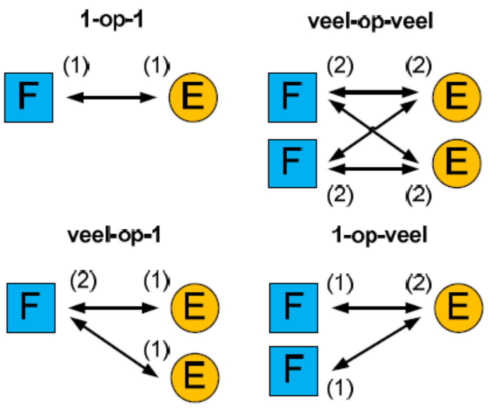
Momenteel worden de principes van mass customization nog niet toegepast in de infrastructurele sector van de constructie industrie. Dit afstudeeronderzoek gaat dan ook over het toepasbaarheid van de principes van de mass customization (standaardisatie en modularisering)voor een infrastructureel object: een viaduct.

Onderzoeksmethodiek

Aan de hand van de methodiek hieronder beschreven is het mogelijk om te onderzoeken welke onderdelen van een civieltechnisch bouwwerk gestandaardiseerd of gemodulariseerd kunnen worden. Het model is opgezet volgens de kenmerkende aspecten van het productplatform: (1) een modulaire productarchitectuur, (2) raakvlakken en (3) standaarden. U als constructeur zal alleen deel b en c bekijken. Om echter een goed beeld te krijgen zijn alle te nemen stappen uitgelegd.

Onderzoeken (en vastleggen) modulaire objectarchitectuur

Binnen de system engineering methodiek worden functies gekoppeld aan elementen (functievervullers). Zo wordt duidelijk uit welke onderdelen het object moet bestaan om als systeem te functioneren. In de eerste stap van deze methodiek wordt de koppeling tussen de betreffende functies en elementen onderzocht. Deze koppelingsrelatie impliceert de mate waarin het gekozen objecttype modulair of integraal is opgebouwd.



A—15 Koppelingsmogelijkheden, functie aan element

Volgens (Ulrich, 1995) zijn de relaties waarbij functies en elementen 1-op-1 gekoppeld zijn modulair. Bij veel-op-1, veel-op-veel en 1-op-veel zijn de betreffende relaties integraal. In figuur 1 zijn alle mogelijke koppelingsrelaties tussen een functie en een element weergegeven.

<u>i. Vaststellen objectarchitecturen – definiëren functieboom (FBS) en objectenboom (OBS)</u>

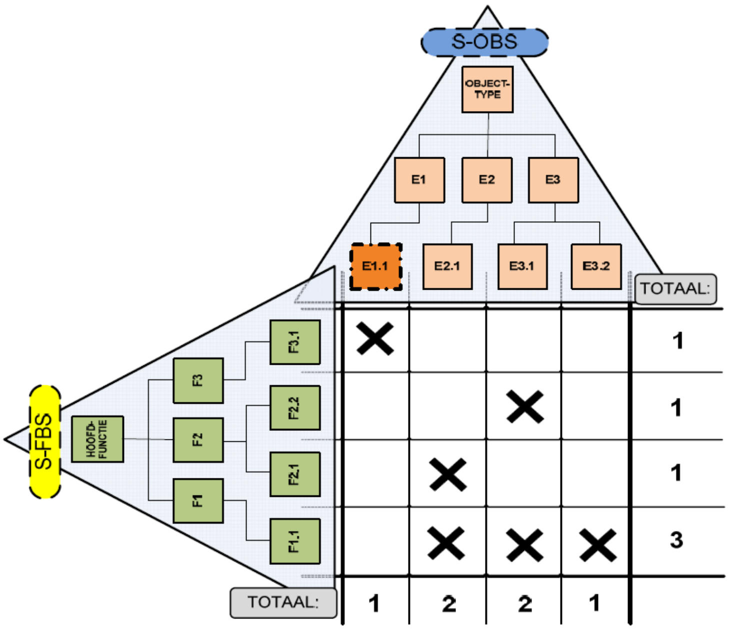
Bij objecten welke middels system engineering (SE) zijn ontworpen zijn de gevraagde objectarchitecturen reeds verkregen. Het zijn de functie- (FBS) en objectenboom (OBS) die binnen de systems engineering methodiek als projectbeheersstructuur worden gebruikt. De objectarchitecturen dienen van zoveel mogelijk objecten van hetzelfde type te worden opgezocht, teneinde er voldoende inzicht in te krijgen.

<u>ii. Vaststellen platform objectarchitecturen - vergelijken FBS en OBS van gelijksoortige objecten</u>

Zoeken naar overeenkomsten in functies en elementen door het vergelijken van de FBS en OBS van zoveel mogelijk gelijksoortige objecten. De overeenkomende functies/elementen zijn in potentie de telkens terugkomende platformfuncties/platformelementen. Deze zullen in een standaardfunctieboom (S-FBS) en standaard-objectenboom (S-OBS) worden geplaatst. De unieke objectonderdelen die in deze stap geïdentificeerd worden zullen niet in deze S-FBS en S-OBS worden opgenomen. Deze afwijkende functies/elementen zijn optioneel en zullen, bij een goede modulaire opzet van het systeem, alsnog gekoppeld kunnen worden.

<u>iii. Vaststellen koppeling functie-element – onderzoeken functionele eigenschappen elementen</u>

Het vaststellen van de koppeling tussen de functies en elementen wordt gedaan door de S-FBS en SOBS tegen elkaar uit te zetten. Hiermee ontstaat de tabel zoals weergegeven in figuur 2. Elke koppeling die plaatsvindt tussen functie en element kan hierin gemarkeerd worden. Zoals te zien is in het voorbeeld heeft alleen element 1.1 een modulaire relatie.

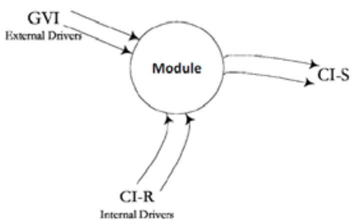


A—16 Voorbeeld van uitzetten S-FBS tegen S-OBS

<u>iv. Vastleggen modulaire objectarchitectuur</u>
Aan het eind van deze eerste stap worden de modules vastgelegd. Dit wordt gedaan door de elementen uit de S-OBS (object breakdown structure) te clusteren op basis van de koppelingsgraad tussen functies en elementen. De elementen met 1-op-1 relaties kunnen alle als zelfstandige modules worden gezien. Ook elementen zonder modulaire relaties kunnen tot modules worden omgezet, wanneer er gestreefd wordt naar zo min mogelijk functionele relaties over het raakvlak van de module heen. Bij het clusteren van de elementen moet zoveel mogelijk worden vastgehouden aan modules van gelijke omvang. Om inzicht te krijgen in de moduleomvang en de raakvlakken tussen de modules, worden t.b.v. de vervolgstappen de modules gevisualiseerd. Het gaat hier niet om objectdetails, een grove schets is voldoende. De modules uit de S-OBS (object breakdown structure)moeten alle eenduidig worden weergegeven.

Onderzoeken (en vastleggen) raakvlakken tussen modules en omgeving

Om te voorkomen dat een ontworpen objectmodule in de toekomst veelvuldig her-ontworpen moet worden, is het van belang dat ontwerpteams inzicht hebben in de factoren die aanpassingen veroorzaken. Externe en interne factoren kunnen beide ten grondslag liggen aan het moeten veranderen van een module. In de door Martin & Ishii (2002) vastgelegde methode zijn de variatie-index over tijd (GVI) en de koppelingsindex ontvangst (CI-R) beide graadmeters voor respectievelijk deze externe en interne factoren. Daarnaast kunnen de wijzigingen van de betreffende module ook weer voor wijzigingen van andere modules zorgen. De koppelingsindex afgifte (CI-S) is een maat voor de benodigde wijziging van aangrenzende modules, wanneer de betreffende module gewijzigd moet worden. In figuur 3 is een beeld gegeven van deze indicatoren.



A—17 Aanleidingen voor wijziging van modules binnen een object met bijbehorende gevolgen

2A. Externe factoren - vaststellen GVI (variatie-index over tijd)

De GVI (variatie-index over tijd) geeft een indicatie van de mate waarin modules binnen een object gevoelig zijn voor verandering door externe factoren (Martin & Ishii, 2002). Deze gevoeligheid voor verandering over tijd is een indirecte maat voor de te verwachten (her-)ontwerpwerkzaamheden bij het project specifiek maken van een object. De noodzakelijke veranderingen van een module zijn gebaseerd op externe, niet beheersbare factoren zoals toenemende of veranderende klantwensen, gewijzigde regelgeving en locatie specifieke randvoorwaarden.

Externe factoren komen bij een civiel object veelal voort uit de omgeving. De omvang van het object en de inpassing op een telkens unieke locatie maakt dat locatie specifieke omgevingsfactoren een grote invloed hebben op het objectontwerp. Daarnaast spelen klantwensen ook een grote rol; een civiel object wordt door bijvoorbeeld een gemeentelijke instantie als een uniek object gezien. Dit leidt tot een breed pakket aan klantwensen en uiteindelijk een op maat gemaakt object.

- <u>I. In kaart brengen externe factoren:</u>
  De externe factoren van een te bouwen object worden door opdrachtgevers vertaald naar een eisenspecificatie. Elke eis die hierin wordt vermeld zorgt ervoor dat de oplossingsruimte wordt ingeperkt. Wanneer een eis wisselt van object tot object is het een externe, niet beheersbare factor.Om de wisselende eisen per type object te identificeren is het nodig de door opdrachtgevers opgestelde eisenspecificaties te analyseren.

- <u>II - Analyseren gevoeligheid module bij externe factorwijziging – bepalen GVI-score:</u>
  In de volgende stap worden de geïdentificeerde externe factoren gekoppeld aan de modules uit stap 1. Dit gebeurt door te kijken welke modules als gevolg van een externe factorwijziging moeten veranderen. Het is goed mogelijk dat een wijziging van een externe factor gevolgen heeft voor meerdere modules. Daarnaast kan het ook zijn dat er geen wijziging van een module nodig is; het blijkt dan geen externe factor te zijn.

  Naast het koppelen van externe factoren aan modules wordt tevens de consequentie van de verandering ingeschat. Dit wordt gedaan door de gevoeligheid van de module voor een externe factorwijziging te bepalen. In een ontwerpsessie wordt beoordeeld of de wijziging kleine of grote gevolgen heeft voor het ontwerp van de betreffende module. De bepaling is gebaseerd op een subjectieve beoordeling die wordt uitgedrukt in een GVI-score per module. Bij de beoordeling wordt een waarde toegekend van 0,1,3,6 of 9, waarbij een lage waarde een lage gevoeligheid voorstelt. De waarde wordt per externe factorwijziging toegekend en in de matrix bijgeplaatst.

- <u>III. Berekenen totale GVI-score per module:</u>
  Als laatste worden alle GVI-scores die aan een module zijn toegekend opgeteld. Het totaal wordt weergegeven in de onderste rij van de matrix, als in figuur 4. De totale GVI-score geeft aan welke modules wel en welke modules niet erg gevoelig zijn voor een verandering van de externe factoren.

<u>*GVI - Rating Description*</u>

9 Requires major redesign of the component (>50% of initial redesign costs)
6 Requires partial redesign of component (<50%)
3 Requires numerous simple changes (<30%)
1 Requires few minor changes (<15%)
0 No changes required

Variatie-index (GVI)		Module A		Module B		Module C		Module D		Module E		Module F	
Externe factoren:	indicatie												
Ontwerpsnelheid	70 km/h	x	1			x	1			x	6		
Aantal rijbanen	FE1.2	x	3										
Gevaarlijke stoffen	ADR-E							x	3				
Grondwaterstand	GWS NAP +2.0m									x	6		
Grondsoort	klei op veen					x	9					x	9
Totale GVI-score		**4**		**0**		**10**		**3**		**12**		**9**	

A—18Voorbeeld opzetten GVI-matrix

<u>2B. Interne factoren - vaststellen CI-R en CI-S (koppelingsindex)</u>
Met het vaststellen van de GVI is bekend welke modules gevoelig zijn voor verandering door externe factoren. De wijzigingen van een module aan de hand van deze factoren kan daarbij ook andere (interne) veranderingen in het ontwerp met zich mee brengen. Dit zijn de veranderingen die nodig zijn om de wijzigingen van de module op te vangen. Er is in dit geval sprake van een zekere koppeling tussen modules. Volgens Ulrich (1995) zijn componenten binnen modulaire productarchitecturen ontkoppelbaar; de geschetste koppeling tussen modules is dus niet aanwezig. Om dit te bewerkstellingen is het cruciaal een beschrijving van de fysieke raakvlakken van het modulaire productplatform te hebben.

De koppelingsindex wordt door Martin & Ishii (2002) gedefinieerd als een indicator voor de mate van koppeling tussen de modules binnen een object. Bij een sterke koppeling tussen modules is de kans groot dat, door het wijzigen van een module, een aangrenzende module ook moet veranderen. De koppelingsindex wordt vastgesteld door aan te geven welke 'informatiestroom' in het fysieke raakvlak tussen modules wordt doorgegeven. Deze informatiestroom wordt ook wel omschreven als de ontwerpinformatie die ontwerpers onderling moeten uitwisselen om hun eigen module te kunnen ontwerpen. Dit zijn de stappen die doorlopen moeten worden om de koppelingsindex vast te stellen:

- I. In kaart brengen informatiestroom tussen modules: (zie tabel components and functions)
  Er wordt verder gebouwd op de vastgestelde modules uit stap 1. Deze modules worden verspreid op papier gezet waarbij ze worden begrensd door middel van een cirkel. Vervolgens wordt per module de in- en uitgaande informatiestroom bekeken. Eerst worden pijlen gezet tussen de modules waarmee wordt aangegeven dat er een raakvlak is. Vervolgens worden de raakvlakken concreet gemaakt door aan te geven welke specifieke informatie er nodig is van module B om module A te ontwerpen. Omgekeerd gebeurt dit ook; welke informatie van module A is nodig om module B te ontwerpen.
- II. Analyseren gevoeligheid interne factor-wijziging – bepalen CI-R/CI-S-score. De resultaten worden verwerkt in een matrix (zie figuur 4.6) waarbij de modules tegen elkaar worden uitgezet. In de bovenste rij komen de modules te die informatie vereisen en in de linker rij de modules staan die informatie afgeven. Vervolgens wordt bepaald welke modules gevoelig zijn voor aanpassingen aan aangrenzende modules. Dit wordt gedaan aan de hand van de gevolgen van een (kleine/grote) verandering in de informatiestroom. Als een kleine verandering in de informatiestroom een verandering van de module tot gevolg heeft, heeft deze een hoge gevoeligheid. Wanneer een grote verandering geen veranderingen van een module met zich meebrengt heeft deze een lage gevoeligheid. Bij de beoordeling wordt een waarde toegekend tussen de 1 en de 9, waarbij een lage waarde een lage gevoeligheid voorstelt. De waarde wordt per module toegekend en in de matrix weergegeven (zie figuur5)
- iii. Berekenen totale CI-R en CI-S score per module:
  Als laatste worden de CI-R en CI-S scores die aan een module zijn toegekend opgeteld.
  De CI-S score van de module wordt weergegeven in de rechterrij en de CI-R score van de module in de onderste rij.(Let op, dit is anders als in het voorbeeld)

<u>CI rating system for sensitivity of specifications - Rating Description</u>
9 Small change in specification impacts the receiving component (high sensitivity)
6 Medium-high sensitivity
3 Medium-low sensitivity
1 Large change in specification impacts the receiving component (low sensitivity)
0 No specifications affecting component

Koppelings-index (CI)		Modules die informatie afgeven						
		Module A	Module B	Module C	Module D	Module E	Module F	CI-R
Modules die informatie vereisen	Module A			x 1		x 6		7
	Module B			x 3	x 9			12
	Module C		x 2		x 3			5
	Module D	x 4				x 6		10
	Module E							0
	Module F	x 3	x 9					12
	CI-S	7	11	4	12	12	0	

A—19 Voorbeeld van opzetten CI-R en CI-S matrix (In Excel bestand vaiduct: net andersom)

Onderzoeken (en vastleggen) te standaardiseren/modulariseren modules

Op basis van Martin & Ishii (2002) zijn de variatie-index over tijd (GVI) en de koppelingsindex (CI-R en CI-S) voor alle modules vastgesteld. Aan de hand van de volgende ontwerpregels uit Martin & Ishii (2002) (zie figuur 6) kan worden bepaald welke modules geschikt zijn voor standaardisatie dan wel modularisatie. Voor de betekenis van de waardes word u verwezen naar paragraaf 1,7.

Uitleg methode

Binnen mijn onderzoek zal de methode van Vanessa Veenstra toegepast worden, zoals is paragraaf 1.2 besproken.
U word betrokken bij de processen b en c. Welke en hoe deze tabellen ingevuld moeten worden is uitgelegd in paragraaf 1.4,1.5,1.6.

Invullen tabel koppelings-indexen - Directe constructieve relatie

a. *Directe relatie: interface*

1. *Identificeer relaties tussen de elementen*
   Markeer welke elementen van het viaduct een directe relatie(interface), ofwel welke verschillende elementen zijn aan elkaar verbonden/ zitten direct aan elkaar vast. Dit geeft een indicatie in welke mate de elementen direct invloed op elkaar hebben. Als element A en B een koppelingsrelatie hebben, zal een verandering in het element A van invloed zijn op het element B. Binnen deze tabel; "directe constructieve relatie", is het de bedoeling dat men alleen naar de direct koppeling kijkt. Hierbij kijkt men dus niet naar de parametrische (verschaling) relaties. Hiervoor is een aparte tabel, die na het invullen van de directe constructieve relaties ingevuld zal moeten worden.
2. *Toekennen waardes van mate van koppeling*
   In deze stap moet men de vraag stellen: als ik component A veranderd, wat heeft dit voor effect op component B. Ofwel hoeveel moet component B dan aangepast worden, zodat het geheel blijft functioneren. Geeft de gemarkeerde elementen een waarde van 1 tot en met 9, op basis van in welke mate de elementen aan elkaar gekoppeld zijn. Hierbij betekend 9 dat de elementen een grote koppelingsrelatie hebben, en 1 dat deze koppelingsrelatie erg klein is, maar wel aanwezig. De waarde 0 betekend dat er geen koppelingsrelatie is tussen de elementen, die is het geval voor de niet gemarkeerde vlakken.
3. *Optellen waardes in tabel*
   Tel de waardes in horizontale richting bij elkaar op: CI-S(staat voor coupling index – supply, ofwel koppeling index afgifte). Tel de waardes in verticale richting bij elkaar op CI-R (staat voor couplingindex- recieve, ofwel koppeling index ontvangst)
4. *Analiseer de tabel met de uitkomsten.*
   Deze stap zullen we tijdens de brainstormsessie bespreken. Op basis van de door u, en door de andere constructeurs, gegeven relaties en hun waarde. In paragraaf 1.7 word uitgelegd wat de verschillende waardes betekenen.

Koppelings-index (CI)		Modules die informatie afgeven						
		Module A	Module B	Module C	Module D	Module E	Module F	CI-R
Modules die informatie vereisen	Module A			x 1		x 6		7
	Module B			x 3	x 9			12
	Module C		x 2		x 3			5
	Module D	x 4				x 6		10
	Module E							0
	Module F	x 3	x 9					12
	CI-S	7	11	4	12	12	0	

A—20 Voorbeeld tabel koppelings-index

Invullen tabel koppelings-indexen - Parametrische relatie (verschaling)

b. *Parametrische relatie*

1. *Identificeer relaties tussen de elementen*
   Markeer welke elementen van het viaduct een parametrische relatie hebben, ofwel welke verschillende elementen zijn van invloed op elkaar wanneer de elementen vergroot of verkleind worden. Dit kan gezien worden als in welke mate de elementen invloed op elkaar hebben. Als element A en B een parametrische koppeling relatie hebben, zal een verandering in de dimensionering van element A van invloed zijn op de dimensionering of andere karakteristieken van element B.
   Bijvoorbeeld, als een dek zwaarder gedimensioneerd moet worden, heeft dit invloed op de onderdelen die de krachten van het dek naar de grond afdragen. Dit kan dus invloed hebben op meerdere elementen, de dimensionering van de funderingspalen zullen bijvoorbeeld aangepast moeten worden.
2. *Toekennen waardes van mate van koppeling*
   Geeft de gemarkeerde elementen een waarde van 1 tot en met 9, op basis van in welke mate de elementen parametrisch invloed hebben op elkaar. Hierbij betekend 9 dat de elementen een grote parametrische koppelingsrelatie hebben, en 1 dat deze parametrische kopplingsrelatie erg klein is, maar wel aanwezig. De waarde 0 betekend dat er geen koppelingsrelatie is tussen de elementen, dit is het geval voor de niet gemarkeerde vlakken.
   Het is belangrijk dat goed wordt gedocumenteerd waarom bepaalde waardes toegekend worden.
3. *Optellen waardes in tabel*
   Tel de waardes in horizontale richting bij elkaar op: CI-S (staat voor couplingindex- supply, ofwel koppelingindex afgifte). Tel de waardes in verticale richting bij elkaar op CI-R (staat voor couplingindex – recieve, ofwel koppelingindex ontvangst).
4. *Analiseer de tabel met de uitkomsten.*
   Deze stap zullen we tijdens de brainstormsessie bespreken. Op basis van de door u, en door de andere constructeurs, gegeven relaties en hun waarde. In paragraaf 1.7 word uitgelegd wat de verschillende waardes betekenen.

Invullen tabel General Variety Index (GVI)

1. *Kans optreden situatie*
   Kans dat de geschetste situatie optreedt. (Chance of occurence/likely to happen)
   Geeft waardes van 1, 2 of 3.
   3= Zeer waarschijnlijk (High chance of occurence)
   2= Gemiddeld (Medium chance of occurence)
   1= Kleine kans (Small chance of occurence)
   Deze waardes, zullen meegenomen worden in de tabel als weegfactor. Deze vermenigvuldiging hoeft u zelf niet te berekenen.
2. *Identificeer welke elementen beïnvloed worden.*
   Markeer welke elementen van het viaduct beïnvloed worden/zullen moeten veranderen door de nieuwe situatie(de nieuwe situatie staan in de linker kolom). De waarde geeft aan hoe gevoelig het component is voor veranderingen die mogelijk plaatsvinden. Hierbij moet men dus de vraag stellen hoeveel er aan een component veranderd moet worden, als men te maken krijgt met veranderde omstandigheden.
3. *Toekennen waardes – mate van invloed*
   In deze stap moet de gevoeligheid, de hoeveelheid verandering die nodig is, ingevuld worden. Dit door de gemarkeerde elementen een waarde van 1,3,6, of 9 toe te kennen. Om aan te geven hoeveel invloed de geschetste situatie zal hebben. Hier betekend 9 een zeer grote invloed, het element zal significant veranderd moeten worden en 1 bijna geen invloed, slecht een kleine verandering is nodig.
4. Optellen waardes in de tabel – verticale richting
   Tel de waardes in verticale richting bij elkaar op, onderaan de tabel. De uitkomst is de GVI waarde van de verschillende elementen. Hoge GVI-waarde betekend dat het zeer waarschijnlijk is dat het specifieke component aan veranderingen onderhevig is. En geeft hiermee dus een indicatie van de kans dat ontwerp van het component aangepast zal moeten worden.
5. *Voeg eventuele "change of occurence/likely to happen" in de tabel toe.*
   Verandering waarvan u denkt dat dit invloed heeft op het ontwerp van een viaduct en nog niet opgenomen is in de tabel, mag/kunt u toevoegen. Hiervoor is lege ruimte gereserveerd in de tabel.
6. *Optellen waardes in de tabel – horizontale richting*

Tel de waardes in horizontale richting bij elkaar op. Hier maakt u gebruik van een kolom: Sum. Vervolgens moeten deze waardes vermenigvuldigd worden met de “kans dat de geschetste situatie optreedt”. Zet deze vermenigvuldigde waardes in de tabel: Sum –with weight factors. Dit geeft een beeld van hoe groot de kans is dat de situatie voorkomt, gecombineerd met wat dit betekend voor de verschillende elementen.

7. *Analiseer de tabel met de uitkomsten.*
Deze stap zullen we tijdens de brainstormsessie bespreken. Op basis van de door u, en door de andere constructeurs, gegeven relaties en hun waarde. In paragraaf 1.7 word uitgelegd wat de verschillende waardes betekenen.

Variatie-index (GVI)		Module A		Module B		Module C		Module D		Module E		Module F	
Externe factoren:	indicatie												
Ontwerpsnelheid	70 km/h	x	1			x	1			x	6		
Aantal rijbanen	FE1.2	x	3										
Gevaarlijke stoffen	ADR-E							x	3				
Grondwaterstand	GWS NAP +2.0m									x	6		
Grondsoort	klei op veen					x	9					x	9
Totale GVI-score		**4**		**0**		**10**		**3**		**12**		**9**	

A—21Voorbeeld GVI

Wat betekenen de waardes

l. Standaardisatie (GVI en CI-R gerelateerd)

- *Volledig te standaardiseren modules:*
Van deze modules wordt verwacht dat ze over tijd niet zullen veranderen. Dit betekent dat de GVI en CI-R van de module beide gelijk zijn aan 0 (nul). De CI-S is hierbij niet van toepassing want of deze nu hoog of laag is heeft geen consequenties.

ll. Modularisatie (CI-S gerelateerd)

- *Volledig te modulariseren modules:*

De kenmerken van deze modules kunnen worden aangepast aan wijzigende externe/interne factoren, zonder dat dit consequenties heeft voor andere modules. Dit betekent dat de CI-S van deze module gelijk is aan 0 (nul).

- *Gedeeltelijk te modulariseren modules:*

Door veranderingen in de kenmerken van de module moeten ook aangrenzende modules worden aangepast. Dit komt omdat de CI-S van deze module hoger is dan 0 (nul). Bij een relatief lage CI-S score is het nog mogelijk om gedeeltelijk te modulariseren, bijvoorbeeld door verschillende modules te maken die de CI-S waarde terug naar 0 (nul) brengen.

- *Niet te modulariseren modules:*

Hoe hoger de CI-S van een module, hoe meer aanpassingen aan een aangrenzende module worden verwacht en des te minder modulair de module zelf is. Bij relatief hoge waarden van de CI-S en het gegeven dat de GVI en CI-R geen 0 (nul) zijn, loont het daarom niet meer om de betreffende modules te standaardiseren/modulariseren.

Standaardisatie	GVI	CI-R	CI-S
Volledig	0	0	0
	0	0	>0
Modularisatie	**GVI**	**CI-R**	**CI-S**
Volledig	>0	>0	0
Gedeeltelijk/Niet	>0	>0	>0

A—22 Standaardisatie vs. Modularisatie

Consequenties integrale vs modulaire productarchitectuur.

Aan de hand van de aanhangers van Ulrich (1995) wordt in deze bijlage toegelicht wat de consequenties zijn van een integrale productarchitectuur. Een viaduct, op de manier zoals die nu wordt gebouwd, heeft een integrale architectuur. In de figuren op pagina 7, heeft aanhanger 1 een modulaire productarchitectuur en aanhanger 2 een integrale productarchitectuur.

Functie valt weg

Wanneer het niet meer nodig is om de lading te beschermen tegen weersinvloeden (het is bijvoorbeeld altijd droog), dan kan bij aanhanger 1 de 'box' worden verwijdert. Bij aanhanger 2 kan dit niet; het verwijderen van de 'bovenste helft' heeft ook consequenties voor andere functies die door de module worden ingevuld. Door het verwijderen van de 'bovenste helft' zou bijvoorbeeld ook de last dragende functie van de aanhanger komen te vervallen.

Functie verandert

Wanneer aanhanger 1 minder last hoeft te dragen dan waar die op is gedimensioneerd, kan zonder bijkomende gevolgen de 'aanhangerbodem' worden aangepast. Bij aanhanger 2 kan dit niet; omdat de 'bovenste helft' van de aanhanger naast een last dragende functie meerdere functies vervult, moet continu worden gecontroleerd of de module ook blijft voldoen aan de functionele eisen van de overige functies.

Het is ook mogelijk dat er elementen/modules van het systeem aangepast moeten worden, zonder dat hier een functionele verandering aan ten grondslag ligt. Het kan bijvoorbeeld zijn dat een wijziging van een aspecteis op het gebeid van onderhoud of veiligheid, de basis is voor aanpassing van een module. Ook een raakvlakeis kan er voor zorgen dat een module moet worden aangepast.

Een element veranderd

Het veranderen van een module zonder dat hier een functionele verandering aan ten grondslag ligt, heeft zijn consequenties. Wanneer we bijvoorbeeld de aanhanger aan willen sluiten op een auto met een grotere trekhaakkogel (raakvlakeis), dan kan bij aanhanger 1 de dissel zonder gevolgen worden vervangen door een grotere dissel. Het vervangen van het neusdeel van aanhanger 2 voor een neusdeel met een grotere kop, heeft ook consequenties voor de functies 'minimaliseren luchtweerstand' en 'dragen lading'; het kan zijn dat deze functies nu minder goed worden ingevuld. Ulrich (1995) doet deze constatering ook. Hij stelt dat de architectuur van het product sterk gerelateerd is aan het gemak waarmee een verandering van het product kan worden geïmplementeerd. Een modulaire productarchitectuur heeft daarbij voordeel ten opzichte van de integrale productarchitectuur. Daarnaast heeft volgens hem een modulaire productarchitectuur voordelen t.o.v. een integrale productarchitectuur op het gebied van componentstandaardisatie, het op een kosteneffectieve wijze creëren van een variatie aan producten, productprestaties en op het gebied van productontwikkeling.

Deze uitleg van de methode is gebaseerd op de methode van Martin en Isshi en de methode die Wouter Schepers heeft gebruik in zijn thesis.

A.17 COMPONENTS AND THEIR FUNCTION

Viaduct: Engineering construction (structural components)

Foundation

- Carry own load: Carry load of all the different structural components
- Carry load of variable forces: Traffic + Wind + extra add-ons
- Transfer load to the ground.

Elements foundation

- Foundation pad
- Foundation piles

Substructure

- Carry own load: Carry load of all the different structural components
- Carry load of variable forces: Traffic + Wind + extra add-ons
- Transfer load to other structural components, to eventually transfer the load to the ground.

The substructure can be split up into the following sections.

- Intermediate wall/columns (if present)
- Abutment or bank seat
- Wing Walls
  Holding ground in place
- Capping beam
  Distribute and divide the load equally towards intermediate column(s)

Superstructure

- Carry own load: Carry load of all the different structural components
- Carry load of variable forces: Traffic + Wind + extra add-ons
- Transfer load to other structural components, to eventually transfer the load to the ground.

The superstructure can be split up into the following sections:

- Core elements
  - Deck: Prefabricated box-beams
    Facilitate road traffic
  - Edge beam (prefabricated)
    Architectonic view
- Extensions
  - Pavement: asphalt
    Facilitate road traffic
  - Edge element (finishing)
    Architectonic view
  - Parapets (pedestrian + traffic)
    Prevent road-users from falling on the main road or off the viaduct
  - Upstand
    Block vehicle(s)
  - Safety guards (or guard rail)
    Prevent vehicles from breaking off, and therefore falling off the road.

Bearings, expansion joints and approach slab

Between the superstructure and the substructure a bearing is needed to transfer the loads. These transitions consist of bearings and expansion joints.

- Carry own load: Carry load of all the different structural components
- Carry load of variable forces: Traffic + Wind + extra add-ons
- Transfer load to other structural components, to eventually transfer the load to the ground.

- Bearings
  Accommodate variable load
- Expansion joints (between abutment/bank seat and beams)
  Cope with dilatation and shrinkage

- Connection between approach slab and abutment/bank seat)
  Provide comfortable transition between.
- Approach slab
  Provide comfortable transition between (settlement ground and structure)

<u>Viaduct: Non- structural components – Installations + Road</u>

- Facilitate road traffic

- Traffic signs (general and interactive or digital signs)
  Manage traffic system + Inform road users
  - *Provide guidance*
  - *Give directions*
  - *Inform road user about current situation*
- Lighting
  Provide clear view for road-users.
- Cables (electricity etc.)
  Provide electricity
- Water drainage
  Provide dry deck, drain rainwater
- Camera’s and sensors
  Collect data to inform road users and maintenance staff
  - *Collect data about the traffic flow, under and above of the viaduct.*
  - *Collect data about the technical aspects of the viaduct. (the condition/quality of the viaduct)*

Table – components versus functions

Functions vs components / Prefabricated concrete viaduct (NL)		Foundation		Substructure				Superstructure							Bearings, expansion joints and approach slab				Non- structural components					
								Core	Extension															
A	B	Foundation pad (pad for intermediate wall/column(s))	Foundation piles	Intermediate wall/column(s)	Abutment or bank seat (including foundation pad)	Capping beam	Wing walls	Deck: prefabricated beams (box-beams)	Edge beam: prefabricated	Pavement: Asphalt	Edge element (finishing)	Parapets (pedestrians + traffic)	Upstand (schampkant)	Safety guards	Bearings	Expansion joints(abutment/bank seat and deck + beams at the location of the intermediate pier)	Connection between approach slab and abutment/bankseat	Approach slab	Traffic signs (static and digital)	Lighting	Cables	Water drianage	Camara's and sensors	*Number of components a function has*
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
Functions																								
Carry and transfer load																								
Carry own load: Carry load of the different structural components	1																							6
Carry load of variable fources: Traffic + Wind + extra add-ons	2																							7
Transfer load to other structural components, to eventually transfer load to the ground	3																							8
Holding ground in place	4																							1
Facilitate																								
Faciliate road traffic	5																							1
Provide dry deck	6																							1
Architectonic view																								
Provide demanded architectonic view (fit within the surronding area)	7																							2
Safety of the road user																								
Prevent road users from falling on the main road or off the viaduct	8																							1
Block vehicles: Prevent vehicles from shifting to other roadtrack and/or falling off the viaduct	9																							2
Transition/connection																								
Cope with dilatation and shrinkage	10																							3
Provide comfortable transition between.	11																							3
Manage traffic system																								
Manage traffic system - General	12																							
Provide guidance	13																							2
Give directions	14																							1
Guide traffic interactively	15																							1
Manage traffic system - Infrom road user of variable situations																								
Inform users about current situation of the infrastructural system	16																							1
Manage traffic system - Collect data to inform road users and maintenance staff																								
Collect data about the traffic flow, underneath and above viaduct	17																							1
Collect data about the technical aspects of the viaduct	18																							1
Number of functions a component has		3	1	3	3	3	1	3	4	1	1	1	1	1	1	2	2	1	4	1	0	1	2	

Table A—12 Components versus functions

A.18 Five pillars present in the initiatives/projects

W&R concept for modular housebuilding		*Applied*
Reference object	Reference design is the starting point. Make use of a product platform (one grid).	X
Building process	One continuous process. The planning is based on one standard element; the tunnel structure they apply as the constructive basis for the houses. In addition, the project team moves from one project to another project. Projects are planned in such a way that they fully use their own capacity). By this the various disciplines of the fixed team always has a project to work on, and no other work forces that have not experience with the concept have to be hired.	X
Project team	Work preparator, project leader and project managers are fixed. In addition, it is preferred to have skilled team members that have experience with the W&R concept for the assembly on site.	X
Co-makers	Within the concept of W&R co-makers are needed. BAM Housing applies long-term relationships with a fixed number of suppliers and sub-contractors. Use framework contracts for an undetermined period of time.	X
Client focus	The design is made by adapting the reference design. The architect and the client together design the house, while still keeping an eye on the budget, considering their wishes, quality and price.	X
Click and Construct		
Reference object	A standard design is adapted by parametric modelling. (Conceptual design, no details)	X
Building process	Although the web application gives an approximate building time, no specification of how the building process should evolve is given, as the output of the web application is just a simple identification for the earlier stages of a project	X
Project team	-	
Co-makers	-	
Client focus	The web application has been developed to provide civil servants of municipalities and provinces, and architects and urban planners with a tool that could give a conceptual idea for the small bridge	X
Standard railway underpass design		
Reference object	Reference object is used, by parametric modelling the design is adapted to the specific situation. This is the bases of how the railway underpass should be developed eventually, but this process requires time and learning from other projects.	X
Building process	The process is fixed.	X
Project team	Partly work with fixed team members. This means some members of the design team, the project leaders and the management are involved within all the different projects of the standard railway underpass. However, the employees that are present at the building site are not fixed, in comparison to the example of the W&R concept.	
Co-makers	The standard railway underpass design is part of the Tunnel Alliance framework contract, with Pro-Rail. For the realization of the first two railway underpasses, now co-makers were involved. However, as around 50 new railway underpasses will needed to be built in the coming 5 years, the project team is considering to start working with co-makers. The first steps have been taken, as BAM Infra has proposed the idea of co-makers to different companies involved.	
Client focus	The design has been demand driven. Made specifically for the alliance with Pro-Rail. However, the design will not be significantly changed when applied in different situations. No specific design for a specific place will be developed. A design will be made by parametric modelling.	

Reference viaduct research		
Reference object	Apply a reference design. Technical specification choices are made based on developed flowcharts. These flowcharts are based on previous projects. When a new viaduct is developed the flowcharts are used.	X
Building process	Choices about the process are being taken in advance. (When choices about the needed components/modules are made, these influence the building process)	X
Project team	The research advices a fixed project team	X
Co-makers	-	
Client focus	Although the reference viaduct will be constructed out of different standardised components/modules, the aesthetic requirements of the client have been considered, as the edge-element can be design individually for each project.	X
Gravity based foundations		
Reference object	The developed design should be a standard, and hereby a reference for other projects. The reference can be adapted to the different situation, considering the water-depth, wave heights and sea bed conditions.	X
Building process	The building process is fixed, can be applied in each situation	X
Project team	-	
Co-makers	Within this project BAM is cooperating with Van Oord. BAM and Van Oord here share their knowledge and expertise with each other.	X
Client focus	The developed design is made with market push. The concept has been developed by BAM and can be applied within different projects, considering different clients.	
Modular development and construction		
Reference object	An installation catenary is custom designed from pre-designed standardised modules (references), by using the BAM MEC software. The modules are combined based on the functional requirements.	X
Building process	A BIM-model is made, this model also addresses how the different modules should be assembled and a time schedule is given (3D and 4D model)	X
Project team	-	
Co-makers	-	
Client focus	Although the installation catenaries are custom designed, they are made out of standard components. Here fore, the choices the client has are limited.	X

Table A—13 Five pillars present in the initiatives/projects

A.19 SURVEY: QUESTIONS AND RESULT

Enquête afstudeeronderzoek: Standaardisatie en modularisering van een viaduct

Beste medewerkers van BAM Infra en BAM Infraconsult,

Voor mijn afstuderen aan de Universiteit Twente, master Civil Engineering and Management, ben ik op dit moment bezig met een onderzoek binnen uw organisatie. Mijn afstuderen betreft de toepassingsmogelijkheden van standaardisatie en modularisering, ook wel beter bekend als "legolisering". Hierbij onderzoek ik of standaardisatie en modularisering geschikt en gunstig zijn voor BAM Infra/Infraconsult en hoe dit binnen BAM Infra/Infraconsult kan worden geïmplementeerd. Hierbij is het onderzoek gericht op een infrastructureel object, een viaduct.
Het onderzoek voer ik uit binnen de afdeling multidisciplinaire projecten van BAM Infra. Mijn begeleiders zijn Jeroen Dunnebacke, Bart Simons en Gerard Waayer.

De enquête is opgebouwd uit zeven delen.
Deel 1: Introductie van standaardisatie en modularisering
Deel 2: Algemene vragen
Deel 3: Huidige situatie binnen BAM Infra
Deel 4: Hoe kijkt u aan tegen standaardisatie en modularisering?
Deel 5: Toepassingsmogelijkheden van standaardisatie en modularisering voor een viaduct.
Deel 6: Hoe kan standaardisatie en modularisering geïmplementeerd worden binnen BAM Infra?
Deel 7: Afsluiting: Heeft u nog opmerkingen of vragen over deze enquête en/of mijn onderzoek in het algemeen?

Deze enquête is alleen bedoeld voor mijn onderzoek. Uw gegevens worden anoniem behandeld en niet voor andere doeleinden gebruikt. De resultaten van de enquête worden anoniem gepresenteerd in mijn afstudeerrapport. Het invullen van de enquête neemt ongeveer 20 minuten in beslag.

Hartelijke dank voor uw medewerking,

Ancella Stout

Als u nog vragen heeft betreffende de enquête of mijn onderzoek, of geïnteresseerd ben in de onderzoeksresultaten na afronding van mijn afstudeerrapport, dan kunt u uiteraard contact met mij opnemen. Dit op het volgende mailadressen: ancella.stout@bam.nl of ancellanne@gmail.com

Deel 1: Introductie

Binnen mijn afstudeeronderzoek onderzoek ik de toepassing mogelijkheden van de principes van mass customization, namelijk standaardisatie en modularisering, in de infrastructurele industrie. Hierbij kijk ik specifiek naar een viaduct.

Standaardisatie en modularisering

Bij standaardisatie en modularisering moet u zich het LEGO-concept voorstellen. Het ontwikkelen van een bouwwerk door het in elkaar zetten van standaard modulaire elementen heeft veel weg van de ideeën achter LEGO®. Standaard modulaire elementen kunnen namelijk worden gezien als de afzonderlijke LEGO-steentjes waarmee ontelbare combinaties kunnen worden gevormd, waarbij de connectie tussen de LEGO-steentjes vastligt (standaard interface). Men kan zelfs breder kijken door te stellen dat de LEGO-steentjes gemakkelijk uit elkaar te halen zijn en dan voor een nieuw LEGO-ontwerp gebruikt kunnen worden. Binnen een bouwproject is dit allemaal veel complexer, maar de ideeën zijn in de basis gelijk.

Ontwikkeling van product platform.

Het hogere doel van het toepassen van de standaardisatie en modulariseren is om uiteindelijk een product platform te ontwikkelen. Platform gedreven engineering binnen productontwikkelingsprocessen is gebaseerd op 'platform denken': het proces gericht op het identificeren en exploiteren van gemeenschappelijke kenmerken tussen de verschillende bouwkundige of infrastructurele objecten, producten en/of diensten, de beoogde doelgroepen en de realisatieprocessen. Dit door deze gemeenschappelijke kenmerken vast te leggen en het ontwerp hergebruikt kan worden om op efficiënte wijze nieuwe ontwerpen te kunnen ontwikkelen.

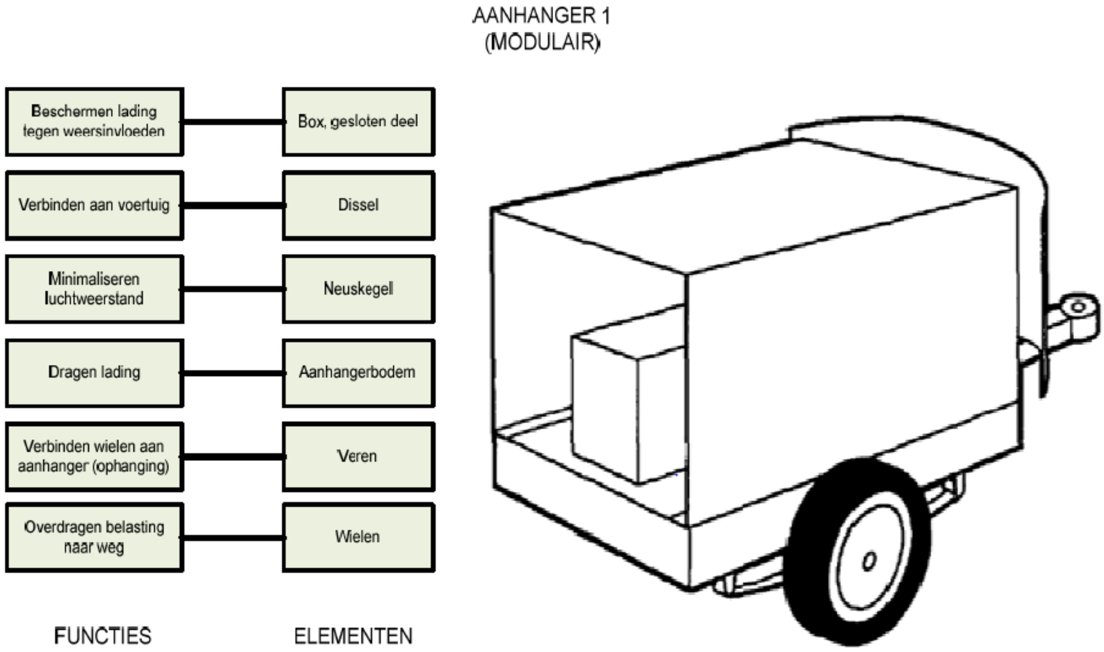
De principes van standaardisatie en modularisering, die van toepassing zijn bij een product platform, zijn afkomstig uit de mass customization industry. Hier worden de principes gebruik om de markt te voorzien van voldoende variatie aan producten, in essentie zal standaardisatie en modularisering resulteren in hogere flexibiliteit. Dit is in tegenstelling wat men vaak verwacht als je over een standaard begint, maar juist door de interface (hoe zijn elementen gekoppeld) vast te leggen kunnen er snel vele verschillende varianten worden ontworpen. Daarnaast zal men een zekere mate van productstandaardisatie aan kunnen brengen in de ontwerpprocessen. Men kan gebruik maken van de repetitie die aanwezig is. Hierbij kan men op efficiënte wijze variatie aanbieden, die voldoen aan specifieke eisen van de verschillende klanten, voor relatief lage kosten. Product platform word gedefinieerd als: een verzameling middelen (componenten, processen, kennis en personen) die worden gedeeld door meerdere producten.

Voor het toepassen van product platforms is het noodzakelijk dat wordt uitgegaan van:
1. Modulaire productarchitectuur - Een modulaire opzet
2. Interfaces - Standaard interfaces zodat modulen gemakkelijk kunnen worden vervangen door verbeterde versies zonder dat het productontwerp wijzigt (hoe elementen aan elkaar vastzitten ligt vast)
3. Standaarden - Het gebruik van ontwerpregels.

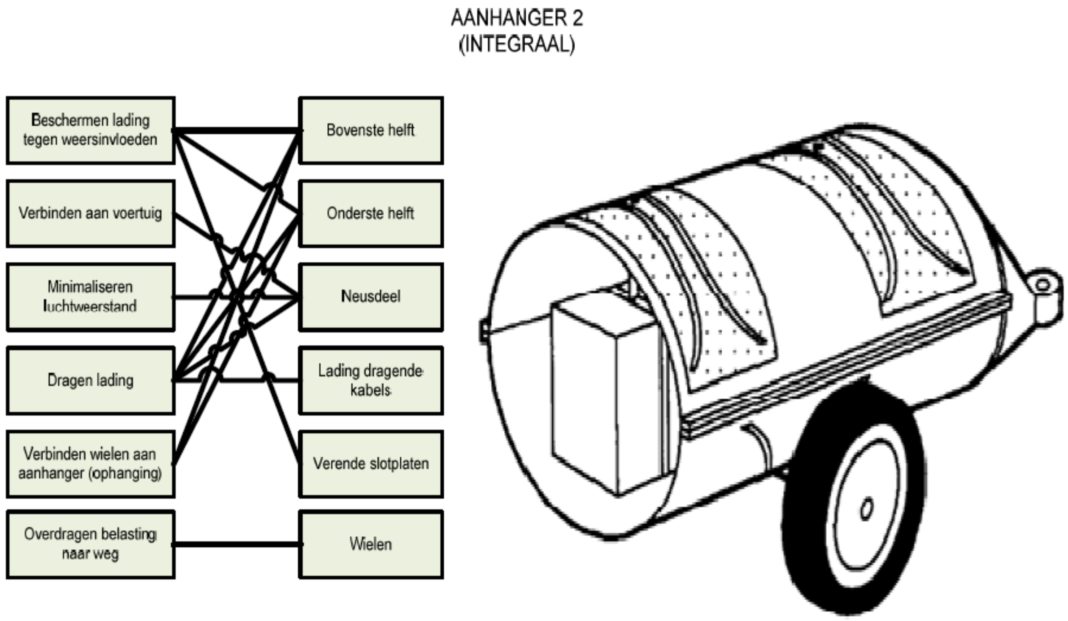
Daarnaast moet de productarchitectuur:
1. Zodanig modulair zijn dat subsystemen aan- en ontkoppeld kunnen worden.
2. Het platformdeel (subsystemen en/of raakvlakken) van de productarchitectuur zal als standaard aangemerkt worden.

In de figuren hierbeneden wordt een integrale aanhanger en een modularie aanhanger weergegeven. Het principe van modularisatie wordt hiermee relatief simpel gepresenteerd. De gedachte hierachter is dat als elementen slechts beperkte koppeling hebben met andere elementen (en hierbij functies) ,men door gebruikt te maken van een standaard interface (vastgelegd hoe elementen aan elkaar verbonden worden) deze elementen los van andere elementen kunnen worden ontworpen en kunnen worden door ontwikkelen. Echter is volledige modulariseren van objecten vaak niet mogelijk en niet wenselijk. Men heeft hier dus te maken met verschillende gradaties van modulariteit.

Aanhanger - modulair



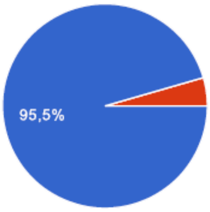
Aanhanger - Integraal



Deel 2: Algemene vragen

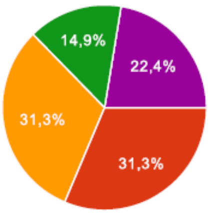
In deze sectie worden u wat algemene vragen stelt. Deze vragen worden gesteld omdat er mogelijk een relatie meetbaar is tussen de door uw beantwoorde vragen en uw geslacht, leeftijd, functie(s) en werkervaring .

2.1 Wat is uw geslacht?



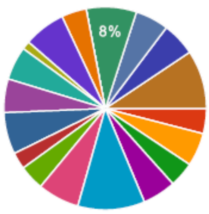
Man	**64**	95.5%
Vrouw	**3**	4.5%

2.2 Wat is uw leeftijd?



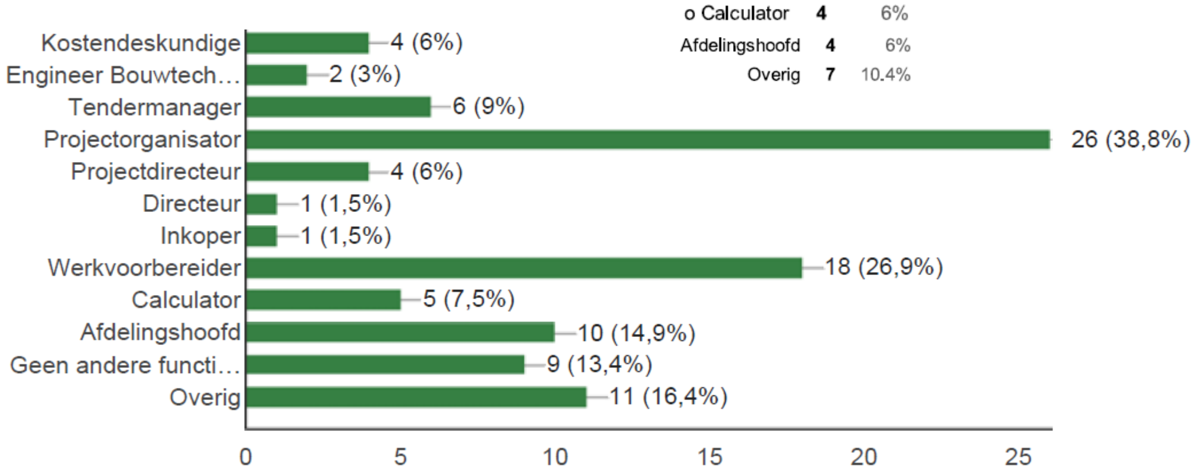
o Jonger dan 25	**0**	0%
o 25- 35 jaar	**21**	31.3%
o 36 – 45 jaar	**21**	31.3%
o 46 – 55 jaar	**10**	14.9%
o Ouder dan 55 jaar.	**15**	22.4%

2.3 Welke functie/rol heeft u momenteel?

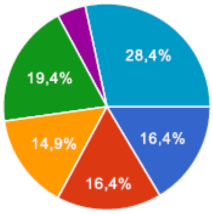


o Adviseur	**0**	0%
o Specialist	**3**	4.5%
o Ontwerper	**4**	6%
o Uitvoerder	**3**	4.5%
o Projectmanager	**4**	6%
o Projectleider	**8**	11.9%
o Projectorganisator	**5**	7.5%
o Uitvoerder	**3**	4.5%
o Procesmanager	**2**	3%
o Procescoördinator	**5**	7.5%
o Kostendeskundige	**4**	6%
o Engineer Bouwtechniek	**4**	6%
o Tendermanager	**1**	1.5%
o Projectorganisator	**5**	7.5%
o Projectdirecteur	**3**	4.5%
o Directeur	**0**	0%
o Inkoper	**0**	0%
o Werkvoorbereider	**6**	9%
o Calculator	**4**	6%
Afdelingshoofd	**4**	6%
Overig	**7**	10.4%

26 (38,8%)

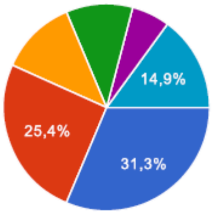


2.5 Hoeveel relevante werkervaring heeft u? (aantal jaren)



0-5	**11**	16.4%
5-10	**11**	16.4%
10-15	**10**	14.9%
15-20	**13**	19.4%
20-25	**3**	4.5%
>25	**19**	28.4%

2.6 Hoeveel jaar bent u al werkzaam voor BAM Infra of BAM Infraconsult?

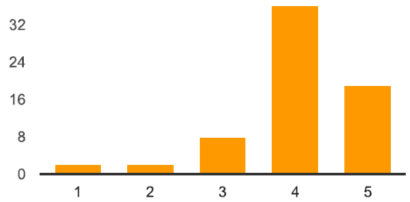


0-5	**21**	31.3%
5-10	**17**	25.4%
10-15	**8**	11.9%
15-20	**7**	10.4%
20-25	**4**	6%
>25	**10**	14.9%

Deel 3: Huidige situatie binnen BAM Infra en BAM Infraconsult (visie werknemers)

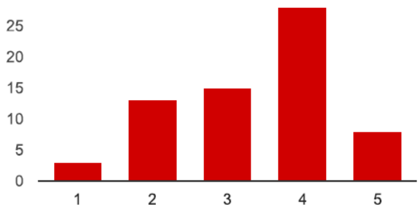
In deze enquête worden verschillende stellingen voorgelegd. Hierbij wordt gevraagd of u het eens of juist oneens bent met de stelling. Of er wordt gevraagd hoe u tegen de situatie aankijkt; positief of negatief. Indien nodig kan men in sommige gevallen een ander antwoord invoeren en/of toelichting geven. Daarnaast zijn er ook nog enkele open vragen opgenomen. De lineaire schaal in de vragen zijn genummerd van 1 tot en met 5. Voor oneens - eens betekend dit: 1= Sterk mee oneens 2= Eens 3= Neutraal 4= Oneens 5= Sterk mee eens Voor positief of negatief betekend dit: 1= Zeer positief 2=Positief 3= Neutraal 4= Negatief 5= Zeer negatief

3.1 Het ontwerpen van klant specifieke, unieke oplossingen kan ook worden gezien als het voortdurend opnieuw uitvinden van 'het wiel'. Dit leidt tot inefficiëntie en kost hierbij veel geld en tijd. In de bouw wordt veel tijd en geld gespendeerd aan het telkens opnieuw ontwerpen van vergelijkbare civiel technische objecten. *



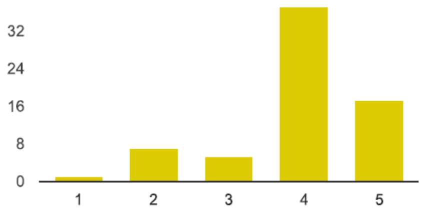
Sterk mee oneens: 1	2	3%
2	2	3%
3	8	11.9%
4	36	53.7%
Sterk mee eens: 5	19	28.4%

3.2 Binnen BAM Infra/Infraconsult is men continue het "wiel opnieuw aan het uitvinden". Elke project word vanaf 'scratch' ontworpen.



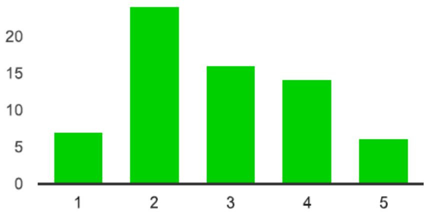
Sterk mee oneens: 1	3	4.5%
2	13	19.4%
3	15	22.4%
4	28	41.8%
Sterk mee eens: 5	8	11.9%

3.3 Stelling - Als u aan een nieuw project begint, bekijkt u al in de beginfase naar vergelijkbare al gedane/gerealiseerde werken om de "best-practices" mogelijk ook toe te passen in het nieuwe project. En daarnaast om gemaakte fouten te voorkomen in het nieuwe project. (Dit op alle vlakken; zowel technisch ontwerp als werkmethodes etc) *



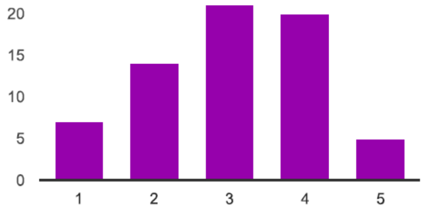
Sterk mee oneens: 1	1	1.5%
2	7	10.4%
3	5	7.5%
4	37	55.2%
Sterk mee eens: 5	17	25.4%

3.4 Binnen BAM Infra/Infraconsult (algemeen) wordt weinig gekeken naar al gerealiseerde projecten als referentie materiaal.



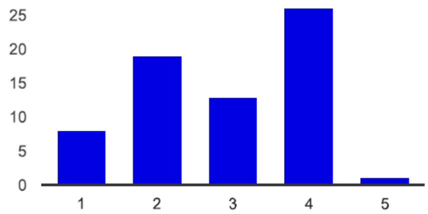
Sterk mee oneens: 1	7	10.4%
2	24	35.8%
3	16	23.9%
4	14	20.9%
Sterk mee eens: 5	6	9%

3.5 Binnen uw afdeling zijn constante optimalisatie van product en proces (verbeteringen doorvoeren) opgenomen in de huidige manier van werken. *



Sterk mee oneens: 1	**7**	10.4%
2	**14**	20.9%
3	**21**	31.3%
4	**20**	29.9%
Sterk mee eens: 5	**5**	7.5%

3.6 Gedurende het ontwerp en realisatieproces worden keuzes goed vastgelegd en worden deze tijdens en na afronding van het project goed gedocumenteerd.(Gemaakte keuzes,motivatie, planning, uitwerking ontwerp, terugkoppling etc)

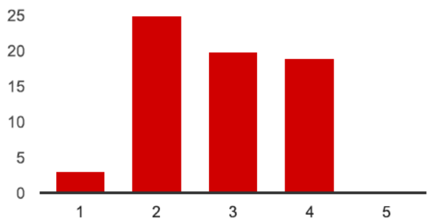


Sterk mee oneens: 1	**8**	11.9%
2	**19**	28.4%
3	**13**	19.4%
4	**26**	38.8%
Sterk mee eens: 5	**1**	1.5%

3.7 De verschillende soorten data (tenderdocumenten, voorlopig ontwerp, definitief ontwerp, uitvoeringsdocumenten etc) van verschillende projecten kunnen makkelijk verkregen worden om te bekijken. *

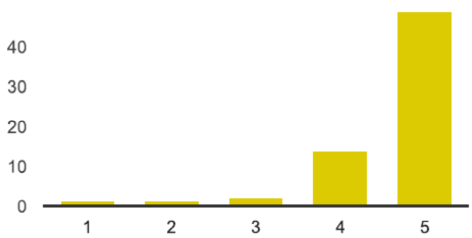
Sterk mee oneens: 1	**16**	23.9%
2	**23**	34.3%
3	**16**	23.9%
4	**12**	17.9%
Sterk mee eens: 5	**0**	0%

3.8 Er is constant terugkoppeling (feedback-loops) tijdens de verschillende fases van een project. *



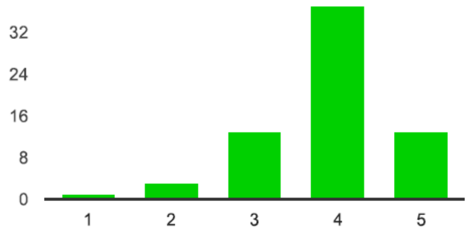
Sterk mee oneens: 1	**3**	4.5%
2	**25**	37.3%
3	**20**	29.9%
4	**19**	28.4%
Sterk mee eens: 5	**0**	0%

3.9 Het is belangrijk dat opgedane inzichten en geleerde lessen (lessons learned) in de verschillende projecten en binnen de verschillende afdelingen gedeeld worden binnen de hele organisatie. *
Door deze opgedane inzichten en lessen te delen binnen de hele organisatie, zal er grotere leer-curve ontstaan. Men zal hiermee meer project overstijgend kunnen werken.



Sterk mee oneens: 1	**1**	1.5%
2	**1**	1.5%
3	**2**	3%
4	**14**	20.9%
Sterk mee eens: 5	**49**	73.1%

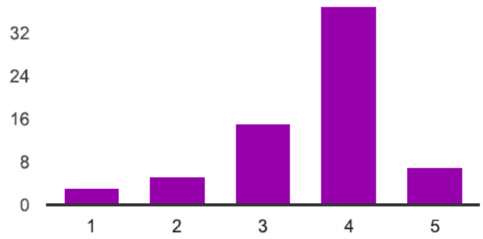
3.10 De communicatie (overleggen over en delen van documenten) tussen de verschillende disciplines werkzaam binnen een project zijn niet altijd effectief en efficiënt. Dit heeft verbetering nodig. *



Sterk mee oneens: 1	**1**	1.5%
2	**3**	4.5%
3	**13**	19.4%
4	**37**	55.2%
Sterk mee eens: 5	**13**	19.4%

3.11 Bent u van mening dat het implementeren van een interface de communicatie binnen BAM Infra en buiten BAM Infra/Infraconsult met andere bedrijven, zal verbeteren? *

Met een interface word bedoelt, zoals eerder uitgelegd: Een gedetailleerde beschrijving van de raakvlakken tussen deze modules/componenten. Hierbij is een standaard vastgelegd over hoe bepaalde elementen aan elkaar verbonden worden. Zolang men zich aan deze standaard houdt, kunnen verschillende elementen individueel van de elementen waar dit element mee gekoppeld is, worden ontworpen, aangepast en doorontwikkeld.

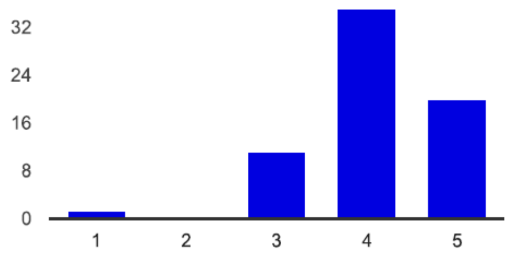


Sterk mee oneens: 1	**3**	4.5%
2	**5**	7.5%
3	**15**	22.4%
4	**37**	55.2%
Sterk mee eens: 5	**7**	10.4%

Deel 4: Hoe kijkt u aan tegen standaardisatie en modularisering?

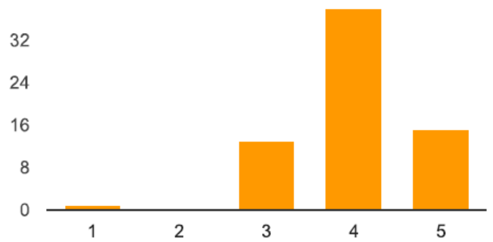
4.1 Hoe kijkt u in het algemeen aan tegen het toepassen van de principes van de mass customization (standaardisatie en modularisering), in de infrastructurele sector? *

Zeer negatief: 1	**1**	1.5%
2	**0**	0%
3	**11**	16.4%
4	**35**	52.2%
Zeer positief: 5	**20**	29.9%

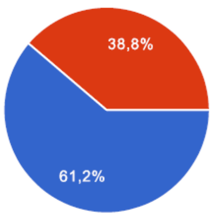


4.2 Hoe kijkt u aan tegen het toepassen van de principes van mass customization (standaardisatie en modularisering) binnen BAM Infra/Infraconsult?

Zeer negatief: 1	**1**	1.5%
2	**0**	0%
3	**13**	19.4%
4	**38**	56.7%
Zeer positief: 5	**15**	22.4%

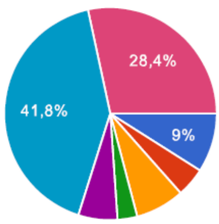


4.3 Heeft u ervaring met/meegewerkt aan projecten waar de principes van standaardisatie en/of modularisering zijn toegepast? *



Ja	**41**	61.2%
Nee	**26**	38.8%

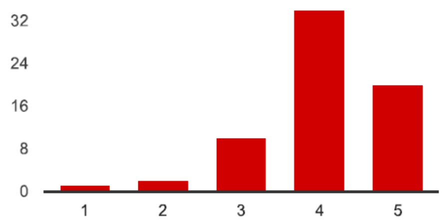
4.4 Als u meegewerkt hebt aan projecten waar iets met standaardisatie en/of modularisering is gedaan. Welk project was dit?



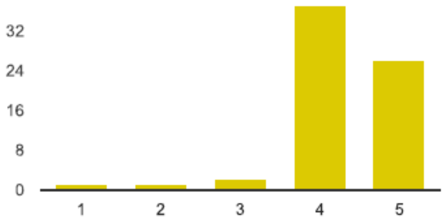
A12	**6**	9%
N18	**3**	4.5%
N261	**5**	7.5%
N33	**2**	3%
Onderzoek: W&R viaduct	**4**	6%
Niet van toepassing	**28**	41.8%
Overig	**19**	28.4%

4.5 Om een standaardisatie en modularisering te bewerkstellen, zal het nodig zijn om een gedeelde interface en/of referentieontwerp(en) te ontwikkelen.

Sterk mee oneens: 1	**1**	1.5%
2	**2**	3%
3	**10**	14.9%
4	**34**	50.7%
Sterk mee eens: 5	**20**	29.9%

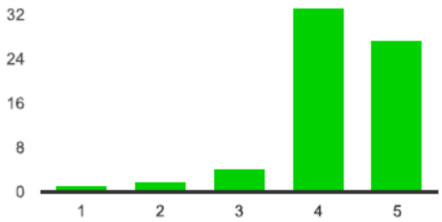


4.6 Om volledig te kunnen profiteren van een standaardisatie en modularisering (product platform) moeten product en proces op elkaar afgestemd worden.



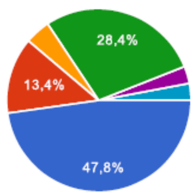
Sterk mee oneens: 1	**1**	1.5%
2	**1**	1.5%
3	**2**	3%
4	**37**	55.2%
Sterk mee eens: 5	**26**	38.8%

4.7 Het vroegtijdig betrekken van toeleveranciers, maar ook opdrachtgevers zoals RWS, ProRail, gemeentes en de provincies om hun hierbij te laten mee denken/werken aan het ontwerp (coproductie) zal het mogelijk/ gemakkelijker maken om een standaard of modulair ontwerp toe te passen binnen een specifiek project.



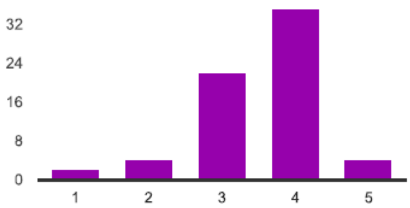
Sterk mee oneens: 1	**1**	1.5%
2	**2**	3%
3	**4**	6%
4	**33**	49.3%
Sterk mee eens: 5	**27**	40.3%

4.8 In welke fase van een project, bent u van mening dat standaardisatie en modularisering de grootste positieve invloed zal hebben?



o Tender fase	**32**	47.8%
o Voorlopig ontwerp	**9**	13.4%
o Definitief ontwerp	**3**	4.5%
o Realisatie/Bouw	**19**	28.4%
o Onderhoud	**2**	3%
o Afbouw/Afbreken kunstwerk	**2**	3%

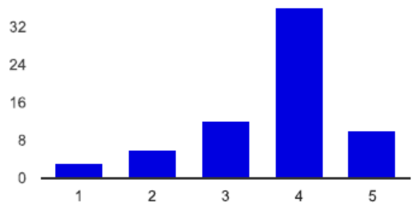
4.9 Ben u van mening dat als BAM Infra/Infraconsult standaardisatie en modularisering implementeert, en hierbij een referentie ontwerp(en) voor verschillende objecten ontwikkelt, dat er voldoende ontwerpvrijheid, flexibiliteit (ruimte voor verandering) is. Maar dat dit wel zo beperkt is dat men nog kan profiteren van de herhaling? (schaalvoordelen, hergebruik ontwerp, optimalisatie product en proces etc)



Sterk mee oneens: 1	**2**	3%
2	**4**	6%
3	**22**	32.8%
4	**35**	52.2%
Sterk mee eens: 5	**4**	6%

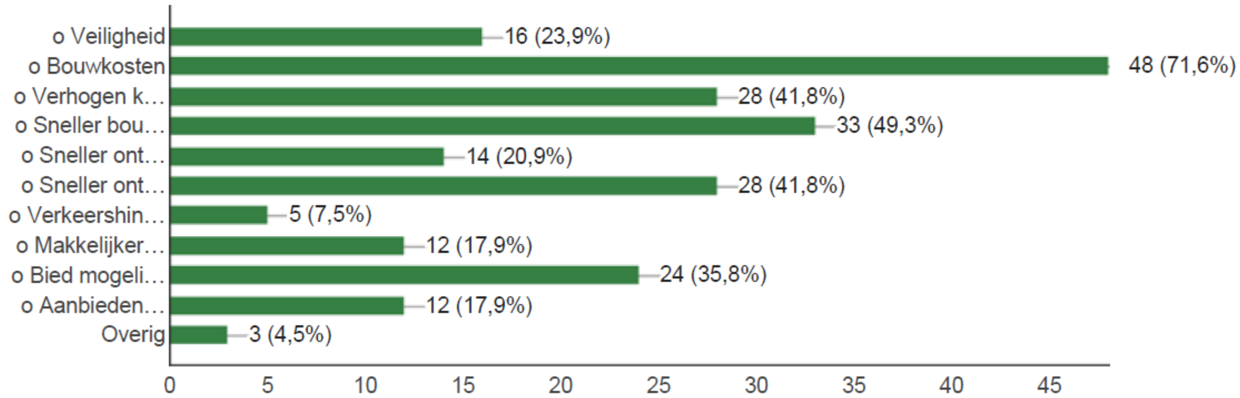
4.10 Hoe kijkt u aan tegen het ontwikkelen/gebruiken van een configurator?

Dit betekend dat men een catalogus ontwikkeld, waarmee het projectteam (en/of de klant) kan kiezen tussen verschillende opties voor de verschillende modules van het kunstwerk. Hierbij moet u denken aan als u een keuken wilt kopen bij Ikea. Dan kunt u online uw keuken in een 3D programma bouwen en keuzes maken tussen verschillende opties (kleur kastjes, handgrepen, aanrecht, vorm etc). De configurator bevat alle mogelijkheden (ook wel standaarden), waaruit men kan kiezen. En vanwege de modulaire verbindingen, kan alles verschillende opties met elkaar gecombineerd worden.



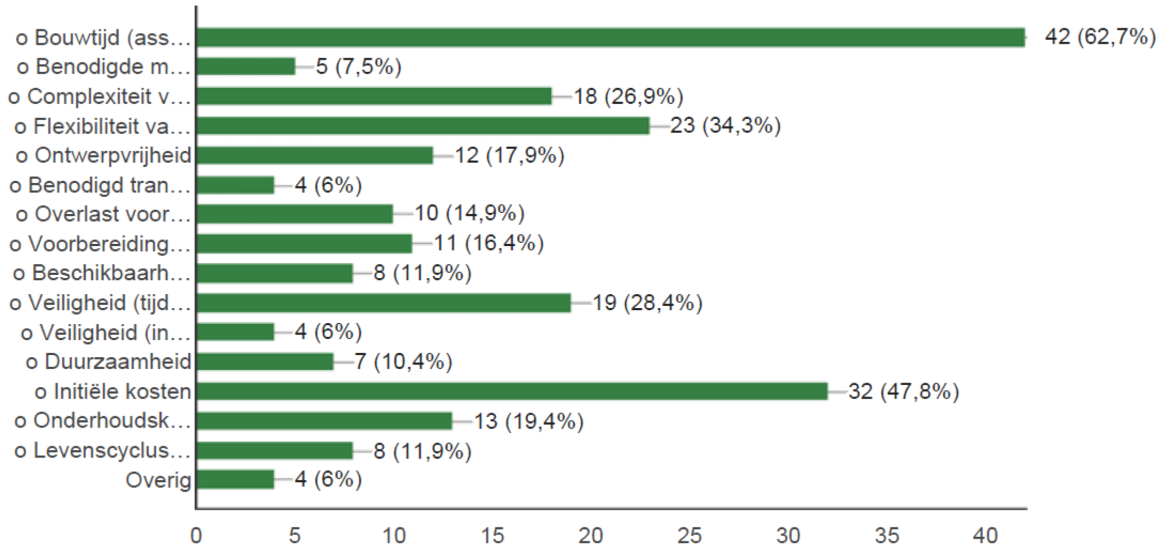
Zeer negatief: 1	3	4.5%
2	6	9%
3	12	17.9%
4	36	53.7%
Zeer positief: 5	10	14.9%

4.11 Welke aspecten zijn de belangrijkste redenen/ visie om standaardisatie en modularisering toe te passen binnen BAM Infra/Infraconsult? .



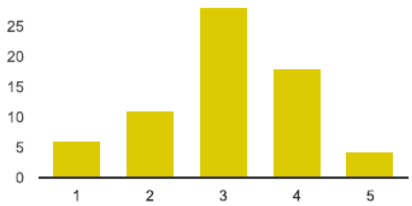
o Veiligheid	16	23.9%
o Bouwkosten	48	71.6%
o Verhogen kwaliteit: ervaring	28	41.8%
o Sneller bouwen	33	49.3%
o Sneller ontwikkelen (ontwerpfase)	14	20.9%
o Sneller ontwikkelen (tenderfase, zowel op ontwerp als op calculatie)	28	41.8%
o Verkeershinder minimaliseren (voertuigverliesuren)	5	7.5%
o Makkelijker verlenen van services en onderhoud in de toekomst	12	17.9%
o Bied mogelijkheden tot continue optimalisatie van product en proces	24	35.8%
o Aanbieden van variabiliteit tegen relatief lage prijs.	12	17.9%
Overig	3	4.5%

4.12 Als u een trade-off matrix zou moeten maken voor de implementatie van een standaard/referentie ontwerp. Welke criteria zou u dan beschouwen als meest belangrijkst?



o Bouwtijd (assemblage op locatie)	**42**	62.7%
o Benodigde materiële inzet	**5**	7.5%
o Complexiteit van de constructie in het algemeen	**18**	26.9%
o Flexibiliteit van de standaard	**23**	34.3%
o Ontwerpvrijheid	**12**	17.9%
o Benodigd transport (logistiek)	**4**	6%
o Overlast voor de omgeving tijdens de bouw.(Geluid, trillingen, voertuigverliesuren)	**10**	14.9%
o Voorbereidingstijd	**11**	16.4%
o Beschikbaarheid en betrouwbaarheid	**8**	11.9%
o Veiligheid (tijdens bouw)	**19**	28.4%
o Veiligheid (in gebruiksfase)	**4**	6%
o Duurzaamheid	**7**	10.4%
o Initiële kosten	**32**	47.8%
o Onderhoudskosten	**13**	19.4%
o Levenscyclus (demontabel bouwen)	**8**	11.9%
Overig	**4**	6%

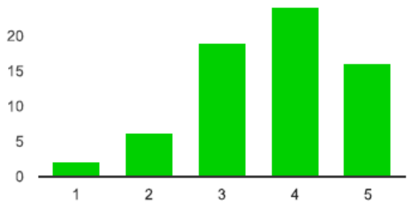
4.13 RWS maakt gebruik van functioneel specificeren. Hierbij word verondersteld dat dit men meer vrijheid heeft dan voorheen. Bent u het hiermee eens?



Sterk mee oneens: 1	**6**	9%
2	**11**	16.4%
3	**28**	41.8%
4	**18**	26.9%
Sterk mee eens: 5	**4**	6%

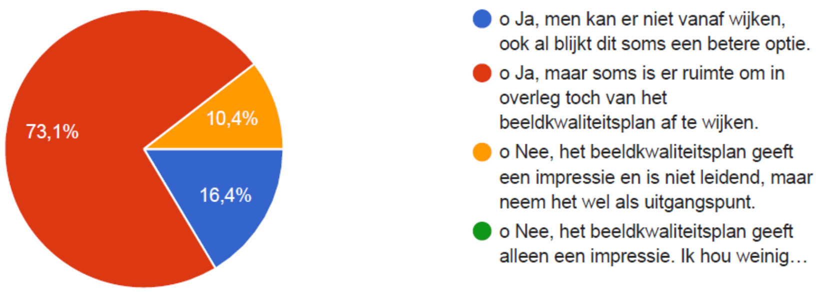
4.14 Bent u van mening dat de eisen van RWS nog steeds te specifiek zijn en daardoor beperkte ruimte om te innoveren aanwezig is?

Sterke mee oneens: 1	**2**	3%
2	**6**	9%
3	**19**	28.4%
4	**24**	35.8%
Sterk mee eens: 5	**16**	23.9%

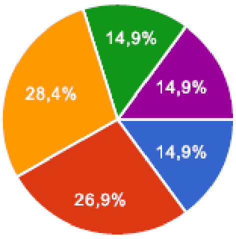


4.15 Ervaart u het beeldkwaliteitsplan als bindend? *

Het beeldkwaliteitsplan is origineel geïntroduceerd als een document dat een impressie en visie van de opdrachtgever weergeeft of wat voor ontwerp gewenst is. Echter wordt het beeldkwaliteitsdocument als bindend ervaren.



4.16 Denk u dat het mogelijk is om tussen de verschillende provincies en gemeentes afspraken te maken omtrent de uitvraag? Dit om het gebruiken van standaardisatie en modularisering mogelijk/makkelijker te maken.

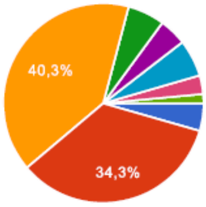


o Ja, er worden al initiatieven genomen op dit gebied (bvb het platform: WoW)	**10**	14.9%
o Ja, maar acht de kans klein dat dit zal gebeuren	**18**	26.9%
Geen idee	**19**	28.4%
o Nee, men zal niet overeenkomen over een standaard uitvraag.	**10**	14.9%
o Nee, want de provincies en gemeentes hebben hier geen direct belang bij. (bouwen relatief weinig viaducten)	**10**	14.9%

Deel 5: Toepassingsmogelijkheden van standaardisatie en modularisering voor een viaduct.

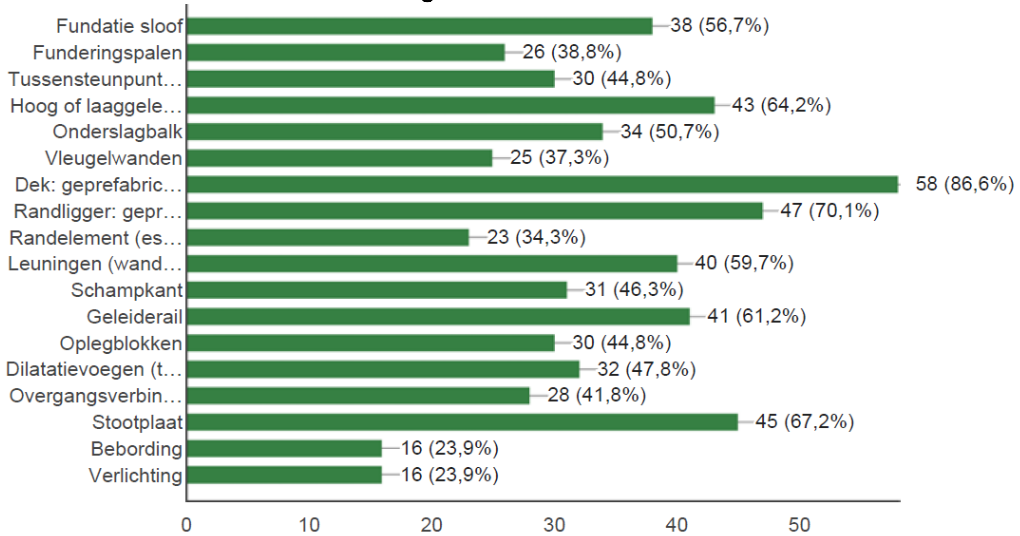
A.19.2

5.1 Binnen het W&R concept van BAM Woningbouw is een 80-20% principe van toepassing. Dit houdt in dat 80% van het ontwerp al volledig vaststaat en men alleen in de overige 20% kan variëren. Welke percentages denkt u dat realistisch is voor een viaduct?



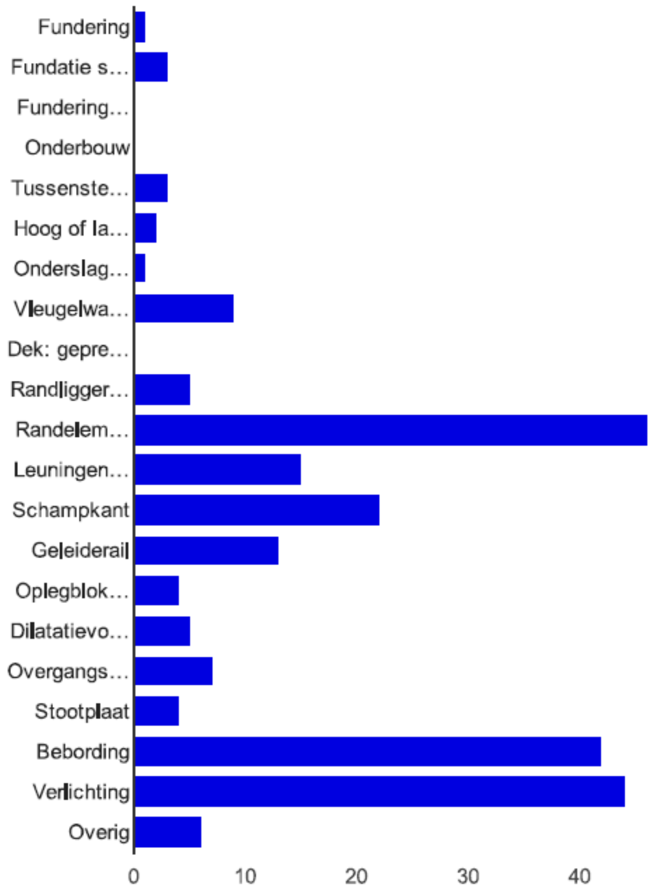
o 100 - 0% (volledig gestandaardiseerd)	3	4.5%
o 80 – 20%	23	34.3%
o 60% - 40%	27	40.3%
o 50-50%	4	6%
o 40 – 60%	3	4.5%
o 30 – 70%	4	6%
o 20 – 80%	2	3%
o 20< - <80% (kleiner dan 20 procent standaard, meer dan 80% variatie)	1	1.5%

5.2 Welke elementen/componenten zijn geschikt om het principe van mass customization toe te passen? Namelijk standaardisatie en modularisering.



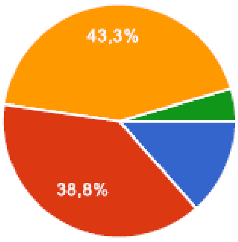
Fundatie sloof	38	56.7%
Funderingspalen	26	38.8%
Tussensteunpunt/wand	30	44.8%
Hoog of laaggelegen landhoofd	43	64.2%
Onderslagbalk	34	50.7%
Vleugelwanden	25	37.3%
Dek: geprefabriceerde liggers	58	86.6%
Randligger: geprefabriceerde randliggers	47	70.1%
Randelement (esthetisch)	23	34.3%
Leuningen (wandelaars + verkeer)	40	59.7%
Schampkant	31	46.3%
Geleiderail	41	61.2%
Oplegblokken	30	44.8%
Dilatatievoegen (tussen landhoofd en dek)	32	47.8%
Overgangsverbinding tussen stootplaat en landhoofd	28	41.8%
Stootplaat	45	67.2%
Bebording	16	23.9%
Verlichting	16	23.9%

5.3 **Welke elementen/ componenten van een viaduct zijn niet essentieel/nodig voor het functioneren van een viaduct?**
Hier mee wordt bedoeld welke elementen/componenten weggelaten zouden kunnen worden. Denk bijvoorbeeld aan elementen die alleen een esthetische functie hebben of voor meer comfort zorgen. Deze zijn niet essentieel/nodig voor het functioneren van een viaduct: constructieve opbouw. U mag meerdere elementen selecteren.



Fundering	1	1.5%
Fundatie sloof	3	4.5%
Funderingspalen	0	0%
Onderbouw	0	0%
Tussensteunpunt/wand	3	4.5%
Hoog of laaggelegen landhoofd	2	3%
Onderslagbalk	1	1.5%
Vleugelwanden	9	13.4%
Dek: geprefabriceerde liggers	0	0%
Randligger: geprefabriceerde randliggers	5	7.5%
Randelement (esthetisch)	46	68.7%
Leuningen (wandelaars + verkeer)	15	22.4%
Schampkant	22	32.8%
Geleiderail	13	19.4%
Oplegblokken	4	6%
Dilatatievoegen (tussen landhoofd en dek)	5	7.5%
Overgangsverbinding tussen stootplaat en landhoofd	7	10.4%
Stootplaat	4	6%
Bebording	42	62.7%
Verlichting	44	65.7%
Overig	6	9%

5.4 **Hoe staat u tegenover het idee om minder gebruik te maken van het verbinden van elementen/componenten door middel van afstorten met beton?**



o Zeer positief: Natuurlijk mogelijk	9	13.4%
o Positief: Mogelijk	26	38.8%
o Neutraal	29	43.3%
o Negatief: Niet realistisch	3	4.5%
o Zeer Negatief: Niet mogelijk.	0	0%

5.5 **Kunt u een toelichting geven waarom u negatief of positief tegen het idee om minder gebruik te maken van het verbinden van elementen/componenten door middel van afstorten met beton?**

Open vraag

<u>Positief</u>

Demontabel:

Hoe meer droge verbindingen, hoe demontabeler de constructie
Demonteren van de constructie is eenvoudiger: langere levensduur + verkleint impact op milieu.
Hergebruik is eenvoudiger

Sneller bouwen/tijd besparen

Het verbinden middels (op)spannen of klikken kan een hoop natte verbindingen besparen.
Afstorten kost tijd en het verhardingsproces ook. Elke verbinding zorgt voor een wachttijd in het totale bouwproces.
Kunnen sneller en flexibeler bouwen
Zo veel mogelijk prefab en minder op locatie doen. : Minder actie op de bouwplaats
Lego-blokjes aan elkaar koppelen.

Meer flexibiliteit

Elementen zijn makkelijker te vervangen

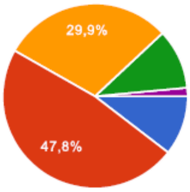
Alles is mogelijk: Aanpassen constructieve principes

Er zijn ook andere methode om de modules te verbinden: staal na-spannen of lijmen.

<u>Negatief</u>

- *Constructieve beperkingen*
  Natte knoop is basis principe, dat kan je niet vermijden.
  Niet altijd constructief mogelijk: andere verbinding elementen zijn niet altijd mogelijk
  Moment vaste betonverbindingen vragen veel en complexe wapeningsdetails.
- *Arbeidsintensief*
- *Beton is onderhoudsvriendelijk*
- *Niet optimaal voor kwaliteit*
- *Markt is er niet klaar voor*
  Alternatief is duurder dan huidige werkwijze: Gunnen op prijs
  Beproefde technieken hebben de voorkeur, innovatieve zaken vaak lastig om deze bij de instanties goedgekeurd/geaccepteerd te krijgen
  Aannemer heeft geen/beperkte vrijheid: meerdere aannemers zouden dit dan moeten doen.
  Wetgeving staat in de weg: Eurocode
  Niet altijd nodig, klant vraagt niet om. Hangt af van contract vorm.
- *Transport: elementen kunnen niet te groot worden, anders onhandelbaar*

5.6 **Hoe staat u tegenover het idee om een "klik"-systeem te ontwikkelen om componenten/elementen met elkaar te verbinden, in plaatst van alles afstorten?**
Bent u van mening dat dit mogelijk is. Dit met het oog op makkelijkere assemblage, demontabel bouwen en verrichten van onderhoud.



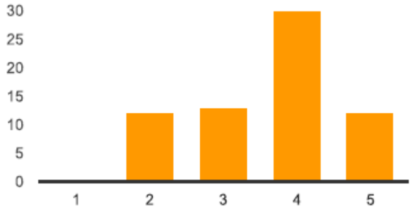
o Zeer positief: Natuurlijk mogelijk	**7**	10.4%
o Positief: Mogelijk, maar complex	**32**	47.8%
o Neutraal	**20**	29.9%
o Negatief: Niet realistisch	**7**	10.4%
o Zeer Negatief: Niet mogelijk	**1**	1.5%

5.7 **Waarom denkt u dat het toepassen van een "klik"-systeem mogelijk/niet mogelijk is? Heeft u hier nog een idee bij/welke mogelijkheden ziet u? En welke beperking(en)ziet u?**
Open vraag

<u>Mogelijkheden</u>
Principe word al deels toegepast met prefab liggers: daar is het succesvol.
Mogelijk: variatie zit meestal in de fundering en aansluiting tussensteunpunten, daarboven is een lego systeem denkbaar
Kwestie van constructieve principes aanpassen
Vergroot mogelijkheden: door toepassen van nieuwe materialen
Verkorte bouwtijd
Kwestie van doorzetten en opdrachtgevers meekrijgen
Eerder rendabel om klik systeem toe te passen bij lichtere constructie.

<u>Beperkingen</u>
- *Kosten: duurder dan traditionele werkwijze (gunnen op prijs)*
- *Lastig garantie geven*
  Degelijkheid verbindingen, onderhoud, beïnvloeding levensduur, ander krachtenspel
  Bevestigingen moeten voldoende sterk zijn: overspanningen en verkeersklassen
  Toleranties toegestaan
  Levensduur verwachting
- *Complex ontwerp, veel factoren van invloed*
- *Constructieve beperkingen*
- Certificering van het "klik"-systeem
- Mogelijk loskomen elementen bij aanrijding of vandalisme.
- Bij tussentijdse problemen moeilijk te veranderen
- Goed op veiligheid letten
- Ketensamenwerking: toleranties tussen aannemers is erg klein
- Transport: afmeting van de elementen zijn te groot.

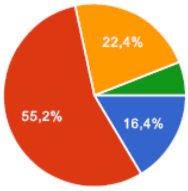
5.8 **Door gebruik te maken van een klik-systeem/demontabel bouwen zou het later aanpassen (uitbreiden) en afbouwen (weghalen) van een viaduct makkelijker en efficiënter kunnen worden.**



Sterk mee oneesn: 1	**0**	0%
2	**12**	17.9%
3	**13**	19.4%
4	**30**	44.8%
Sterk mee eens: 5	**12**	17.9%

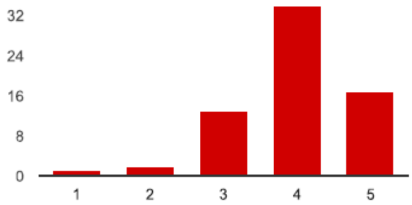
5.9 Hoe kijkt u aan tegen het idee om viaducten te ontwerpen die gedemonteerd kunnen worden, i.p.v. volledig gesloopt worden. (is dit mogelijk?)

De bepaalde elementen/ componenten kunnen direct hergebruikt worden in nieuwe viaducten. Bijvoorbeeld liggers, zonder aanpassing van het ene naar het andere viaduct overgezet kunnen worden.



o Zeer positief: Natuurlijk mogelijk	**11**	16.4%
o Positief: Mogelijk, maar complex	**37**	55.2%
o Neutraal	**15**	22.4%
o Negatief: Niet realistisch	**4**	6%
o Zeer Negatief: Niet mogelijk	**0**	0%

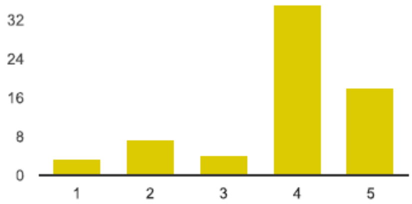
5.10 Hoe staat u tegenover het toepassen van andere/innovatieve materialen dan conventionele materialen (beton en staal) voor een viaduct?



Zeer negatief: 1	**1**	1.5%
2	**2**	3%
3	**13**	19.4%
4	**34**	50.7%
Zeer positief: 5	**17**	25.4%

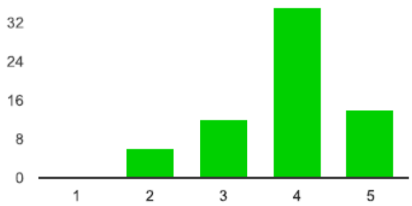
5.11 Het is mogelijk om een viaduct volledig prefab uit te voeren

Bijvoorbeeld, door een landhoofd in drie delen maken en transporteren naar de bouwlocatie.



Sterk mee oneens: 1	**3**	4.5%
2	**7**	10.4%
3	**4**	6%
4	**35**	52.2%
Sterk mee eens: 5	**18**	26.9%

5.12 Het is mogelijk om een viaduct op te bouwen uit prefab bekistingsmallen, die uiteindelijk onderdeel van de constructie worden door de bekisting op locatie te assembleren en dan vol te storten met beton.



Sterk mee oneens: 1	**0**	0%
2	**6**	9%
3	**12**	17.9%
4	**35**	52.2%
Sterk mee eens: 5	**14**	20.9%

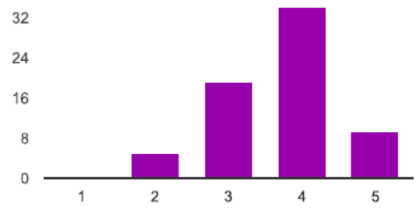
5.13 Heeft u zelf nog innovatieve ideeën voor het ontwikkelen van viaduct, met gebruik van standaardisatie en/of modularisatie? Leg uit. *Open vraag*

- Neem hulpconstructies en veiligheidsvoorzieningen mee in de standaardisatie. Zo zijn deze sneller te verkrijgen en te certificeren: aantoonbaar beter en veiliger
- Standaardisatie in de vorm van 3 types: parametrisch
- Inspelen op 3D-printen (bekisting is dit realistisch, prefab of op locatie)
- Nieuwe materialen: andere eigenschappen, dus mogelijk andere vormvrijheden
- Combineren met bruggenbouw (al bewezen methode toepassen op viaducten)
- Pas oplossingen uit staalbouw toe.
- Kijk goed naar afwijkingen door vervormingen en voer regelmatig tolerantie analyses uit.
- Monitoren life-cycle: sensoren
- Beperken tot simpele elementen die niet onderhevig zijn aan de klantvraag
- Alleen wapening en bekisting buiten het werk prefabriceren: inhijsen in het werk en storten.
- Voor esthetische/niet constructieve delen gebruik maken van licht composiet materiaal

- Mogelijk functies te combineren
- Opdrachtgever meekrijgen: essentieel
- Borduur verder op N261
- Betrek partijen die gaan over voorschriften en normering: ligt de basis voor eenvoudiger en betrouwbaarder ontwerp.
- Meer op staal funderen
- Stel standaarddetails op en standaard werkwijze voor viaduct

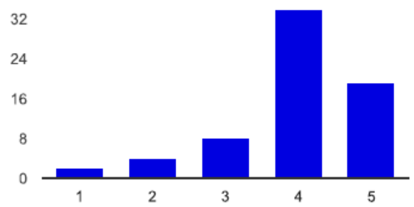
Deel 6: Hoe kan standaardisatie en modularisering geimplementeerd worden binnen BAM Infra/Infraconsult?

6.1 Om een standaardisatie en modularisering te implementeren (product platform te realiseren), is een stappenplan dat de werknemer van BAM Infra moeten volgen erg nuttig.



Sterk mee oneens: 1	**0**	0%
2	**5**	7.5%
3	**19**	28.4%
4	**34**	50.7%
Sterk mee eens: 5	**9**	13.4%

6.2 Een database die voor iedereen in de organisatie beschikbaar is, moet worden ontwikkeld. Dit kan de eerste stap zijn
naar e en meer project overstijgende aanpak.
Bij deze database moet u zich voorstellen dat bepaalde documenten van projecten makkelijk te bekijken zijn voor de medewerkers van BAM Infra. Zoals tekeningen van het definitieve ontwerp, de kostenraming, de planning etc. Er zal hier dan wel een goed onderscheid tussen de documenten die van toepassing zijn gemaakt moeten worden, zodat men niet overspoelt word door data. Daarnaast zal de database de uitgangspunten van de projecten en wie aan het project hebben gewerkt moeten bevatten, zodat men voor verdere informatie deze medewerkers kan benaderen.



Sterk mee oneens: 1	**2**	3%
2	**4**	6%
3	**8**	11.9%
4	**34**	50.7%
Sterk mee eens: 5	**19**	28.4%

6.3 Waarom denkt u dat andere initiatieven/projecten binnen BAM Infra/Infraconsult dat standaardisatie en modularisering toegepast hebben, niet succesvol zijn geweest?

Open vraag

- Omstandigheden binnen BAM: versnipperde organisatie, reorganisatie (medewerkers waren niet met de initiatieven bezig, vanwege de reorganisatie en het back-in shape programma).
- Onderschatting raakvlakken tussen modules
- Complex
  - Last van project specifieke eisen en beeld kwaliteitsplan (te specifieke eisen klant)
  - Discontinuïteit in viaduct-opdrachten
  - Uiteindelijk alleen unieke oplossing mogelijk (technisch)
  - Klant wil iets unieks
- Geen zicht op directe voordelen
- Geen draagvlak
  - Iedere verandering geeft weerstand
  - Te weinig urgentie voor BAM
  - Te ingewikkeld en niet dwingend genoeg opgelegd
- Niet doorgepakt, nooit serieus werk van gemaakt
- Niet nagedacht over de implementatie
- Niet onderzocht of klant het wel wilt: klant wensen
- Cultuur:
  Niet gezamenlijk geloven/gezamenlijk doorzetten
  Haantjes gedrag: zelf graag iets wille ontdekken, eigenwijsheid medewerkers
  Niet alles kan ondervangen worden door een systeem
- Niet communiceren met elkaar, slecht uitwisselen van gegevens
- Veel ideeën: niet alles kan onderzocht worden: tijd en kosten
- Opdrachtgevers zijn bang voor innovatieve oplossingen: klant zit er niet op te wachten.

- Initiatief vraagt mogelijk andere bedrijfsopzet
- Vragen investering naast projecten: gebrek aan geld en tijd om ideeën verder te ontwikkelen
- Weinig kennisdeling binnen de organisatie
- Men is bang om samen te werken: eerste keer zijn de kosten altijd hoog maar dan moet men juist doorgaan op een volgend project met dezelfde mensen/onderaannemers/leveranciers
- Niet voldoende vrijheid geboden binnen de contracten

6.4 Wat zijn de meest essentiële succes factoren voor het implementeren van standaardisatie en modularisering, met de visie om uiteindelijk een product platform te ontwikkelen?

Open vraag

- Genoeg repetitie
    - Opdrachtgevers met dezelfde eisen, grote mate van herhaling
    - Voldoende projecten hebben waar het platform toegepast kan worden: schaalvoordelen.
- Gedragen worden binnen de organisatie (Draagvlak):
    - Cultuur: Organisatie structuur die bereid is vanuit een platform te denken
    - Voorlichting en bewustzijn: Voorlichting geven aan medewerkers: zo bijdragen aan het soepel laten verlopen platform. Medewerkers bewust maken wat men met deze aanpak kan “winnen”.
    - Bewijs leveren: moet zich bewijzen op verschillende projecten.
    - Positief uitstralen door directie en veel uitdragen.
    - Goede kennis deling
- Systeem moet compleet zijn, goed ontwikkeld en moet verplicht worden toegepast: Medewerkers moeten het gebruiken.
    - Zorg voor parametrisch ontwerp. Zorg dat het goed toegankelijk is en geen overvloed aan informatie.
- Vrijheid in ontwerp en omgeving: opdrachtgevers moeten de aannemers meer ruimte geven.
- Belangrijk om aan de wensen van de klant te voldoen. Constante analyse van de markt.
- Moet leiden tot verbetering: Tijd en geldbesparing
  De life-cycle kosten uiteindelijk lager moeten zijn. Ook de bouwsnelheid zal sneller moeten worden.
- Men moet doorpakken en investeren (men moet willen)
- Samenwerking tussen klant en aannemer
- Modulaire elementen moeten generiek toepasbaar zijn. De randvoorwaarden moeten hierbij duidelijk zijn.
- Inventarisatie van de mogelijkheden die er zijn en in projecten worden gevraagd betreffende kunstwerken (vraag van de klant)
- Implementeren in kleine stapjes
- Delen kennis: documenteren data en voldoende communicatie.
    - Bestaande kennis documenteren en ervaring gebruiken.
    - Analyse van reeds uitgevoerde kunstwerken; kijken of deze gestandaardiseerd hadden kunnen worden,
- Werken met een vast team. Juist mensen
- Concept moet eenvoudig zijn
- Concept moet flexibel zijn.
- Creatief niet beprekende geest: “out of the box” kunnen denken, niet denken in beperkingen.

6.5 Wat ziet u als de grootste beperkende factor(en) om standaardisatie en modularisering door te voeren binnen de infrastructurele sector?

Open vraag

- Cultuur en Mensen
    - Conservatieve mensen. Traditionele werkwijze
    - Mensen hebben kennis en ervaring en belang bij huidige methodes. Onvermogen en gebrek aan geloof en vertrouwen in andere methodes. Geen inzicht in wat het oplevert.
    - Koppigheid mensen
- De opdrachtgevers
    - Veel verschillende opdrachtgevers, met verschillende gedachten, eisen en wensen: complex.
    - Ontwerpvrijheid: opdrachtgevers (klant) moeten voldoende vrijheid geven
    - Markt vraag het nu niet om standaardisatie en modularisering toe te passen.
    - De opdrachtgever wil uiteindelijk eigen ontwerp, keuzes en architectonische visie terug zien. Daarom zal ook de opdrachtgevers standaardisatie moeten doorvoeren.
    - Op de korte termijn geen voordelen voor opdrachtgevers
    - Acceptatie van de klant
- Niet rendabel

    - Demontabel bouwen is niet rendabel. De vereiste ontwerplevensduur is 100 tot 120 jaar. Heeft wel kans als demontage al over paar jaar is.
- Esthetische voorwaarden maakt toepassing erg complex: Architectuur staat overal hoog op de agenda.
  Esthetisch ontwerp ligt meestal al vast vanuit de klant voordat BAM betrokken is bij het project.
  Voldoen aan eisen gesteld in beeldkwaliteitsplan
  Visie/randvoorwaarden vanuit de architecte en de opdrachtgevers werken gestandaardiseerde oplossingen tegen.
- Project specifieke omstandigheden en eisen en wensen: Uniek karakter elk project.
- Risico nemen (koudwatervrees): het niet kunnen/durven kiezen voor een bepaalde richting om aan te werken voor langere periode (10-15jaar), omdat het eindresultaat onbekend is.
  Ook opdrachtgevers moeten risico durven nemen.
- Niet voldoende samenwerking: meewerken van architecten en de opdrachtgever (geëiste vormgeving). Veelal bepalend voor het ontwerp en uitvoeringsmethodiek
- Te weinig repetitie in de markt: aantal malen dat een standaard model kan worden toegepast zonder grote aanpassingen.
- Niet voldoende draagkracht binnen de sector en binnen BAM. Men moet alle partijen meekrijgen.
- Slechte communicatie
- Kennis moet gedeeld worden: database + men moet kennis willen delen met directe collega's.
- Concurrentie
- Huidige aanbestedingsvorm

6.6 Wat zie u als de grootste beperkende factor(en) om standaardisatie en modularisering door te voeren binnen de huidige werkwijze van BAM Infra/Infraconsult?

Open vraag

- Cultuur
    - Ingenieurs vinden het leuk om telkens het wiel opnieuw uit te vinden (uitdaging en eigenwijs): project specifieke oplossing genereren. Men wil eigen stempel op project drukken.
    - Mensen binnen de organisatie die niet open staan voor het nieuwe concept: bereidwilligheid. Men heeft moeite met verandering
    - Niet hebben van de juiste denkwijze: men is hier niet voor opgeleid. Wijzigen denkwijze is lastig.
    - Sluit niet aan op huidige werkwijze en ontwerp cultuur.
    - Mensen: kennis en ervaring en belang bij de huidige methodes. Onvermogen en gebrek aan geloof en vertrouwen in andere methodes. (Geen bewijs)
- Risico nemen
    - Men moet durven te investeren
    - Gebrek aan "lef", om een dergelijk plan een keer in uitvoering te brengen.
    - Gaan liever uit van bewezen methoden dan innovatieve methoden: risico aan verbonden
    - Men pakt niet door.
- Gedragen worden
    - Vanuit directie
    - Vanuit werknemers
- Niet betrekken van alle disciplines + onvoldoende overkoepeling tussen de afdelingen binnen BAM Infra.
- Kans dat te veel uitzonderingen en noodoplossingen toegepast zullen worden: te veel aanpassingen
- Geen standaard berekeningsdocumenten, dit is voor elke project anders. Maar men moet wel aantonen dat de constructie aan de norm voldoet.
- Focus is op afzonderlijke projecten/tenders en thuisbasis van product platform is smal.
    - Lopende tenders en projecten vragen de komende tijd alle beschikbare capaciteit. Dit krijgt voorrang op het implementeren van de principes van mass customization. (te weinig capaciteit ivm lopende tenders/projecten)
- Investeren
    - Te hoge initiële kosten om het op te zetten (investeren)
    - Tijd en geld vrijmaken
    - De gehele sector zal moeten investeren.
- Repetitie: volume is onzeker
- Kennis en ervaring wordt niet voldoende gedeeld

6.7 Wat is in uw visie de beste manier/aanpak om standaardisatie en modularisering te implementeren binnen BAM Infra/Infraconsult?

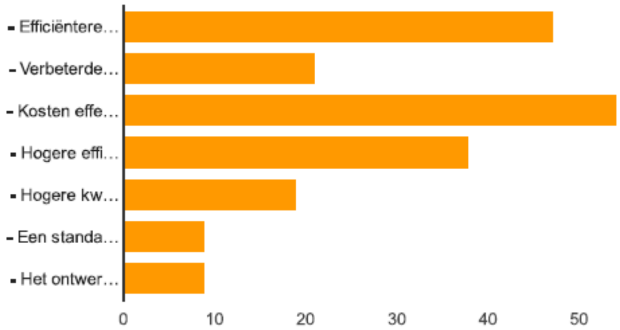
Hierbij kunt u bijvoorbeeld denken aan: Binnen huidige projecten ontwerpen en toepassen; Buiten huidige projecten ontwerpen; Los ontwerpteam aanstellen die drie verschillende referentie viaducten ontwerpen; Standaard laten opleggen door management; Een al gerealiseerd project als standaard referentie aanwijzen, bijvoorbeeld N18. U mag een open antwoord geven, graag wel met toelichting waarom u dit de beste manier/aanpak vindt.

Open vraag

- Opleggen
  - Binnen elke tender moet zoeken naar standaardisatie moet altijd de opgave zijn.
- Constante verbetering doorvoeren (lessons learned)
  - Goede resultaten terugbrengen in de verbeterde standaard: constant verbeteringen doorvoeren.
  - Niet in een keer alles omvattend ontwerp/oplossingen willen neerzetten. Ontwerp ontwikkelen binnen huidige projecten en deze toepassen, vervolgens uitbreiden en verbeteren.
- Pilot
  - Start met een klein overzichtelijk project, evalueer dit goed en bepalen of dit verder doorgevoerd zou moeten worden.
  - Start met een component: bijvoorbeeld landhoofd
- Partijen/personen aantrekken die niet uit de bouwbranche afkomstig zijn. Deze laten meedenken/ontwikkelen tijdens het ontwikkelproces
- Los ontwerpteam aanstellen: apart team een aantal referentie ontwerpen uitwerken en in de markt zetten.
  - Team moet gevarieerde club van zorgvuldig gekozen mensen op basis van kennis, ervaring, geloof en vertrouwen.
  - Team opzetten die los van een project zich verdiept in de mogelijkheden en met een goed plan/catalogus komt. Zodat er in het geval van een project voldoende input ligt om snel en eenvoudig een modulair ontwerp te kunnen indienen.
- Goed documenteren
  - Iemand verantwoordelijk maken voor het verzamelen van data en het beheren van het platform.
  - Bij nieuw project, documentatie van al gedane projecten bekijken. Wat kan men meenemen bij huidig project?
  - Langzaam een standaard ontwikkelen (door gebruik documentatie) en deze standaard door ontwikkelen: project overstijgend werken.
  - Projectervaring verzamelen en met bepaalde filters vindbaar maken
- Kennismanagement: voor en nadelen moeten gedeeld worden. Successen uitdragen en waarschuwen voor mogelijke valkuilen.
- Opknippen in kleine delen en hier duidelijke doelstellingen aan hangen.
- Stap voor stap implementeren/proberen verder te komen. Van grof naar fijn werken.
- Uitdragen naar veel mensen: zodat iedereen zich bewust wordt en het gaat toepassen. (aantonen dat het succesvol is)
- Binnen huidige projecten en tenders oppakken. Op project zaken uitdenken: gelijk vruchten plukken van
- Inventariseren of opdrachtgevers geïnteresseerd zijn in dergelijk concept. Daarna plan van aanpak opstellen.
- Beheersorganisatie voor het platform + aan begin van project keuze maken: Gaan we conform de standaard werken of nemen we een meer unieke aanpak.
- Koppelen aan BIM-ontwikkelingen. Visuele informatie is snel duidelijk en men kan deze makkelijk hergebruiken.
- Snel-kookpan-sessies houden. Beste constructieve ideeën verder uitwerken en in trade-off matrixen beschouwen.
- Begin met een basisontwerp (standaard pakket waaruit de opdrachtgever kan kiezen). Maak voor de uitstraling/afwerking een keuze menu van verschillende standaard oplossingen.
- Samenwerken met vaste leveranciers
- Gerealiseerd project als referentie aanwijzen. Uit recente project standaard ontwikkelen tijdens het volgende project.
- Eerst processen standaardiseren, vanuit daar kijken wat er verder mogelijk is.

6.8 Wat vindt u de meest belangrijkste voordelen van standaardisatie en modularisering, met de visie om een product platform te ontwikkelen?

In literatuur worden meerder voor en nadelen (risico's en beperkingen) van standaardisatie en modularisering, met de visie om een product platform te ontwikkelen genoemd, de meest belangrijkste zijn hier genoemd. Selecteer de drie meeste belangrijkste.



- Efficiëntere ontwerpfase (kortere ontwikkel/ontwerp tijd: ontwerp maar een keer, en hergebruik het ontwerp in meerdere projecten)	47	70.1%
- Verbeterde project planning (door optimalisatie en ervaring met het ontwerp)	21	31.3%
- Kosten effectief (hergebruik ontwerp + minder faalkosten door bekend product/proces)	54	80.6%
- Hogere efficiëntie en productiviteit. (men kan het ontwerp en proces optimaliseren, en men wordt steeds ervarener)	38	56.7%
- Hogere kwaliteit vanwege optimalisatie van het ontwerp en het gebruik van prefab-elementen.	19	28.4%
- Een standaard interface, zal resulteren in betere communicatie en transparantere documentatie.	9	13.4%
- Het ontwerpproces word minder complex (product kan worden opgedeeld in kleine "problemen")	9	13.4%

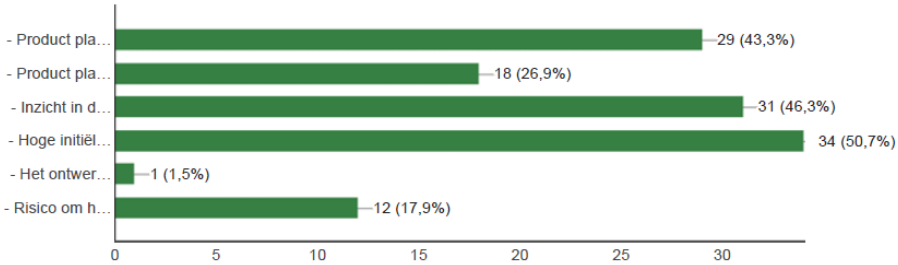
6.9 Ziet u nog meer voordelen van standaardisatie en modularisering, met de visie om een product platform te ontwikkelen dan eerder genoemd?

Deze vraag is specifiek op de bouwsector gericht en hiermee de voordelen voor BAM Infra.

Open vraag

- Snellere goedkeuring van omgevingsvergunning
- Kortere doorloop tenderfase/ minder inzet tijdens tenders.
- Tender kosten omlaag
- Kwalitatief betere aanbieding: men leert van project tot project.
- Men weet snel waar die aan toe is. Betreffende ontwerp en betreffende kosten.
- Sneller oplossing paraat.
  - Ontwerp en kosten liggen op de plank
  - Meer tijd over om aandacht te geven aan andere moeilijkere/complexe zaken binnen het project.
- Eenduidige uitstraling (BAM-viaduct)
- Kosten effectief in onderhoud
  - Schaalvoordelen : meerdere projecten onderhouden op dezelfde manier
  - Componenten makkelijker en sneller vervangen.
- Modules in geconditioneerde omgeving maken (fabriek):
  - Efficiënt en verhoging kwaliteit.
  - Arbo zaken makkelijker te regelen.
- Vaste en betrouwbare partners waarmee je samenwerkt en samen leert.
- Door het toepassen van een standaard (proces en/of product) verminderd de improvisatie die nodig is op de bouwplaats. Dit zal leiden tot meer veiligheid op de bouwplaats.
- Ontwerp word simpeler (opdelen in deelproblemen)
- Minder discussie met de klant: men weet wat ze krijgen. Begrip en duidelijkheid voor de opdrachtgever.
- Demonteerbaar maken viaduct: Losse onderdelen opnieuw te gebruiken
- Eenvoudiger om bestaande kunstwerken aan te passen of bepaalde componenten te vervangen.
- Geheel zal product en proces beter en efficiënter worden.
  - Verminderde faalkosten
  - Sneller ontwerp en bouw
  - Verhoogde kwaliteit

6.10 **Wat vind u de meest belangrijke nadelen van standaardisatie en modularisering, met de visie om een product platform te ontwikkelen?**



6.11 Ziet u nog meer nadelen van standaardisatie en modularisering, met de visie om een product platform te ontwikkelen dan eerder genoemd? *
Deze vraag is specifiek op de bouw-sector gericht en hiermee de nadelen voor BAM Infra.

Open vraag

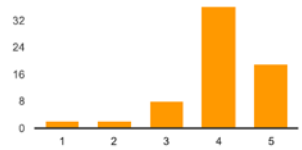
- Risico dat we niet 'out of the box' blijven denken. Hiermee dus voorspelbaar zijn voor de concurrent
- Verlies kennis en kunde om complexe unieke projecten te realiseren
- Flexibiliteit word minder. (in de praktijk red dit ons vaak)
- Niet meer nadenken
    - Omdat men niet meer nadenkt maar de standaard toepast. Omdat men denkt dat we zo het beste/scherpste resultaat hebben.
    - Kan er toe leiden dat de men creativiteit verliest, door alleen toepassen van standaard
- Vormgeving zal altijd nog uniek blijven. Men moet zich focussen op standaarddetails en verbindingen.
- Complex en technisch moeilijk te ontwikkelen
- Vraagt om aanpassing van de huidige werkwijze dit al heel lang wordt gevolgd.
- Beperkte kans tot specifieke BAM ontwikkeling. Men is afhankelijk van prefab leveranciers.
- Men moet kritisch blijven: de afweging tussen modulair bouwen of ieder andere werkwijze dient moet aan het begin van ieder project gemaakt worden.
- Te weinig tegemoet kunnen komen aan de wensen van de architect en/of de opdrachtgever
- Iemand aangesteld/verantwoordelijk gemaakt worden voor het onderhouden van het platform. Dit zal anders niet gebeuren. Men doet het liefst zijn "taak" en alles wat daar niet direct bij hoort te lijken wordt opzij geschoven.
- Toekomst is onbekend
    - Men weet niet hoe de infra er over 20 tot 30 jaar uit ziet.
    - Hoe toekomst vast is het platform?
- Vanwege platform niet meegaan met de veranderende markt. Men blijft stil staan, terwijl innovatie nodig is om blijven te voldoen aan de vraag van de markt.
- Eerst grote investering doen. De winst komt pas op termijn en het is onbekend of het rendabel zou zijn.
- Zit de klantenkring van BAM Infra hierop te wachten?

A.20 Survey – Discussion of interesting question.

In this section, some questions of the survey that are not immediately clear or straight forward are analysed and reviewed.

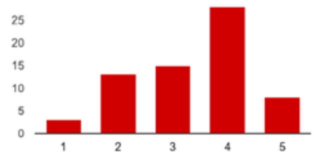
Q3.1 and Q3.2

Q3.1 – The design of customised (client-specific), unique solutions can also be seen as constantly reinventing 'the wheel'. This leads to inefficiency and by this cost a lot of time and money. In the construction industry, a lot of time and money is spent on redesigning similar civil engineering objects from scratch.



Sterk mee oneens: 1	2	3%
2	2	3%
3	8	11.9%
4	36	53.7%
Sterk mee eens: 5	19	28.4%

Q3.2 – Within BAM Infra/Infraconsult is constantly reinventing the wheel. Every project is designed/developed from scratch.

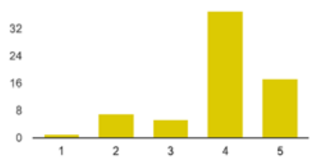


Sterk mee oneens: 1	3	4.5%
2	13	19.4%
3	15	22.4%
4	28	41.8%
Sterk mee eens: 5	8	11.9%

The outcome of question 3.1 implies that the experts of BAM Infra are aware that companies within the construction industry are constantly reinventing the wheel. From question 3.2, it can be concluded that the experts of BAM Infra also experience this in their own organisation. They are constantly reinventing the wheel within their projects. They are aware that the current way of working is not optimal, and the efficiency needs to increase. Around 70% of the participants agree that the current practices in the construction industry are inefficient. Around 55% of the participants agree that the current BAM Infra is reinventing the wheel in their projects. Around 23% of the participants are neutral, and around 24% of the participants disagree. When an organisation wants to change their way of working, it is important that the experts of the organisation see the need to change. The outcome of this question could mean that within BAM Infra, the problem is known, and it, therefore, is likely that there will be sufficient support to implement a new strategy. However, around 24% disagrees and around 23% is neutral, when a new approach will be implemented it is important to have sufficient support. These people will need to be convinced. In addition, the differences in the outcome can be caused by different way of working in different departments and disciplines.

Q3.3

Q3.3 - Theorem - If you start a new project, in the initial phase you analyse and review similar already made /realised projects, to consider and maybe apply the "best practices" in the new project. In addition, also learn from the mistakes in these projects, to prevent mistakes in the new project. (This considering all different aspects, both technical design and working methods, etc.)

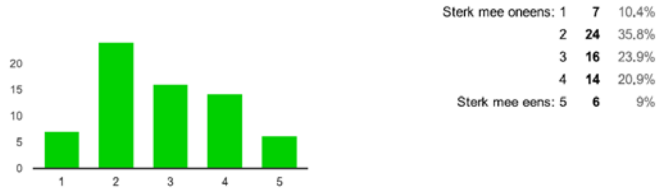


Sterk mee oneens: 1	1	1.5%
2	7	10.4%
3	5	7.5%
4	37	55.2%
Sterk mee eens: 5	17	25.4%

The outcome of this question implies that when people start working on a new project they first review and analyse already realised projects, to learn from these projects, considering both their success and their mistakes. However, based on how data is shared within the organisation and interviews and non-structure conversations, a different conclusion can be drawn. The experts do consider already realised projects, but this is more based on the experience they have considering these different projects and maybe from stories told by colleagues. The experts take the experiences from their project with them to the next project. Within this new project, they share their experiences and thought of how this approach/innovation/concept could also be beneficial within the new project. The insights gained from the different projects are transferred to the next project, but not in a structural way. The knowledge and expertises are in the minds of the people. Because the insights gained are not shared in a structural way, BAM Infra misses out on a valuable opportunity. In addition, there is a risk that the knowledge and expertise will get lost when experts leave the organisation. The knowledge and expertise will not be available for BAM Infra anymore. Good knowledge management is essential, but BAM Infra is not the only company struggling with this. However, currently, there is no common database where all the projects can be reviewed. For the experts of BAM Infra it is only possible to review projects that they have been involved with, or can review projects based on experiences shared by colleagues. However, if nobody knows about the existing/ appliance of a certain idea/concept, it will not be reviewed and analysed by others. Here BAM Infra misses out on opportunities, as the organisation can learn from these projects and innovations that have been applied can be developed further.

Q3.4

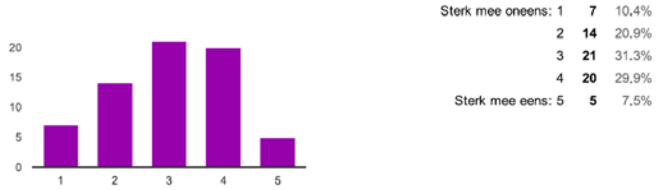
Q3.4 – With-in BAM Infra/Infraconsult in general only limited attention is given to review and analyses references.



The outcome of Q3.4 implies that around 45% is of the opinion that BAM Infra/Infraconsult does review and analyses references. 24% of the participants are neutral about this, and around 21% is of the opinion that only limited attention is given to reference projects. Based on conversations with experts of BAM Infra/Infraconsult, it became clear that references projects are considered. However, again, as also point out by Q3.3, these references are put forward by experts based on their experience. Here the same advice that was given in Q3.3 is appropriate.

Q3.5

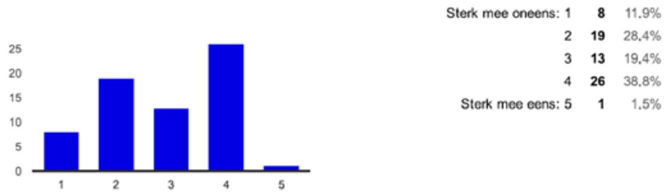
Q3.5 – Within your own department continuous optimisation of product and process are included in the current way of working.



The outcome of question 3.5, shows that the participants of this survey mainly are of the opinion that continuous optimisation of product and process are included in the current way of working. Based on the outcome of question 3.5, the interviews conducted and general conversations with experts, it can be argued that there is continuous optimisation of product and process within the different departments. However, this is mainly based on own experiences and is not applied in a structured way. Implementing a structural approach within the different departments is advised. There is still a lot to be gained.

Q3.6

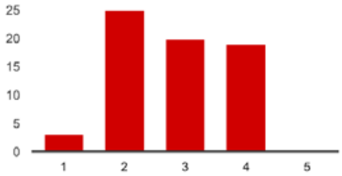
Q3.6 – During the design and construction process the choices made are clearly written down, and are documented after the finishing of a project.



The answers to question Q3.6 show that the opinions, considering if choices made are documented, differ significantly. However, this question is twofold. Almost all projects are documented, and validation and verification are applied when a project is finished. Documenting how the processes revolve is mainly only done for specific projects. However, here so much data is collected that the data is hard to interpret for people who were not involved in the project. Not one clear overview of this data exists, and people get lost in the data. In addition, this data is mainly only assessable for certain members of the project team. It can be concluded that BAM Infra/Infraconsult does document the different aspects of their projects, this is mainly about the construction process. question Q3,6 does not give an answer to the question if it is clearly documented why certain decisions are taken within the design phase. Although a lot is documented during a construction project, this is probably not the case for the design phase. It is important that also in this phase the decisions made have to be documented. It will help when certain decisions have to be made within a new project. For example, trade-off matrixes that are made within a certain project should be reviewed when trade-offs need to be made within a new project. By this, a learning-curves occurs, and it can save time as not everything has to be investigated all over again. It remains important that to documented it in a simple way. It provides experts with clear insights, by reviewing these documents.

Q3.8

Q3.8- There are constant feedback loops during the various phase of a project

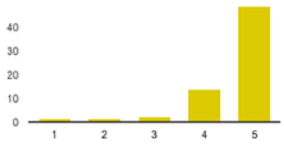


Sterk mee oneens: 1	**3**	4.5%
2	**25**	37.3%
3	**20**	29.9%
4	**19**	28.4%
Sterk mee eens: 5	**0**	0%

Based on the outcome of question Q3, 8, no clear conclusion can be drawn. However, based on the outcome it can be concluded that there is still room for improvement. Only 28, 4% agrees that there are constant feedback loops.

Q3.9

Q3.9 – It is important that insights gained and lessons learned from the various projects are shared within their department and other departments of BAM Infra

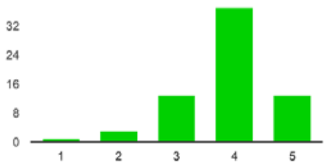


Sterk mee oneens: 1	**1**	1.5%
2	**1**	1.5%
3	**2**	3%
4	**14**	20.9%
Sterk mee eens: 5	**49**	73.1%

Question 3.9 points out that the experts of BAM Infra are aware of how important it is to share insights gained and lessons learned from the various projects, both within their department and other departments of BAM Infra. Around 94% agree with the theorem. However, although 94% agrees, in practice the theorem is not always applied. Around two years ago, a reorganisation took place at BAM. Different companies have been combined into a new company; BAM Infra. The experts of the different departments (before different companies) are redundant to share their knowledge and expertise. There is still a competitive culture. However, it is essential that the different departments and disciplines cooperate with each other, and share their knowledge and expertise. Together they can establish more and can out-compete the competitors. It is vital that competitive culture should change toward a more open culture. Referring to: *"the whole is greater than the sum of parts".*

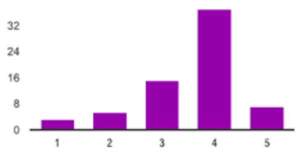
Q3.10, Q3.11 and Q4.5

Q3.10 – The communication between the different disciplines that are working on a project are not always effective and efficient. This needs improvement.



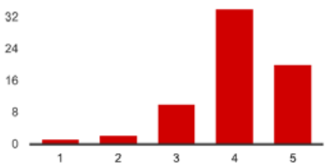
Sterk mee oneens: 1	**1**	1.5%
2	**3**	4.5%
3	**13**	19.4%
4	**37**	55.2%
Sterk mee eens: 5	**13**	19.4%

Q3.11- Are you of the opinion that the implementations of a common interface the communication within BAM Infra and communication with other companies will improve?



Sterk mee oneens: 1	**3**	4.5%
2	**5**	7.5%
3	**15**	22.4%
4	**37**	55.2%
Sterk mee eens: 5	**7**	10.4%

Q4.5 To implement standardisation and modularization, a common interface or reference design(s) will need to be developed.

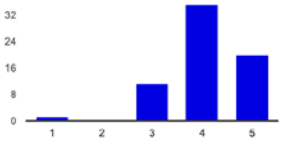


Sterk mee oneens: 1	**1**	1.5%
2	**2**	3%
3	**10**	14.9%
4	**34**	50.7%
Sterk mee eens: 5	**20**	29.9%

Based on the three questions, it can be concluded that the perception of the experts is that it will be likely that the communication will improve when a common interface is developed for the implementation of standardisation and modularization.

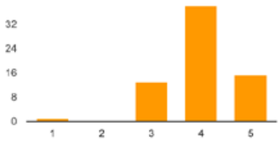
Q4.1 and Q4.2

Q4.1 – What is your general view/opinion on the appliance of the principles of the mass customization industry, within the infrastructural sector?



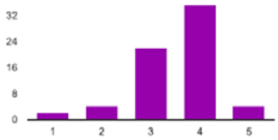
Zeer negatief: 1	**1**	1.5%
2	**0**	0%
3	**11**	16.4%
4	**35**	52.2%
Zeer positief: 5	**20**	29.9%

Q4.2 – What is your view/opinion about the appliance of the principles of the mass customization industry, within BAM Infra/Infraconsult?



Zeer negatief: 1	**1**	1.5%
2	**0**	0%
3	**13**	19.4%
4	**38**	56.7%
Zeer positief: 5	**15**	22.4%

Q4.9 - Do you believe that if BAM Infra / Infraconsult implements standardisation and modularization, and then develop a reference design(s) for different objects, there still will be enough design freedom, flexibility (room for change)? However, this is so limited that they can still benefit from the repetition? (Economies of scale, re-design, product and process optimisation, etc.)



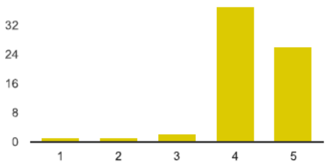
Sterk mee oneens: 1	**2**	3%
2	**4**	6%
3	**22**	32.8%
4	**35**	52.2%
Sterk mee eens: 5	**4**	6%

Both Q4, 1 and Q4.2 imply that the experts of BAM Infra/Infraconsult are positive about the application of the principles of the mass customization within their industry and company. This means that the experts will be open for this new approach. If BAM Infra/Infraconsult wants to apply this new approach, it is good to know that the experts do support this.

In addition, Q4.9 also points out that the experts are positive that when BAM Infra/Infraconsult would implement the principles of standardisation and modularization within their organisation, still sufficient freedom in design will be present.

Q4, 6

Q4.6 – Product and process need to be aligned, to be able to fully benefit from standardisation and modularization.

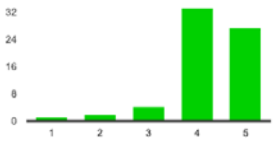


Sterk mee oneens: 1	**1**	1.5%
2	**1**	1.5%
3	**2**	3%
4	**37**	55.2%
Sterk mee eens: 5	**26**	38.8%

From the outcome of question 4.6, it can be concluded that almost all experts agree that to be able to benefit from standardisation and modularization fully, product and process need to be aligned.

Q4.7

Q4.7 - The early involvement of suppliers and clients such as RWS, ProRail, municipalities and Provinces to think along / work on the design (co-production) within a project should be considered. It will make it possible and easier to apply a standard or modular design within a specific project.

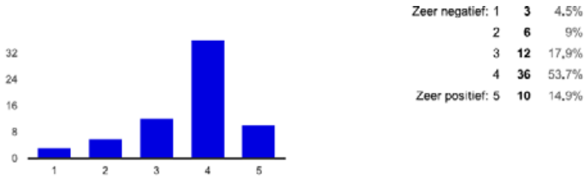


Sterk mee oneens: 1	**1**	1.5%
2	**2**	3%
3	**4**	6%
4	**33**	49.3%
Sterk mee eens: 5	**27**	40.3%

The outcome of Q4.7 shows that 40.3% strongly agree and 49.3% agrees with the theorem. Only 6% is neutral, 3% disagrees and only 1, 5% completely disagrees. Here the question can be asked, why this is currently not the case. It has to be noted that already initiatives to involve the parties earlier in the project. However do to how the market currently works, and due to regulations considering procurement, this is a complicated process. If we want to involve parties earlier in the project, this will mean a new approach within the industry is needed. This is something that needs to change over time, and cannot be changed directly.

Q4.10

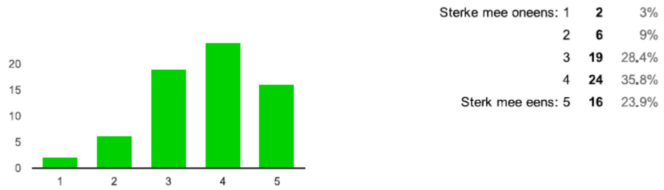
Q4.10 – What is your opinion about the development of a configurator?



From question 4.10 it can be concluded that the experts are mainly positive about the development of a configurator.

Q4.14

Q4.14 – Are you of the opinion that the (more functional) requirements of RWS are still too specific and the possibilities to innovate are limited.

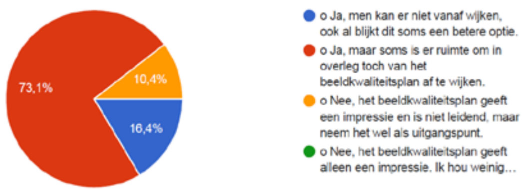


It can be concluded that the majority of the experts is of the opinion that the (more functional) requirements of RWS are still too specific and the possibilities to innovate are limited.

Q4.15

Q4.15- Do you experience the ascetical quality plan (beeldkwaliteitsplan) as a binding document?

The quality plan was originally introduced as a document which gives an impression and vision of the client of what is desired for design. However, the document is perceived as binding.

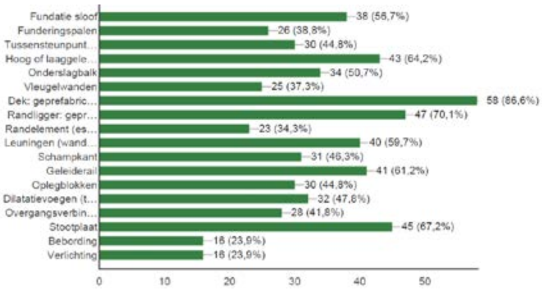


The outcome of this question shows that the experts of BAM Infra/Infraconsult experience the "beeldkwaliteitsplan" as a binding document. 89, 5% of the participators experience the document as binding. However, during the interview with Paul Waarts of the province of South-Holland, he clearly pointed out that the document was not binding and only give an impression. It is something that all the market parties together should discuss. If the document is not leading, there will be a lot more freedom in design for the contractors.

Q5.1 and Q5.2

Q5.1- Within the W&R concept of BAM Housing (Woningbouw) the principle of an 80-20% rule is applied. This means that 80% of the design is standard and only 20% can vary. What percentages do you think is realistic for a viaduct?

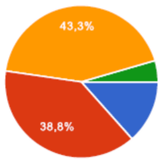
Q5.2- Which components are suitable for the appliance of the principles of mass customization: standardisation and modularization?



The outcome of question 4.0, 5.1 and 5.2 imply that the experts think it is possible to implement the principles of mass customization within a viaduct. All the listed components are thought to be suitable. The deck, the edge beam, the approach slab and the abutment/bank seat are ranked as having the most potential.

Q5.4, Q5.5, Q5.6 and Q5.7

Q5.4 - How do you feel about the idea to make less use of connecting elements/components by depositing with concrete?

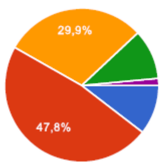


o Zeer positief: Natuurlijk mogelijk	9	13.4%
o Positief: Mogelijk	26	38.8%
o Neutraal	29	43.3%
o Negatief: Niet realistisch	3	4.5%
o Zeer Negatief: Niet mogelijk.	0	0%

The outcome of question 5.4, as can be seen above, was that 13.4% was very positive, 38.8 was positive, 43.3% was neutral and only 4.5% though it was not realistic to make less use of connecting elements/components by depositing with concrete. This outcome implies that there is awareness and openness that there can be other solutions besides pouring with concrete to make a connection.

Within question 5.5 it was asked why the participants thought positive or negative about the idea to make less use of connecting elements/components by depositing with concrete. Only positive answers were given and can be categorised by: building demountable, decrease of the building time, increase of the flexibility, and everything is possible it only needs some adjustments of the constructive principles.

Q5.6 - How do you feel about the idea of developing a "click" system to connect components/elements, instead of the traditional approach of pouring concrete specie? Do you believe that this is possible? This is with a view to easier assembly, build demountable and to perform maintenance.



o Zeer positief: Natuurlijk mogelijk	7	10.4%
o Positief: Mogelijk, maar complex	32	47.8%
o Neutraal	20	29.9%
o Negatief: Niet realistisch	7	10.4%
o Zeer Negatief: Niet mogelijk	1	1.5%

The result of Q5.6 shows that in general, the participants are mainly positive about a “click”-system. Within the next question (Q5.7) an open answer was asked about why the participants thought it was possible or why they thought it was not possible. The main reasons that were given were:

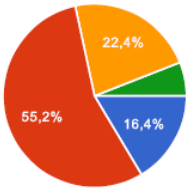
Possible/advantages:
- The principles of a “click”-system are already has been applied for prefabricated beams, there it is successful.
- A Lego system can be applied. Only the constructive principles need to be adapted. However, it is possible.
- Increases the possibilities for the application of new materials.
- Shorter building time

Not possible/disadvantages:
- Constructive limitations (also limitations in dimensions due to transport)
- Will be more expensive
- Complex design, many factors are of influence.
- Certification of a “click”- system: for example safety

Interesting to note is although in general, the participants were positive about the "click"-system, many reasons why it was not possible and disadvantages were filled in. From this, we can conclude that building a system that applies "click"-systems is very complex.

Q5.10

Q-5.10 What do you think about the idea to design viaducts that can be de-assembled, instead of fully demolishing the structure, is this possible. Certain components can be reused directly in new viaducts.

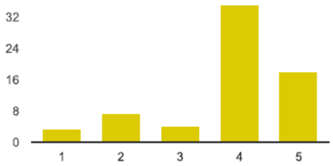


o Zeer positief: Natuurlijk mogelijk	11	16.4%
o Positief: Mogelijk, maar complex	37	55.2%
o Neutraal	15	22.4%
o Negatief: Niet realistisch	4	6%
o Zeer Negatief: Niet mogelijk	0	0%

The outcome of this question implies that the various experts are positive that it is possible to make a viaduct that can be de-assembled and to reuse these components in other structures. However, although they think it is possible, does not mean they think this will be beneficial or this is an approach BAM Infra should follow.

Q5.11

Q5.11 – Do you think it is possible to construct a viaduct out of only prefabricated parts? (Not in-situ)

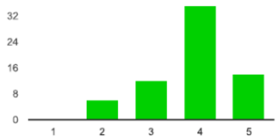


Sterk mee oneens: 1	3	4.5%
2	7	10.4%
3	4	6%
4	35	52.2%
Sterk mee eens: 5	18	26.9%

Around 85% of the participants do think it is possible to construct a viaduct only out of prefabricated parts (no in-situ)

Q5.12

Q5.12 - It is possible to build up a component of a viaduct out of prefabricated moulds, which in the end becomes part of the construction. By assembling the prefabricated formwork on site, and then fill these moulds with concrete. The prefabricated moulds then become a part of the component.



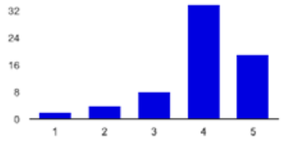
Sterk mee oneens: 1	0	0%
2	6	9%
3	12	17.9%
4	35	52.2%
Sterk mee eens: 5	14	20.9%

The researcher had this idea already at the beginning of this research and has also asked this question in some of the interviews. Most people were positive about it, and they do see potential. When an interview with Jan Pieter van Heten, currently the project leader of the gravity based foundations, was conducted, he responded that it was a great idea and BAM Infra had already applied this concept in the tunnel for the A4. However, the most experts did not know about this. Jan Pieter, hereby, argues that this was a typical example of the fact that BAM Infra does not work project-exceeding. Of course, the concept is not exactly the same, but nothing is further done considering the tunnel of the A4. The concept could have been, or maybe still is a great opportunity.

Q6.2

Q6.2 - A database that is available within the organisation for everyone should be developed. It can be the first step towards a more project-exceeding approach.

In this database, you must imagine that certain documents of projects are easily available for the experts of BAM Infra. Such as drawings of the final design, cost estimation, planning, etc. A good distinction between the documents should be made applicable, so one does not get flooded by data. Additionally, the database will need to contain the characteristics of the project, and it should be clear who was involved/was a member of the project team. By this anyone can approach these experts for more information.

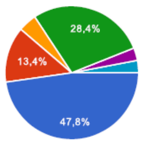


Sterk mee oneens: 1	2	3%
2	4	6%
3	8	11.9%
4	34	50.7%
Sterk mee eens: 5	19	28.4%

The outcome of this question is that a database that will be available for all experts needs to be developed. This is something that immediately became clear, as many experts are not satisfied with the way the access to data is arranged currently. However, this could also be solved in other ways than a database. The essence of this question lies in the idea proposed by the researcher to develop a database based on labelling the projects. It would be ideally if a system could be developed where you only need to select the characteristics, the circumstances and the value you give certain aspect within a sheet. The system will then search for these characteristics, circumstances and other values. The projects that are put into the database will be compared with the list of the new project. The system matches the different projects in the database with the list of the new project. Eventually, the system will give advice about which project will be interesting to analyse and review.

Q4.11, Q4.8, Q6.8, and Q6.10

Q4.8 – In which phase of a project, do you think that standardisation and modularization will have the biggest positive effect.



o Tender fase	32	47.8%
o Voorlopig ontwerp	9	13.4%
o Definitief ontwerp	3	4.5%
o Realisatie/Bouw	19	28.4%
o Onderhoud	2	3%
o Afbouw/Afbreken kunstwerk	2	3%

The tender phase (47.8%) and the realisation phase (28, 4%) are the phases of a project that were standardisation and modularization will have the biggest positive effect.

Q4.11 – Which aspects are the most important reason to implement standardisation and modularization in BAM Infra's current strategy?

o Veiligheid	16	23.9%
o Bouwkosten	48	71.6%
o Verhogen kwaliteit: ervaring	28	41.8%
o Sneller bouwen	33	49.3%
o Sneller ontwikkelen (ontwerpfase)	14	20.9%
o Sneller ontwikkelen (tenderfase, zowel op ontwerp als op calculatie)	28	41.8%
o Verkeershinder minimaliseren (voertuigverliesuren)	5	7.5%
o Makkelijker verlenen van services en onderhoud in de toekomst	12	17.9%
o Bied mogelijkheden tot continue optimalisatie van product en proces	24	35.8%
o Aanbieden van variabiliteit tegen relatief lage prijs.	12	17.9%
Overig	3	4.5%

The outcome of Q4.11 identifies that according to the participants of the survey the most important reason to implement standardisation and modularization is the building costs. In addition, the building time, increase of quality and faster development in the design phase, are considered as important.

Q6.8 – What do you think the most important advantages are of standardisation and modularization, with the vision to eventually develop a product platform?

In this question, the participants were asked to point out the three advantages that they considered as the most important. The outcome is presented below.

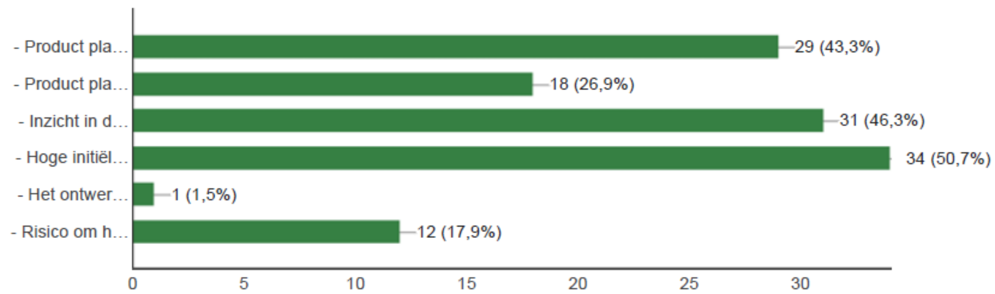
Advantage	*Amount of times chosen*	*Percentages*
Efficiency in the design phase	*47*	*70,1%*
Improved project planning	*21*	*31,1%*
Cost efficiency	*54*	*80,6%*
Higher efficiency and productivity by optimisation of processes	*38*	*56,7%*
Higher quality, due op optimisation of the design and the application of prefabricated parts.	*19*	*28,4%*
Standard interface will result in better communication and transparent documentation	*9*	*13,4%*
Design process will become less complex	*9*	*13,4%*

The outcome of Q6.8 identifies that according to the participants of the survey the most important advantages of standardisation and modularizations are: cost efficiency (80, 6%), efficiency in the design phase (70.1%) and higher efficiency and productivity by optimisation of processes (56, 7%).

- Efficiëntere ontwerpfase (kortere ontwikkel/ontwerp tijd: ontwerp maar een keer, en hergebruik het ontwerp in meerdere projecten)	**47**	70.1%
- Verbeterde project planning (door optimalisatie en ervaring met het ontwerp)	**21**	31.3%
- Kosten effectief (hergebruik ontwerp + minder faalkosten door bekend product/proces)	**54**	80.6%
- Hogere efficiëntie en productiviteit. (men kan het ontwerp en proces optimaliseren, en men wordt steeds ervarener)	**38**	56.7%
- Hogere kwaliteit vanwege optimalisatie van het ontwerp en het gebruik van prefab-elementen.	**19**	28.4%
- Een standaard interface, zal resulteren in betere communicatie en transparantere documentatie.	**9**	13.4%
- Het ontwerpproces word minder complex (product kan worden opgedeeld in kleine "problemen")	**9**	13.4%

Q6.10 – What do you think the most important disadvantages are of standardisation and modularization, with the vision to eventually develop a product platform?
In this question, the participants were asked to point out the three advantages that they considered as the most important. The outcome is presented below.

Disadvantages	*Amount of times chosen*	*Percentage*
Product platform needs to be constantly adapted, to meet the constant changing market.	*29*	*43,3%*
Requires insight about the future market conditions to be able to develop a product platform that is suitable and can be developed further for several years: Future is unknown.	*18*	*26,9%*
Product platform needs to be managed and monitored	*31*	*46,3%*
High initial costs	*34*	*50,7%*
The design processes become more complex	*1*	*1,5%*
The risk of abandoning current practices, and thereby the risk of losing their competitive position in the market.	*12*	*17,9%*



The outcome of Q6.10, identifies that according to the participants of the survey the most important disadvantages of standardisation and modularizations are: High initial costs (50, 7%), Product platform needs to be managed and monitored (46.3%), and product platforms need to be constantly adapted, to meet the constant changing market. (43.3%)

A.21 NEW PROCUREMENT METHOD

Several years ago, the way construction projects are procured has been changed. A new procurement method and integrated contracts are implemented. An important driver for implementation of new procurement method and more integrated contracts is the male functioning of the construction industry. Continuous budget and time overruns, limited efficiency, limited innovation, fraud and adversarial relationships where present when the tradition procurement method was applied. A new method was needed, to overcome the inherent weaknesses of the traditional procurement model. The traditional procurement model is characterized by a high level of customization, a separation between design and realization phases and a static construction process. The new procurement methods apply a more integrated approach. The design, actual construction (realization), finance, operation and maintenance can all be integrated into one contract. This means that contractors who traditionally only focused on the construction process are now also involved in the design, engineering or maintenance processes. The various companies in the construction industry need to cooperate with each other and integration is required. In the traditional procurement model the construction object is fixed in terms of full specifications that are put out to tender and as a result there is little opportunity to make strategic trade-offs, innovate and perform activities differently than the competitors. Now that clients exploit more of the knowledge and expertise at the market and contractors or collaborations of various contractors are involved in an earlier stage of the construction process. The involvement of contractors is more integrated. This result in more design freedom, and by this increases the opportunity to innovate. However, the new procurement method and the more integrated contract currently do not work optimal, Functional specification and less interference of client within the design process is still limited. For example RWS does provide more functional specification. However these requirements are still very detailed, therefore still limited freedom in design is present. The new method still needs to be adopted in the way the construction industry works, considering the client and the contractors. Construction companies, as BAM Infra, are struggling to with the new way of working in de industry. Due to the new procurement and contract forms the demand-driven construction industry with its fragmented processes is becoming a more supply-driven market where processes are integrated. The construction industry could become a more market push industry, instead of the market pull industry it has been the last decade. This could be enhanced by the application of the principles of standardisation and modularization.

A.22 ADDITIONAL LIMITATIONS

In this chapter six, the general limitations of the research are already discussed. This section discusses additional limitations identified. The limitations discussed have resulted in constraints for answering the various research questions.

A.22.1.1 Limitations – Literature review

There is much literature available about the subject of standardisation and the subject of modularization. The concepts both come from the computer industry. The literature that can be found is mostly focused on the computer industry and the mass productions industries. The literature is very diverse and a lot of different perspectives can be found. However, only little can be found on the application of the principles of standardisation and modularization, within the infrastructural sector of the construction industry. Considering standardisation and modularization, no general term can be found and the two concepts are use together and are mix up in literature. However, the literature found on the application of the principles of mass customization, all point out the same issues. They mainly elaborate on the difficulties of the implementation in the construction industry. Eventually, some sources of literature where found that are specified on the infrastructural sector of the construction industry. However, because only limited literature about the application in the infrastructural sector can be found, the answer to sub-question one is bounded by some constraints.

A.22.1.2 Limitations – Analysis of current practices

- A limitation of this research was that for the analysis of large infrastructural projects where a form of standardisation has been applied, the main input was the opinion and experiences during the project of various experts involved. The trade-offs made in the design phase have not been clearly documented and it is not clear why certain decisions are taken. Various meetings and interviews with experts that were involved in one of the projects were held. However, because the projects are very large and a lot of different disciplines are involved in making a decision, it is very hard to get a good overview of decisions taken and why they are taken. In addition, the experts admitted that not always clear trade-offs were made, but decisions were taken based on different experiences of the project team. These choices were not further investigated, but are applied because they had been successful in other projects. But other possibilities could have also been successful in the specific situation. Because it is not clearly documented and some experts cannot remember why certain choices are made, it is hard to analysis these current practices. However, by having meetings and conduction of interviews with various (more) experts per project, the main choices made and why these are made could be identified.

A.22.1.3 Limitations – Survey (Quantitative research)

- The survey conducted is a quantitative part of this research. However, the survey is based on analysis of current practices, having conversations with experts and interviews conducted. These are qualitative data. The survey has provided us with deeper insights of the opinion of the experts of the research field. The quantitative data is used to support the findings of the qualitative data.
- Another limitation identified is that the survey is filled in by a selective group. The survey has only been sent to experts of the department multidisciplinary contracts of BAM Infra and the constructors, the planning engineers and the head of departments of BAM Infraconsult. These are mainly experts, they are high educated and open for a new approach. This group has been chosen because they will have knowledge about and understand the principles of standardisation and modularization.
- Finally, a limitation in the survey is that a not all experts where the survey has been sent to have responded. A non-respondent error has to be considered.

A.22.1.4 Identify components suitable for standardisation and/or modularization.

- A limitation of this research is that the method of Vanessa Veenstra that has been used as a guideline has been changed significantly for this research. Therefore, it can be argued that the results cannot be compared to other research results and are less reliable. However, the method developed and applied has been derived from the method of Vanessa Veenstra. The method of Vanessa Veenstra is suitable for the housebuilding industry. Design and construction of infrastructural objects are significantly different from design and construction of a house. Therefore, the method is adapted to be suitable for an infrastructural object. This has been changed in a structured way, and clear trade-offs are made.
- Although, the method of Vannesa Veenstra, used as a guideline, and within this method, the design for variety method of Martin and Ishii is applied, there are also limitations to this method. The tables that have been filled in are objective. The value constructors assigned variety significantly. They all have their own perspective and interpretation of the values given. In addition, the years and amount of experience with a viaduct also influence the data. Constructors which had a lot of experience with a viaduct filled in higher values than the constructors who had less experience. Therefore, the values have been ranked. Although not clear pattern or conformity could be identified from the results of these filled in tables and tables direct, a clear pattern and conformity between the outcome of the tables of the five constructors could be identified by when the outcome values were ranked.

- Another limitation of this research was that only five constructors participate by filling in the GVI-tables and tables for the coupling indexes. However, the research conducted is a qualitative research and the findings derived from the tables for every constructor individually were comparable. Therefore, it is not likely that the conclusion drawn would vary significantly from the findings of the research when a larger group of constructors was asked to fill in the tables.
- A general session with all the five constructors was held to discuss and agree on the values filled in the tables and tables. The outcome was more a compromise between the different viewpoint of the constructors. The values were more an average, no extreme values were present. The peaks are also interesting data but were lost in this approach. However, the session did provide a lot of insights about why certain numbers were assigned. And by combining the outcome of the session with the outcome of the individually filled in tables, the high and low extremes could be considered .
- Within the general session, there was not sufficient time to fill in all the tables together. However, the table that was considered to be the most important for the application of the principles of standardisation and modularization by the development of a standardised interface has been filled in during the session: Direct constructive relations.
- The tables are only filled in by constructors, no another discipline has been involved in the assignment of values in the tables. To increase the validity and reliability of the outcome of this research more people and also people out of other disciplines should participate by filling in the tables. However, the choice to let only constructors fill in the tables was made, this resulted in a clear focus on the constructive relations within a viaduct. When various disciplines would be asked the interpretation of the values would have been very complex and it will be harder to draw conclusions.
- A shortcoming of the method applied is that the design for variety method of Martin and Ishii prescribes that the project team should decide how they analyse the data, based on how the way Martin and Ishii have analysed their data in their research. In this research the interpretation of that data has been based on the approach of Martin and Ishii, however, criteria are developed by the researcher without the help of others. It would have been more reliable if more experts were involved in the describing the criteria for the analysis. However, the researcher can be considered as an expert in the research field.
- The various circumstances and possible changes over time that have been identified for the development of the GVI-tables are common knowledge about trends occurring and based on meetings and in consultation with the five constructors. If other constructors or experts would have been asked for the identification of the GVI's, completely different GVI could have been mentioned. This would have a significant impact on the result, other various circumstances, possible changes and trends could have been identified. However, in addition, to discussing possible GVI's with the constructors the conversations and interviews conducted with experts were considered and confirmed and provided other viewpoints. The GVI-tables developed, therefore, takes a lot of viewpoints into account and can be considered as reliable.
- When the tables had to be filled in, the constructors had to ask themselves the following question: if a change in external situation (GVI) or component X (internal situation) occurs, will change in component Y be required, and how big is the influence and change required. The constructors found it very complicated to give a clear answer to this question. The effect of a specific change is different in every situation occurring and depends on a lot of aspects. In addition, there are many relations between the different components. Therefore, no "unambiguous" answer can be given. Within this research, it has been chosen to identify the coupling relationships and their perceived index values, but no description why certain values have been assigned is documented. However, although full description of why certain values are assigned have not been documented, estimation about the coupling of components and the sensitivity of the components to the change in other components or external factors are made. This already provides great insights into the architecture of a viaduct.

A.22.1.5 Critical view on own research

- In this research, it has been investigated if the application of the principles of standardisation and modularization, with the vision to eventually develop a product platform, is suitable and will be beneficial for a viaduct. Within the literature review, it has been mentioned that by application of a product platform products can be easily adapted, easy maintenance by replacement of parts, can be expanded, add-ons can be added or components can be reused. Although this can also be considered for a viaduct, it has to be questioned if it is realistic. A viaduct is built to function for 100 years and during the use of the structure, the connections between and shapes of components will change. Expanding this structure, by adding a module, may not be possible anymore. The same can be questioned for the maintenance by replacement of parts. However, a viaduct can be designed in such a way that these limitations of deformation of the components and connection will not occur. In addition, considering the reuse of components, this has already been applied within projects. Although this required tremendous effort to undo the steel pipe from the poured concrete, it shows it is possible only needs to be further developed. In the project of knooppunt Hoevelaken, reuse of the beams of current structures investigated. This does not affect the outcome of this research as the development of a standardised interface, for the development of a product platform, has been with the main vision to establish efficiency and effectiveness in project development phases as in the realisation phases.

A.23 Core values of Royal BAM Group

Below the core values of Royal BAM Group are presented. *These core values have been derived from the general BAM website, with the following link: http://www.bam.com/en/about-bam/business-principles*

A.23.1 Introduction core values

The social, environmental and economic aspects in the short and long term are weighed up whenever strategic decisions are taken. The BAM Business Principles, or core values, are derived from the strategic agenda and form the basis for managing the Group's corporate social responsibility.

The business principles are defined on the basis of public interest in dialogue with stakeholders, and based on BAM's impact on these issues. The principles are reviewed annually during a stakeholders' meeting. In 2010, the stakeholders indicated that they felt further clarification of the current principles was important. There was also a need to focus more explicitly on BAM's responsibilities as regards its supply chain partners and its vision as to how sustainability and economic growth can go hand in hand. The business principles have been adjusted accordingly.

We build the facilities society needs, such as housing, hospitals, schools, retail areas, leisure and industrial facilities, transport facilities, utilities and infrastructure. When we create this built environment, we also have a responsibility to keep our impact on society and the natural environment to a minimum.

Royal BAM Group works closely with its employees, clients, suppliers and subcontractors on all aspects of corporate social responsibility. We seek to achieve a balance between the short and the long-term interests, and to make economic, environmental and social considerations an integral part of our strategic decision-making. We aim for open dialogue with the parties that will be affected by our activities and we communicate in a timely and effective way with our external partners.

BAM is committed to being a responsible company. This means that we conduct our activities in accordance with the applicable ethical, professional and legal standards. We consider corruption, bribery and unfair competition to be unacceptable.

A.23.2 People: Offer added value to clients, employees, business partners and the community.

<u>Clients: We always do our utmost to exceed the client's expectations.</u>
We work in partnership with our clients to deliver high-end projects within the timescale set, both safely and with respect for the environment. We will encourage our clients to work with us in developing suitable sustainable solutions. We aim to be the preferred supplier for CO2-neutral solutions.

<u>The community: We promote good contacts with the local community.</u>
By its very nature, our construction and renovation work has an impact on the local community, occupiers and other users of buildings and infrastructure, and society as a whole. We are therefore proactive in minimising the level of nuisance in the local environment and seek to make a positive contribution to the local community.

<u>Employees: We believe in our employees.</u>
We create a safe and inspiring environment for our employees to develop their skills, enabling them, in turn, to contribute to the further development and growth of our organisation. The commitment to our employees is demonstrated by:

Health and safety – We consider health and safety to be a top priority for our company. We are committed to the continual improvement of our performance in health and safety for all our employees and subcontractors and everyone involved with our activities, including the general public.

Equality and diversity – We offer a challenging working environment where everyone feels valued and respected. We are committed to the principle of equal opportunities and we ensure that job applicants and employees do not face discrimination on the grounds of gender, marital status, race, skin colour, ethnic origin, religious belief, sexual orientation, disability or age.

Learning and development – We aim to create a learning culture and provide opportunities for our employees to fully apply their knowledge and skills in the service of the company. We will help our employees to continue their development in the interests of the company and its objectives.

<u>Supply chain partners: We procure responsibly.</u>
We treat our supply chain partners honestly and responsibly. We work with subcontractors and suppliers to ensure that they operate in a safe and environmentally-conscious way. Together with our preferred partners, we promote and develop sustainable solutions and best practice for the sector.

A.23.3 Planet : We recognise our responsibility to future generations

Energy: We strive to reduce our impact on climate change.
We will improve our energy efficiency, reduce our CO_2 emissions and work with our clients to develop CO_2-neutral solutions.

Raw materials: We are becoming more efficient in our use of materials.
We believe in reducing our impact on the supply of natural raw materials used in our products. We will work with our clients and suppliers to use alternative materials and methods in order to optimise the use of raw materials. We also promote measures to recycle and restrict waste.

Environment: We will limit our environmental impact.
We take all possible reasonable measures to ensure that our activities are conducted in a way that minimises the impact on the local environment. We promote environmentally-friendly operations and seek opportunities to promote biodiversity on our construction sites.

A.23.4 Profit: Creating economic value

Innovation: We innovate to identify balanced sustainable solutions.
Innovation is essential for our company's development and to identify powerful sustainable solutions in the built environment. Together with our partners in the supply chain from customers to subcontractors and suppliers, we will provide sustainable solutions in which economic, environmental and community interests are well balanced. This approach ensures that we use materials efficiently and provide good value to our customers.

Prosperity: We believe that sustainability results in economic value.
We choose to create value by working on effective and profitable solutions for our shareholders that contribute to a sustainable future. We believe that by applying these Business Principles, we create value for our shareholders, clients, employees and for society as a whole.

B.1 Interviews conducted

In this section, the result of several interviews conducted during the research is presented. During the research many meeting with employees of BAM Infra took place, only a small amount is completely worked out. The various interviews that have been completely worked out are presented in this appendix.

Interview number	Interviewees	Date (sort by date)	Function and background	Abbreviation
1	a) Chris van der Zwaard and b) Avinash Gangaram-Panday	13 May 2016	a) Head of department Civil Design – BAM Infraconsult b) Structural engineer – BAM Infraconsult bv Has done his Master Thesis about the standardisation of beams for a viaduct.	a) CZ b) AGP
2	Folkert van Schagen	17 May 2016	Planning engineer construction (Werkvoorbereider) for the tunnel alliance with ProRail.	FS
3	Kitting Lee	18 May 2016	Tender Manager – BAM PPP Nederland bv	KL
4	Jan Pieter den Heten	18 May 2016	Project leader – BAM Infra bv	JPH
5	Nicky Brieffies	20 May 2016	Project leader and coordinator management and development - BAM Woningbouw bv	NB
6	Paul Waarts	24 May 2016	Senior adviser - Province of Noord-Holland President – Infra Innovation Network	PW
7	Leon Hendriks	25 May 2016	Sr. Design leader – BAM Infraconsult bv	LH
8	Aad van der Horst	26 May 2016	Former Technical director - BAM Infraconsult bv Professor - TUDelft	AH
9	Johan Bolhuis	1 June 2016	Head of the department Civil Design and Regions – BAM Infraconsult bv	JB
10	Ad van 't Zelfde	20 June	Advisor Innovation – BAM Infraconsult bv	AZ
11	Liona Lim	13 July 2016	Specialist Business Development – BAM Infraconsult bv	LL
12	Kees Quartel	24 August	Head of sales department - Spanbeton	KQ
13	Frank van de Geijn	25 August	Project leader – BAM Regions Nord-West Civil	FG
	Additional			
14	Maryia Smahlei	19 February 2016	Specialist BIM – BAM Infraconsult bv. Has done a PDEng about a standard railway underpass	MS
15	Cor Notenboom	12 May 2016	Head of DBFMO – BAM Bouw en Techniek	CN

B.1.1 Interview 1

Interview considering: Vision and opinion for “legolisering” + Approach of the N261

<u>Interviewee – Chris van der Zwaard – 13 May 2016</u>

Personal Details	
Title:	Head of department of civil constructions
Initials:	CJ
Company Information	
Operating Company Name:	BAM Infraconsult bv
Working as:	Head of the department civil design
Department:	Civil design
Office:	Gouda
Company Contact Information	
Mobile phone:	+31 651582271
E-mail:	chris.vander.zwaard@bam.nl

<u>Interviewee– Avinash Gangaram- Panday – 13 May 2016</u>

Personal Details	
Title:	Structural engineer
Initials:	A
Company Information	
Operating Company Name:	BAM Infraconsult bv
Working as:	Constructor
Department:	Civil Design
Office:	Gouda
Company Contact Information	
Mobile phone:	+31 182590486
E-mail:	avinash.gangaram@bam.nl

Introduction interviewees

Chris van der Zwaard is the head of the department of civil constructions at BAM Infraconsult, which is located in Gouda. Chris van der Zwaard has been the design manager for the N26, a project where standardisation has been applied successfully. When I contacted him, he was very enthusiastic and really is of the opinion that BAM should make better use of the repetition that occurs, he highlights that standardisation can be beneficial. He asked Avinash Gangaram-Panday to join the interview. Avinash Gangaram-Panday is a structural engineer at BAM Infraconsult. Three years ago, he has executed his master thesis at BAM Infra, under the guidance of Chris van der Zwaard. Avinash Gangaram-Panday explored if a standardise viaduct can be established. His output has been used within the research of the reference viaduct conducted by BAM Infra.

1. **What are your thoughts on standardisation and modularization, by implementation of a product platform in general? (Referring to “legolisering”).**

Chris van der Zwaard is of the opinion that standardisation can bring many benefits. He states that he has been trying to convince the people working at BAM for almost 20 years now, but not with great success. Although some people do agree with his standpoint, standardisation is not implemented yet. Chris van der Zwaard had/has the idea to make a small book for every type of project, object and even processes about the standard of how the project teams should start, referring to the considered standard. From the established standard on specific projects that have already been applied and have proved to be successful, a new design can be established. By going through a process by which the standard can be optimised and new innovations specific for the standard design can be developed. By this constant improvement occurs, and a learning curve occurs.

Chris van de Zwaard highlights that before the new contract forms RWS had a standard detail book. BAM Infra used these standard elements for their entire project, as this was specified by RWS. However, RWS started to use more functional requirements. The result was that constructing companies got more freedom in design. Although this also meant that construction companies have to develop their own details. As RWS does not update their details any longer, and the old details were not sufficient to meet the demands of the client and the regulations.

Although the new contract forms and more functional requirements give BAM more freedom, this also means more responsibilities. Chris van der Zwaard highlights that new detail design needed to be developed, however, he states that this also brings possibilities to consider safety, which he considers as very important.

Although his is very positive about a product platform, he states that it is important to keep updating the platform, so that the companies can keep up with the developments within the dynamic and fast changing market. Constant validation is important to make sure the design still meets the changing requirements.

Chris van der Zwaard sees a lot of possibilities for standardisation. He states that it is possible to standardise, but it will not be appropriate for everything. However, if a client has very specific requirements, this will also result in more unique, custom made solutions, the consequence here is that the price will be higher compared to choosing a more standardise design.

2. **The concept already has proven itself in the house building sector. What makes infrastructural projects different from house building? And do you consider it to be applicable for infrastructural projects/objects?**

Chris van der Zwaard and Avinash Gangaram-Panday are both of the opinion that standardisation, as referring to the W&R concept, is applicable for infrastructural objects. And they do not see a big difference with the house-building sector and the infrastructural sector, in their opinion the concept of the W&R housebuilding can be used within infrastructural object as well. The researcher points out that there are major differences, for example, market push and market pull. Chris van der Zwaard further elaborates on this, by saying that within infrastructural projects there has to be dealt with a lot of different stakeholders. Within the house-building, a number of stakeholders are significantly lower. Due to this, an infrastructural project is more complex, but still, standardisation should be possible.

3. **Is the initiative/research for the development of an infrastructural object currently continued?**

Avinash Gangaram-Panday says that after his thesis was used for the reference viaduct initiative, he has heard nothing about it anymore since that initiative stopped in 2014. However, Avinash Gangaram-Panday still thinks it can be very beneficial to implement a standard, or just to work with a clear reference. The flow charge that he developed can be a useful tool in this process.

Chris van der Zwaard states that he thinks it is sad that the initiative did not resulted in the implementation of standardisation. He still things BAM Infra should start applying the concept of standardisation and therefore is very interested in my research.

4. **Can you tell a bit more about the standardisation that has been done for the project N261 considering viaducts?**
   a. **Considering the product: What can we learn from the standardisation of the N261 for new projects?**

Within the N261, standardisation has been applied for: the columns, the capping beams (onderslagbalk) and the edge elements. So it is possible to standardise and in new projects, we should use this knowledge. Chris van der Zwaard here states that there have been more projects that have been successful with some form of standardisation. For example, the N33 and the A12. He states that projects have to documented and reviewed, in order to learn from them. This is currently missing within the organisation. And in the situation when verification and validation does occur, and the project is documented correctly, the big problem is that the employees of BAM Infra do not (insufficiently) take the successful project as starting point, and even worst it is very hard to get access to the documents and drawings of the different projects. The researcher asks if we can say the problem revolves around more aspects, as she has already pointed out by the three aspects in her thesis: communication, learning curve, standardisation and modularization. Avinash Gangaram-Panday and Chris van der Zwaard agree.

Also, a new innovation has occurred on a product level within the N261, this new technique has been accepted by RWS. The proposed technique was not according to the requirements, however, BAM Infra could convince RWS that the technique was an effective solution. This new technique gave a new way of working for the “hydrofoberen” of the deck of a viaduct. This means that the deck has to be made waterproof, so the water does not negatively affect the structure. Before the process of “hydrofoberen” was done when applied concrete had been cured sufficiently, the concrete then has sufficient strength to “hydrofoberen”. This process has to be repeated two times. However, it takes a few days before the concrete is stiff enough. The new technique is based on applying a small layer of special material on the concrete deck, this can be done relatively fast after the deck has been assembled, and only one layer is needed. The result of this new innovation can save a lot of time, in comparison to the old approach. Chris van der Zwaard points out that he thinks this has to become the new standard. However, it has not been clearly documented and therefore it is not used in new projects. He states that we must use this new technique in all our projects. In Dutch he says, we need to “doorpakken”. The researcher concludes him, by saying that the innovation has to be used within other projects as well. BAM Infra should work on a more project-exceeding level. Gangaram-Panday and Van der Zwaard both agree with this.

b. Considering the process: What can we learn from the standardisation of the N261 for new projects? This question refers to what tips and tricks Chris van der Zwaard and Avinash Gangaram-Panday have for the development and implementation of a product platform for viaducts? (Considering standardisation and modularization: what opportunities are there, and which difficulties did you come across considering the standardisation that has already been established?)

When the tender of the N261 was procured, it immediately became clear that a new idea was needed in order to be able to deliver the project within budget. Chris van der Zwaard point out the second place had a design that was 20 million more expensive than the price BAM Infra signed up for. The price was not realistic, and in order to deliver the project for the procured price, a new innovative approach was needed. The phase of the provisional design therefore had a long duration. However, the result was there eventually, as the designed construction could be constructed very fast and the project was delivered 1, 5 year earlier than required. This was also partly due to the fact that the municipalities, provinces and architect were already involved in the first phases of the project.

5. **Within my research, I aim to identify components that are suitable for standardisation/modularization for the development of a product platform. Here I look at repetitive elements, the coupling relationships of the different elements, elements that need a lot of maintenance, have to be replaced, and/or have a high risk of failure. Additionally, by thinking "out of the box", new ideas for which and how different elements can be standardised and modularized.**

Avinash Gangaram-Panday thinks this is a good approach for identification of components to standardise. In his research, he made use of trade-off matrixes and has established a flow charge for the design of a viaduct considering parts that can be standardised. He refers to his research and thinks it could be a good source of information. As he points out, that it is very hard to get access to and find the right data within the company.

6. **What do you consider as parts that can be prefabricated, that are currently produced on-site?**

Avinash Gangaram-Panday and Chris van der Zwaard both think that all parts of a viaduct can be prefabricated. And point out that is can save a lot of time on the building site. This is very important as an infrastructural project has to deal with a lot of different stakeholders that are influenced by the construction project. By building fast, less hindrance will occur as roads can keep functioning or only need to shut off for a small time period. In addition, prefabrication also results in better quality.

7. **Do you think it is possible to make use of a click system, instead of joining by the use of concrete (Maintenance, adaptable to future demands, demountable)**

Considering my viewpoint of the possibilities a product platform with the application of the concept for standardisation and modularization, I asked the question if they consider it to be possible to make use of a click-system, instead of joining all elements by the use of concrete. As here I pointed out that this, in theory, could be beneficial. As current construction objects can be updated more easily, can be demountable faster and can become more sustainable. Referring to if a standard interface will be developed, all the different elements could be easily combined, and as they all click together in the same way (the idea of Lego blocks).

Chris van der Zwaard thinks this a nice new viewpoint on the concept of standardisation. However, he is not sure if this works in practice. He states that BAM currently still has a long way to go in the development of a standard, and constantly adapt the standards to changes in the market: an iterative process. He, therefore, states that although he does see potential, he does not think this will be a driver for BAM for development and application of a product platform, this is more focused on the learning curve, to optimise and not "re-inventing the wheel" constantly.

8. **What are materials that you consider to be appropriated for the construction of a viaduct? I currently have the idea to work with other materials than the conventional concrete. Do you work with new innovative materials? And do you consider that it can be possible and will be beneficial to use polystyrene (plastic) in combination with concrete for a viaduct?**

Avinash Gangaram-Panday and Chris van der Zwaard both point out that within the industry some initiatives considering the use of other materials combined with concrete as being taking by different suppliers and construction companies. BAM here innovates as well. They refer to the Fibre-core, where the recently had a lunch lecture from. Fibre-core develops concrete mixture with plastic fibres, this increases the strength and durability of a construction. The concept of a fibre-reinforced concrete is used within the construction industry, it is still a relatively new technology, but is applied on relatively big constructions recently, referring to the doors of a sluice doors and movable bridges.

Chris van der Zwaard states that FibreCore has two main options/solutions which we can choose from. They have applied standardisation but stated that still, a more specific design is possible. However, the more specific a design is, this means the less standard it is, and the higher the price will be. Van der Zwaard points out that the products that FibreCore develops are light and relatively require not much maintenance. However, the concept is not fully accepted, as they do not know how the construction made with fibre-reinforce concrete will stand the test of time. And currently, no guaranty that the construction will be sufficient for the 100 years can be given.

Although BAM sometimes uses fibre-reinforced concrete, this is still new, and the application, therefore, is still limited. Van der Zwaard thereby states that it is possible, and we should use it more often. He refers to the competitor, Heijmans, as they have built a movable bridge where they apply a truss structure with the reinforced concrete deck. This has resulted in enormous weight savings. Therefore the total construction could be lighter resulting in a smaller dimension of the foundation. But Chris van der Zwaard states, that although he does see potential, BAM Infra currently does not use other innovative materials. They mainly use concrete, RVS and aluminium. Avinash Gangaram-Panday remarks that currently within the project of "knooppunt Hoevelaken" they want to make us of a synthetic plastic in their construction, however, this is still in the research phase.

9. What do you see as risks and/or barriers, as well as opportunities in the future market?

Chris van der Zwaard immediately state: The people. He states that a mind-shift will be needed. And points out that it should be demanded by the management and the project leaders. If this is not the case, the employees of BAM will not adopt the concept. He points out that he is tried several times to implement standardisation during his career, but this has not yet been successful.

10. Why do you think the initiatives that are taken are not always a success? What can we learn from these initiatives?

Chris van der Zwaard state that he has been asking himself this question for quite some years now. He does not know why BAM is not successful in implementing new approaches. But he sees that it is possible, as other construction firms innovate. He refers to Volkert&Wessel, they were able to make a standardise viaduct. Within BAM this resulted in the fact that the initiative of a reference viaduct was again considered, and the research was continued. However, he states that apparently, BAM does not push through. He thinks this is because BAM still works as if different firms that are work together, however, they should work as an integrated team. Currently, still, the culture of individual firms is present, although we are one big organisation right now. We should work together, also on the level of new innovations. Together we have to invest in this. Avinash Gangaram-Panday, hereby points out that there is not sufficient time for the initiative to be developed further. Currently, the further development is done when limited work is procured, as then there is time to continue with the research. He points out that there will need to be a budget in order for the initiative to be further developed.

11. Do you think the development of configurator for different infrastructural objects is beneficial and/or applicable? Or are the situations to "unique", too much different circumstances, and is there still a lot of changes that are required and/ or design of new elements needed? As architects can change the reference model, do you consider that is sufficient room for change?

Avinash Gangaram-Panday and Chris van der Zwaard both think this is possible, and sufficient variety can be delivered. Chris van der Zwaard refers to the initiative of the click and construct the project for a small bridge, and points out that this concept can be applied. He points out that this at first mainly will be suitable for application in the tender phase. This is an important phase, as the outcome of this phase is essential for getting the contract, and eventually to build the procured design.

Chris van der Zwaard also point out that, although he thinks a configurator would be a great tool, this will not be easy to implement. First, the standardisation has to be nailed down.

12. How do you think new methods and/or techniques can be implemented. As the customer, rather not have the risks of a new concept? And procurement is based on EMVI criteria?

The N261 is a good example of this, as innovation was needed to be established in order to be able to build the project within time and budget. A new to innovate occurred. Within the project, the client has given BAM Infra sufficient room to innovate, and that had confidence in that BAM Infra. Chris van der Zwaard states that this confidence is essential and the client should give us more freedom in design. With the current level of specifications/requirements, there is almost no room for innovation, as a lot of requirements are demanded. This has to change, but Chris van der Zwaard does question if this will happen.

13. What is your opinion considering co-production?

Co-production is needed. Van der Zwaard hereby refers to Toyota, as they have long-term relationships with their suppliers. Here the suppliers also are motivated to innovate, as Toyota demand them to develop the product further, for example, they will have to further develop components, in order to decrease the cost of this component by 10%. If this innovation is not established and the goal is not reached, Toyota goes to another supplier. This driver for innovation is important. The researcher also points out that suppliers and constructing firms can learn from each other, as they all have different viewpoints and expertise. It can be stated that: "The whole is greater than the sum of parts". Van der Zwaard and Gangaram-Panday agree with this.

14. **Within the BAM Infra, some people are sceptical about the implementation of a product platform for viaducts, as they consider every project as unique. Additionally, it has been pointed out the current specification of the requirements of RWS are still too specific, although they are made functional. Do you think the different provinces and municipalities can make an agreement for their specific requirements, considering infrastructural objects? So that a reference object can be made, and a common interface can be developed?**

This is one of the concerns Chris van der Zwaard has. He argues that this has to change in order to be able to fully benefit from a product platform.

During the interview, Chris van der Zwaard constantly points out how he thinks standardisation should be implemented within the company. Here he refers to the documentation of standards. Standards have to be chosen and then imposed within the organisation. He refers to his idea of a “standard reference book”. For the current situation he thinks a group of experts of the different projects where standardisation has been applied have to form a discussion group, in order to figure out what a good standard will be. A standard has to be chosen and shared within the organisation. This standard needs to be used within all new projects. He considers this to be the easiest way to implement standardisation. He wants to put together a focus group, however, when these people are busy with projects, their department will not let them go for this. BAM needs to work more like one organisation, helping each other out and learning from each other. By implementing a standard, the idea can constantly be improved, as it is applied in different projects. Considering the documentation and efficient data sharing within the company he thinks this has to become easier, we cannot only say to our employees that they should adopt standardisation, we also have to provide the tools that are required to accomplish this; This by choosing standards.

15. **Do you have other tips, considering the implementation of a product platform for a viaduct? Documents I need to review or people to interview?**

Contact Hans Ramler, he can also tell you a lot about standardisation from his viewpoint. Maybe you can also go the department business and development for an interview. Avinash Gangaram-Panday notes that if I have questions considering his research, I can contact him anytime.

B.1.2 Interview 2

Interview – Folkert van Schagen – 17 May 2016

Function: BAM Infra – work preparator ("werkvoorbereider")

Personal Details

Initials:	FH

Company Information

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Working as:	Work preparator (Werkvoorbereider)
Department:	Project preparation (Voorbereiding)

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1. **What was your general function and what was your function within the tunnel alliances?**

Folkert van Schagen works as a work preparator (werkvoorbereider) at BAM Infra for the tunnel alliance. Within this alliance, he facilitates the process. The process has been standardised. However, the product has not been standardised successfully, although it has been investigated if this is/was possible. But improvement is still needed. Considering the tunnel alliance, Folkert van Schagen was proud to say that this weekend BAM Infra has successfully inserted (jacking) a railway underpass, it was even ready 2,5 hours earlier than needed.

2. **What are your thoughts on standardisation and modularization, by the implementation of a product platform in general? (referring to "legolisering").**

Folkert van Schagen thinks the concept sounds great but states that it is hard for him to picture how this can work in practice, and how this could be implemented within their current practices of the tunnel alliances.

3. **Can you tell a bit more about the standardisation that has been done for the tunnel alliance for railways underpasses?**
   a. **Considering the product**

Folkert van Schagen states that the standardisation of the product (railway underpass) was not a success due to;
- Province and municipalities have certain requirements for the design, these are different within all projects.
- The "profit" (benefits) of product standardisation are not clear within the company, the employees do not see how standardisation could be beneficial. They mainly see the down site, that it takes more time and energy to start innovating, than just applying the traditional practice. They state that it will result in higher failure costs. This is true, but this is something that happens with new concepts/ideas that are implemented, eventually it will become better than the current practices.
- Uncertainty: Politics considering the norms and requirements can significantly change over the last couple of years. Folkert van Schagen states that considering the construction industry the politics are capricious, therefore nothing is certain.
- Finance: The municipality pays for the product (railway underpass). Who pays, is mainly in charge of the design. The municipalities can, therefore, demand a design that meets their wishes.

Folkert van Schagen does state that the functional shape of the object is already determined by the location, this is already a standard. The researcher ask the question; how much influence do the aesthetic requirements have on the design? Folkert van Schagen has to admit that this is very limited, as the researcher has asked critical questions about this. He points out that they have tried, and a research is conducted, to implement more standardisation within the design of the railway underpass. This is done within the cost-leadership program of BAM Infra.

   b. **Considering the process:**

Considering the railway underpasses, here mainly the process had been fully standardised. The different phases and processes are fully elaborated until documentation level. Folkert van Schagen states that during the first phases of the projects, the start-up phase could be more standardise, considering a more detailed description of the output of this phase. Van Schagen states that the standardisation of processes will eventually lead to standardisation of the product, they are interrelated.

4. **Why is this so important to standardise both process and products? And what lessons can be learned?**

Folkert van Schagen does share the opinion the standardisation of product and process, together will bring the most benefits. For railway underpasses, he thinks the process could be future standardise, however, this will go gradually by the experience gain within the different projects. Within the projects for railway underpasses more structuring the process by standardisation, could result in less chaos. Folkert van Schagen points out that the exact process of the construction of a railway underpass is not suitable for another kind of projects. As they all ask for different techniques and are of a different scale.

5. **As architects can change the reference model, do you consider that are is sufficient room for change. Or less or more design freedom/ changes are needed? (Referring to the quotation of Henry Ford; "Any customer can have a car painted any colour that he wants so long as it is black.")**
   Does the design of the "railway underpass" suitable for all the different situations, and can be easily adapted by parametric modelling, or does still a significant change in the design needed?

Folkert van Schagen states that currently, no standard reference design exist for their railway underpasses. Hereby the researcher refers to the research of Maryia Smahlei, here a solution with a reference design and using parametric modelling has been proposed. Folkert van Schagen states that they did consider the result of the research, they now always use a "Box" within every project, and this is now the standard. In addition, to this, the researcher asks if Van Schagen thinks it is possible to just have 5 different types of objects considering different lengths. Within a tender, van Schagen does think this is possible and could be efficient. However, he is sceptical about this considering the actual development of projects. He states that they have considered implementing different standard types, with different dimensions and for different situations (soil). However, this has not resulted in action. Van Schagen thinks current practices are currently good enough. Therefore there is no driver to further investigate the possibilities.

6. **How is the learning within the team transferred? Does this need improvement? (knowledge is project-exceeding, constantly updating the model?)**

The development and construction of a railway underpass are always managed by one core-team. The core-team exist out of the tender manager, the program's manager and himself as responsible for the preparation. In addition, evaluation and feedback loops are applied, however, this is still limited. Folkert van Schagen is of the opinion that in the ideal situation, the core-team would manage different projects at the same time. Here they are responsible for the different projects with railway underpasses. He states that then the concept can be secured by the core-team.

7. **Considering the tunnel alliances, do co-production/co-makers took place?**

Folkert van Schagen states they within the tunnel alliances, they do have long-term relationships with co-makers. However, although they have worked with the same suppliers within the different project, no real contract has been signed. Examples of co-makers here are: Mammoet, responsible for the heavy-lifting, and BAM Infra here collaborate with their sister firms: BAM Rail and BAM roads. Within this collaboration between the different parties, they try to work with the same persons in every project. Here a learning curve can take place. However, currently, only the core team stays the same. The "Dream state" will be that just like in the W&R concept, the total project team moves from one project to the next. However, this is the dream scenario, currently we are not that far yet.

8. **Within the design, have maintenance and adaptability to future demands, and demountable of the construction taken into consideration? And are there sufficient possibilities: for the different soil types, surrounding, load etc. Can, therefore, a reference be established?**

Van Schagen states that considering:
- Maintenance: there are standard norms and requirements. But here no driver for innovation occurs, as the different components are relatively simple and do not require much maintenance.
- Adaptability to current demands: Expansion of a railway underpass is not easy. Van Schagen states that although it is possible, it is not realistic that the current structures will be adapted in the future. He thinks it is more likely that a new structure will be built next to the current construction. In addition, he states that it is not realistic when you want to make a structure more future prove, this has to be considered in the early phases of the design. In his opinion, it is then better to over-dimension the design so that it can handle more traffic (a bigger capacity).
- Demountable: Van Schagen does not see why they should think about this phase, currently when a structure becomes obsolete, it is just demolished. The researcher hereby argues that RWS is currently already specifying that the structure has to be sustainable and easy to deconstruct so that the different materials can be recycled and the deconstruction has to be done within a small time-scope so that the road will not have to be shot off or only for a limited time. Therefore it is important to also consider how the structure can be demolished.
- Sufficient possibilities: Van Schagen initially does not see why different possibilities have to be proposed/documented, as they currently make a design from scratch. He does state that the structural engineers design based on the same basics. Because the norms and requirements are mostly almost the same, this results in relatively the same designs. The researcher hereby points out that she think therefore it is a good idea to clearly document the different projects, and point out one standard for the structural engineers to use as a starting point. By this, the product can be optimised.

9. **Do you think it is possible to make use of a click system, instead of joining by the use of concrete (Maintenance, adaptable to future demands, demountable)**

Van Schagen states that in theory, this could be possible, but in practice, has does not think this will be realistic. The current norms will not provide sufficient freedom to implement a click-system. And van Schagen states that they currently mainly use concrete, the structure is not demountable. Considering a railway underpass, this object is constructed next to the site, by an in-situ process. He points out the pre-fabricated parts are not used, as they are not easy to transport to the side. And when prefabrication is possible, it is more expensive that when constructed in-situ.

Van Schagen states that the concept works fine, and does not see why they should change current practice. Considering the adaptation to future demands, van Schagen points out that we have to ask ourselves how often the functional demands for different structures change during their life-cycle. He is of the opinion that this does not happen often, and therefore thinks taken the possible needed adaptation in design should not be considered. As he thinks that the change that the functional demand of a structure will be very small.

10. **I currently have the idea to work with other materials than the conventional concrete. Do you work with new innovative materials? And do you consider that it can be possible and will be beneficial to use polystyrene (plastic) or Styrofoam (piepschuim) in combination with concrete for a viaduct?**

Van Schagen does think the use of polystyrene is a good development, and can also be applied within the tunnel alliances. However, currently, the norms that Pro-Rail and RWS appoint do not provide us with the freedom to actually use new materials. If the norms will be more flexible, this would become possible.
The idea of using Styrofoam within a viaduct can be a good idea according to van Schagen. However, more research will be needed. In theory, it has benefits, as has been pointed out by the researcher. The construction has to bear its own weight, this is the main load. Therefore when a lighter material is applied, this will have a positive effect on the supporting structures as they can be dimensioned smaller.

11. **Within literature, different opinions about the implementation of industrialisation within the infrastructural sector can be found. What are, in your opinion, the main essential success factors for the implementation of a product platform? What has been essential for the tunnel alliance, and what do you consider to be essential for the successful implementation of a product platform for viaducts?**

Folkert van Schagen immediately answers this question, by stating that a dedicated team is required. He states that a team that wants to take the best out of the situation, delivering a successful project is essential. Modification and innovation are processes that take a lot of time, and many obstacles have to be overcome. However, he states that when you really believe in a new concept, you should do your best to establish the concept, although this will not always be easy. The knowledge of the team has to grow. Considering the tunnel alliances, Van Schagen points out that the construction industry is a very conservative industry. When a new innovation is implemented, the process or product does not work optimal right away. Always something will go wrong, the pessimistic people involved will then argue that the new approach has failed. The resistance can be high, as within this business limited amount of innovation occurs in comparison to other industries.

12. **Within the BAM Infra, some people are sceptical about the implementation of a product platform for viaducts, as they consider every project as unique. Additionally, it has been pointed out the current specification of the requirements of RWS are still too specific, although they are made functional. How was this arranged in the case of the tunnel alliances? Do you think the different provinces and municipalities can make an agreement for their specific requirements, considering the tunnel?**

RWS will be prepared to make an exception for a certain project. However, then you have to convince them why this is appropriate. For one project they will be prepared to do this, however, Van Schagen does not think it is realistic that RWS will adapt their norms.
This is also related to profit. There needs to be a first time for everything, but these first times are mostly more expensive that traditional practices. And in order to benefit from the innovation, not sufficient repetition occurs. Within the tunnel alliances currently, still, a lot is uncertain. At that moment only two tenders for a railway underpass have been established from the 40 to 50 that will have to be ready within a period of four years.

13. **What do you see as risks and/or barriers, as well as opportunities in the future market?**

A risk is the uncertainty of the backlog* (orderportefeuille). Van Schagen thinks standardising construction details is an opportunity, but this has to be forced by the management.

*Backlog: A backlog is a list of features or technical tasks which the team maintains and which, at a given moment, are known to be necessary and sufficient to complete a project or a release:
- If an item on the backlog does not contribute to the project's goal, it should be removed
- On the other hand, if at any time a task or feature becomes known that is considered necessary to the project, it should be added to the backlog. These "necessary and sufficient" properties are assessed relative to the team's state of knowledge at a particular moment; the backlog is expected to change throughout the project's duration as the team gains knowledge.

14. **From my literature study, I have found that different parties have argued that risks occur with the increased use of standardisation and modularization when large prefabricated models are applied. They stated that currently for the whole market to apply this concept there will not be enough suitable producers of the modules, and not enough transport and heavy-lifting is available.**

Railway underpasses are currently constructed with an in-situ process, next to the eventual location of the structure. When the in-situ structure is finished, the total construction is jacked under the railway. Van Schagen states that they do have considered prefabrication of elements, however dividing the structure into smaller parts is difficult and this require complex connections. In addition, in-situ is not expensive. The researcher asked the critical question if there is always sufficient space to build the structure next to the site. Van Schagen answered that he has not had a project where this was not possible, of course sometimes the spaces are small, but we just have to work with the space we got.

15. **What are your tips and tricks for the development and implementation of a similar concept for viaducts? (what opportunities are there, and which difficulties did you came across?)**

Van Schagen refers to the W&R concept. He thinks using the principles of W&R from development until production will result is successful projects. In addition, a project team with a drive for improvement is needed.

16. **Why do you think other initiatives/projects within BAM have not been a success? (what can we learn, what should we do differently?)**

Van Schagen states this is hard to say. He thinks a product platform, using a reference, can be applied in the general outlines of projects. He thinks the different initiatives within BAM have not been successful mainly because not sufficient freedom is given by the client, referring to RWS. He points out that in Switzerland viaducts have been standardised. The municipalities can choose from around 5 designs. These designs are a starting-point (reference) for future development of a design on the specific location.

B.1.3 Interview 3

Interview – Kitting Lee – 18 May 2016
Function: BAM Infra – Tender Manager N18

Personal Details	
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16. **You have been the tender manager for the N18. Can you shortly introduce/explain what your tasks have been within this project?**

Kitting Lee explains his function shortly; he was responsible for the tender for the N18. Kitting Lee was the general tender manager, this means his focus has been on the scoring on the EMVI-criteria, focus on risk management and the management of the surrounding area. He hereby had a counterpart who was responsible for the DBM contract.

17. **What are your thoughts on standardisation and modularization, by the implementation of a product platform in general? (Referring to "legolisering").**

Kitting Lee is convinced that standardisation and modularization will be beneficial. He states that there is still a lot to be gained by applying this, it has a lot of potential. He states that some although all projects are unique, the building blocks (referring to the Lego-blocks) are not unique. Considering, the principles of modularization, Kitting Lee states that the detached modules can be seen as the Lego blocks. He thinks that when we apply the concept of standardisation and modularization, by the development of a product platform can be very beneficial. As this will make us able to faster develop and construct projects, it will result in higher level of efficiency. In addition, he states that it can also speed up the tender process. Kitting Lee highlights that we should not just consider standardisation and modularization, he thinks it is a "must". If BAM wants to stay one of the biggest construction companies in the Dutch market, they will have to apply this concept in order to stay competitive. If BAM does not start using this, they will fall behind and will be outcompeted.

18. **Can you tell a bit more about the standardisation that has been applied for the Tender of the N18?**
    a. **Considering the product**
       - Which elements have been standardised?
       - How is decided and/or indicated which elements/components should be standardised?

Within the tender of the N18, we had to deal with 17 new viaducts. All these viaducts were located on critical point within the current infrastructure of the area. Within the EMVI criteria there was then also stated that a fast construction process was preferred (small lead time).

Within the viaducts we have standardised several components:
The decks have been made of prefabricated beams. The dimensions of the beams have been divided into 5 different distances. This was in order to make the production of the parts easier and reduce costs of prefabrication, as more of the same beams with the same dimensions should then be fabricated. And also with the idea that this can help to increase the efficiency of the assemblage process on the site location. This means some of the beams for the deck of the viaduct have been over-dimensioned. However, the costs of this over-dimensioning of the beams are relatively small and are easy won back within the production and assembly processes. In addition, in the tender, we have cooperated with suppliers of prefabricated elements. We have even investigated if it was possible and if it would be beneficial to make use of prefab foundation blocks (poeren) and land abutment (landhoofd).
Within the bicycle tunnels, we applied prefabricated u-shape (with soft angle) elements. The sloping roads that are attached, the ramp and the exit, are also constructed by applying prefabricated concrete decks. Leon Hendriks can explain this in more detail. Within the total project, we have tried to make use of already existing standardised elements/techniques. Various options needed to be reviewed. This was mainly analysed by trade-off matrixes.

b. **Considering the process**
   - Referring to the tender phase
   - Referring to how the project should have been established? How was the process designed?

The process the N261 was used as a reflection point/ as an inspiration for the N18. The N261 has been analysed by the different members of the tender team and even approached different members of the project team of the N261 were to give advice and feedback. Also, brainstorm and challenge sessions have been held. Here the project teams was challenged to think of other ways of making the viaducts less expensive and optimise the product and their processes (scoring on shorter duration and faster development). Within the tender, we have only made use of prefabrication, as this means we could build faster than using in-situ (takes around 4 months to construct a viaduct).

The tender was in the second phase, the dialogue phase. RWS arranged three dialogue rounds. Within these rounds different issues/considered constraints could be argued and discusses. Within these rounds, the project team tried to convince RWS that a particular requirement is unrealistic and that the will need to adjust this. In some cases RWS than adapts this, however, most of the time this is not the case. Kitting Lee hereby gives the example of shorting the length of a viaduct. A viaduct could be constructed shorter, this would be cheaper to construct than the length that was specified. However RWS agreed with the project team that a shorter viaduct would be a better solution and would save money, they did not agree. This was because for political reasons, as they had an agreement with other stakeholders that were concerned about the surrounding area.

In addition Kitting Lee points out that construction industry is very conservative, however, there are also employees who have an open mind and think “out of the box”. They think everything is possible. Within the tender here facilitators were assigned to facilitate this creativity. Also, cooperation and brainstorms with RomijnBeton are used. This all to be able to deliver the best concept design (tender).

19. **Within the project of the N261, the municipalities and province have been involved already in the first phases of the project. By involving the different parties in the first design processes, they were able to make a design in collaboration with the different parties. The result was less resistance occurred, and eventually, all parties were happy with the end-result.**

Considering the N18, was this approach also applied?

Kitting Lee states that:

a) In the first phase of the project, they have selected experts, considering a pool of people with experience and people that can think “out of the box”. Also, different challenges for the project team have been stated, to trigger them to innovate. Here the mindset of the people within the team is important.
b) The challenges have been described very tight. And the requirements are seen more lightly, as there still need to be sufficient space for establishing new ideas. The start question/challenge, therefore, is taken broad, as this will challenge the different experts of the project team.

20. **Within literature, it has been pointed out that it is important that the standardisation of product and process has to be applied together in order to fully benefit from the standardisation. Why do you consider this to be important? (to align both process and products)**

The design and development processes have to be considered at the same time. Within all the project of BAM Infra, there is always a designer and an executor (work preparation) involve in the tender. The designers and executor than have to thinks about what effect certain designs have on the process. Here the product affects the process of development, and also the other way around. They are interrelated.

Fokke Huisman had developed/ currently works on a Cost-leadership program. Here he does research considering how we could design and develop in a smarter way. This to optimise the product and processes and increase the efficiency and quality within projects.

Within the tender of the N18, the focus was mainly on the product, as the development phase are not the complicated. Here we brainstormed about innovation of the product, rather than the process. However, the innovation of the product also requires/ results in innovation within the process.

21. **For the tender of the N18, your project team made use of the application: Relatics. How was this application used, and what benefits did this have or would have occurred when the project was constructed?**

Kitting Lee states that he uses the program Relatics for almost all projects he works on. He considers this to be necessary within projects with a DBFM contract. Within the N18, they have made use of SharePoint and Relatics, only these two databases have been used. It does not matter which program you use, the programs need make the different aspects of the project explicit and needs to be secured.

22. **It has been pointed out that the current specification of the requirements of RWS are still too specific, this results in a limited amount of freedom in design although the requirements are made functional. Do you agree with the opinion that the requirements of RWS are still too specific, and therefore limited room for innovation occurs?**
Kitting Lee agrees, he says the requirements are currently more functional than before, however, this does not mean there is more freedom, as there is also an aesthetic program of requirements (PVE), this is also leading.

23. **How much freedom in design was there for the Tender of the N18, considering the specified requirements ("uitvraag") of RWS?**
In the N18, RWS did not specify how the paving on the constructions had to realised. We could design this ourselves, but this also means we were responsible for the maintenance for the first 25 years. Considering the ailment and viaduct, there was almost no freedom in design. It had to be within the prescribed trace-decision document. And for the viaducts even a sketch-design was given as a reference, this documented in the esthetical PVE (Program of requirements). The researcher here argues if Kitting Lee thinks it is possible to convince RWS to consider the change of specific requirements. The answer given here is that you can try, and he also advised to do so. However, the chance that RWS will change the requirements for the project are very small. This is also mainly because they have agreements with other parties, for example, the review committee as they are concerned with the wishes and opinion of the people living in the area.

24. **The "omgevingsplan" has also been given for the N18, how this affected the design. (Considering how a viaduct looks, it could not be chosen anymore by the structural engineer to not make use of a column in the middle of the structure, as this had already be nailed down in the drawings of the "omgevingsplan")**
As had been pointed out before, the design would be different, as not have an aesthetic program of requirements (PVE) means the project team has more freedom in design.

25. **For the N18, the project team had to make sure that limited hindrance should occur. Considering hindrance of for the surrounding area, as noise for people living in the area. But also the road need to be kept functioning and or other options (other routes) need to be given. How did you cope with these factors and how has this affected the design and the construction process?**
The project for the enlargement of the N18 only considered 6 Km of already situated highway, and 20 Km of new highway needed to be developed. The road needed to be developed within the currently located grasslands. This sounds easier, but still, this was a large puzzle, as 70 to 80 existing provincial road were affected by the new highway. To limited the hindrance that would occur two main factors were considered. 1) Within the actual construction/assembly process, there has been put a lot of effort in providing solutions to minimalize the hindrance. And 2) For the transportation of parts and other materials etc. (construction traffic), the provincial roads were not used. The construction traffic had to come from the beginning of the N18 of from the end of the N18. In this way, the project had minimal effect on the functioning of the infrastructure within the area. Also, hydraulic transport by spraying sand was applied.

26. **As I have understood correctly is the N261 has been used as a reference for the N18.**
- What are the concepts of the N261 that have been applied in the design of the N18 (Tender)
- Are their also details that have been copied, or have been used as a reference and are only adapted on certain points?
The planner of the N261 has also made the planning for the N18. Here, the planner (Michiel Janssens) did use the approach of the N261 as an input. Within the tender, we have also made use of the same supplier of prefabricated parts as with the N261, namely RomeinBeton. Leon Hendriks can tell you more about this.

27. **What is your vision for BAM Infra to be able to successfully make use of standardisation and/or implementing a product platform for infrastructural objects (viaduct)? What do you consider to be a good approach that can be applied by BAM within the nearby future?**
Kitting Lee states that it can help to already nail down/make a distinguish for the different modules, in the beginning of the design phase. This can be applied by analysing the practices of different projects. Currently, we are trying to implement this. The tender HOV busbaan Utrecht, de tender Amstelveense lijn and the tender for Randweg Barle Nassau al have to develop bicycle tunnels. The three tenders, therefore together contacted the project team of the tender of the N18. In order to see what they have designed, and use what they had already investigated, to build forward on these concepts and trade-offs that have been made. This is a very good development. This helps us to optimise both product and process. We do not have to "reinventing the wheel" all the time.

For the implementation of standardisation/modularization and thereby the development of a product platform, the documentation needs to be improved. The different project member should clearly document their process so that the project can be understood by the other employees of BAM Infra. Based on the documentation, it should be clear why certain decisions have been made, what trade-off did occur. Michel Burghart is working om how we can improve these processes within the organisation.

28. **Do you think it is possible for BAM Infra to choose one standard variant for the design of infrastructural objects can be chosen by the management? And then can be imposed by the management on the employees of BAM Infra to apply this standard, work with this standard as a starting point/ as a reference design.**

    Yes, the only thing is that you have to think about how you communicate this. Considering the more conservative culture within BAM Infra, this will be hard, and resistance will occur as not all employees will accept this new way of working. However, Kitting Lee points out that therefore it is essential you phrase this. As project leader of the tender of the N18, he tried to do this by making suggestions to the different team members. It is important that first research about what has already be established will be conducted. The different member of the project team will need to ask themselves the question; "Which lessons learned within other projects, can I use as a starting-point considering this project?" Bart Simons is specialised in the System Engineering and had contributed to the development of a project management index (PMI) for the total construction project.

    In addition, Kitting Lee, states that he thinks the standard design needs to be relatively simple. If the design is too complex, it will not be used by the employees of BAM Infra and too much adjustment needs to be made in the design, this means it will not benefit from the repetition that occurs.

29. **In addition, as architects can change the reference model, do you consider that are is sufficient room for change, while still be able to benefit from the repetition that occurs? (Referring to the quotation of Henry Ford; "Any customer can have a car painted any colour that he wants so long as it is black.", economies of scale, learning curve and constant optimisation of product and process)**

    This is hard to say. Different trade-offs will have to be made. You will have to have a few different dimensions, considering beams. However, not too many types need to be applied, cause then the benefits will not occur or will be less. Kitting Lee thinks we can start this by analysing which type of infrastructural objects are frequently build. These are objects to standardise.

30. **How are the knowledge and lessons learning within BAM Infra currently transferred? Do you think this needs to improvement?**

    The researcher states that she considers three main important items to establish this.

    i. ***Knowledge/ experience should be shared within and the organisation in a project exceeding way***
    ii. ***Innovation by constantly updating the reference model (optimisation + innovation)***
    iii. ***Feedback loops are considered to be very important. By this points of improvement become clear, and as validation and verification take place, they will be better able to meet the wishes of the client.***

    Kitting Lee is of the opinion that the transferring of knowledge and lessons learn need to be improved. Otherwise, BAM Infra will be outcompeted in the current market.

31. **As my research is about the implementation of a product platform for the infrastructural object, a viaduct, by applying standardisation and modularization. I am interested what your opinion is considering the concept of modularization. Here referring to the coupling relationships between the different parts and their different functions. Do you believe in the concept, and do you think it can be applied within BAM Infra, for example for the object a viaduct?**

    Kitting Lee does believe in the concept but states that there is still a long way to go for BAM Infra.

32. **Within literature, different opinions about the implementation of industrialisation within the infrastructural sector can be found. What are, in your opinion, the main essential success factors for the implementation of a product platform? What do you consider to be essential for the successful implementation of a product platform for viaducts?**

    For the successful implementation of a product platform, Kitting Lee considers that clear communication and documentation will be needed. But also points out the mind-shift has to occur, this is essential.

33. **Within the design, have maintenance and adaptability to future demands, and demountable of the construction taken into consideration?**

    (modularization can be beneficial considering these aspects, RWS does specify that their project should be sustainable, should be constructed in a limited time-span, and should also be deconstructed having limited hindrance and within a small time-span, and the deconstructed parts need to be recycled)

    The project team does take the maintenance in consideration. This has also become more important due to the new contract forms: DBFM(O). Adaptability to the future demand and demountable building are generally not considered.

34. **The N18 mainly connects the different components/modules by using steel cables and joint by cement. Do you think it is possible to make use of a click system, instead of joining by the use of concrete (Maintenance, adaptable to future demands, demountable)**

Kitting Lee thinks pouring concrete currently is essential, it makes one integrated whole from the different elements of the construction. If you want to build an object without the pouring of concrete, you will have to do this mechanic. You can do this by making mechanic connections within a demountable steel construction. He thinks it is an interesting viewpoint. He thinks it could be possible, but he does not know how. Kitting Lee states that he is not a structural engineer , but he can imagine that if we already think about the demolition phase of the object in the design phase, this can be applicable. However, this is currently not the case. He does think that it would be a good idea to already think of how we can adapt the objects to the changed market situation over time. He thinks this would be beneficial, referring to the new contract forms.

However, Kitting Lee does point out that currently this is not asked by RWS. And it is hard to implement a new way of working, as the first development are always more expensive than current practices. Although the will be less expensive when the concept is applied more often, as learning and optimisation take place. In addition, you will also have to deal with the firm's policy. This all makes it more complicated.

35. **Within the tender of the N18 does the design contain the application of new innovative materials?**

No, we have only used already established product and processes. However, we did use state of the art technologies, referring to innovations that have been applied to other projects.

36. **I currently have the idea to work with other materials than the conventional concrete. And do you consider that it can be possible and will be beneficial to use polystyrene (plastic) or Styrofoam (piepschuim) in combination with concrete for a viaduct?**

Kitting Lee things this principle could work. However, he also adds a critical note to this, as a deck cannot have a too large construction height. We have to deal with minimal headroom for the traffic to go underneath. If the beams become higher, this means the abutments (land) needs to be higher. This mean heightening by adding soil, will be needed.

37. **Within the BAM Infra, some people are sceptical about the implementation of a product platform for viaducts, as they consider every project as unique. Within the N18 a certain amount of standardisation has been used, do you think the concept of this design could also be applied project-exceeding?**

Yes, we should use the knowledge that we gained within the N18 for other tenders/projects.

38. **Do you think the different provinces and municipalities can make an agreement for their specific requirements? As this would be the case, this will have significant positive effect on the application of a product platform.**

This should be possible, as the provinces and municipalities have to follow the projects of the government ("rijksoverheid").

39. **The contract was not awarded to BAM Infra. The tender came to the final round, what place has the proposed tender ended? And why do you think the tender did not come out as the economic most value investment? Meaning if you could do it all over again, what would you have done differently?**

Overall the tender ended in the third place. It had the second place for the price and also a second place for the score on the EMVI-criteria. If we could do it all over again, I would still do it the same way. The winning company had the same execution methods as what we have proposed. However, the price was here the eventual prevail. We as BAM had a price of 115 million, the company that was third on price had a price of 140 million, and the winning company had a price of 100 million. Kitting Lee thinks this is a very large gap. However, he does not see a lot of differences in the design of the winning company, and the design of BAM. He thinks it was not completely fair, as the winning firm could use for example sand from their own land, which is nearby the location of where the highway needs to be realised. By this, they could save costs. The only thing Kitting Lee thinks that could have been done differently is to more strictly consider risks and maybe more negotiation with the client.

The following questions have been answered by e-mail by Kitting Lee, as there was not sufficient time anymore to finish the interview. Kitting Lee suggested that the researchers should e-mail the questions. Kitting Lee has responded to these questions a few days later, below the result is given.

40. What do you see as risks and/or barriers, as well as opportunities in the future market?

- RISK: We need to transfer our business mind to service-orientated instead of product-orientated. Potential clients expect services whereas assets are required to perform the service; however, the focus is not on assets!!! If we only focus on product / production, my expectation is that we will not be the main contractor in the future and only be part of projects as a subcontractor. However, it doesn't mean that we do not focus on product development. In contrary, we need to understand products in order to be able to provide the right services.
- RISK: the un-ability to quickly adapt the working methods to new developments / needs of the market due to a rigid organisation. It is also an opportunity if we are able to transform the organisation to quickly adapt. We can have more added value and still be in the leading position in the market
- OPPORTUNITY: more than 50% of governmental turnover in infrastructure projects are related to asset management / maintenance. We need to structurally approach this market

41. What are your tips and tricks for the development and implementation of a product platform for viaducts? (what opportunities are there, and which difficulties did you already experience considering the implementation of standardisation of products and/or processes?)

- RISK: do not focus on which central ICT system to use. It is important to determine the necessary output for this platform and the way of standardisation.
- RISK: not enough budget, focus and involvement of operational business colleagues to succeed the setup of a product platform. Determine a clear goal and budget and use projects / tenders as a pilot to set up and adopt the product platform. Besides, learn from other industries how such platform are realised.

42. Why do you think other initiatives/projects within BAM that applied standardisation and/or modularization have not been a success? (What can we learn, what should we do differently?)

- No common language and interest to involved parties. Lack of budget, time or focus results in failure of implementation
- Create users / early adopters to have a spin-off in the usage of such a platform.

B.1.4 Interview 4

Interview – Jan Pieter den Heten – 18 May 2016
Function: BAM Infra – Project leader at department project management

Currently, Jan Pieter is the project leader from BAM Infra of the gravity based foundations for an off-shore windmill park near the British coast.

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1. **You current function is project leader of the gravity based foundations for an off-shore windmill park near the English coast. Can you shortly introduce the project and explain what your tasks are within this project?**
   Jan Pieter den Heden is the project leader of the development of gravity based foundations for offshore windmill parks, near the British coast.

2. **What are your thoughts on standardisation and modularization, by the implementation of a product platform in general? (Referring to "legolisering").**
   Jan Pieter is very enthusiastic about the concepts of standardisation and modularization. He thinks it is needed for BAM Infra to apply this concept. He thinks the idea of the application of different Lego parts should work in practices, as he refers to the fact that a lot of different designs can be made with the standard building blocks of Lego.

3. **Can you tell a bit more about the standardisation that has been applied for the Tender of the N18?**
   a. **Considering the product**
      - Which elements have been standardised?
      - How is decided and/or indicated which elements/components should be standardised?

   The gravity based foundation are different from other current practices within the offshore wind industry.
   The first offshore windmills have been constructed by putting the windmills on monopoles. These piles need to be driven (heien) within the seabed. This has a number of disadvantages, as it is time-consuming, has a significant impact on the surrounding (vibrations), and requires state of the art technologies for working on open water. However, as windmills are innovated, and become bigger, there is a demand for foundations/piles that can cope with these large windmills. Considering the current market, Van Oord has developed a design called the "Jacket". This is a design that is made out of three piles, and these are combined with a steel framework were a deck is placed on top of these piles. This structure can deal with bigger forces and are suitable for windmills that produce 8 kWh.

   Jan Pieter states that the currently designed product is not yet the optimal. He thinks the concept that has great potential to be developed future, considering both the process as the design. He states that it is a simple and robust design. BAM make the gravity based foundations, on these foundations the windmills can be directly placed. How fast this process will go depends on the water depth and the location. However, as for Jan Pieter van Heten thinks the design is very effective, and the sinking down of the foundation structures is an effective process, he points out that there are already new developments within this field. For example, he knows that in England there is a company that research if they can develop floating foundations for the windmills. By this they will not be attached to the ground, this is constructed by application of anchors. Then the total construction of the windmills can just be dragged to the sea. When located, the anchors (By the use of large steel cables) will make sure the total windmill will stay in place.

   b. **Considering the process**
      - Referring to the tender phase
      - Referring to how the project should have been established? How was the process designed?

   In general, Jan-Pieter states that we should work more with prefabricated components. And we need to design these components with the idea that they will be applicable for different projects, we need to make standards. Jan Pieter hereby states that he thinks my viewpoint, to implement a product platform considering standardisation and modularization could be very successful. The "mix and match" of components can be very beneficial. However, we must be aware that then only a limited amount of standard components need to be applied, as otherwise, the effect of the standardisation is missing. Maybe it is possible to design just two types of systems, and these can be customised be different components that can be easily connected to the main structure.

The researcher refers to the current market, this can be considered as market pull. However, the gravity based foundation are different. Here a concept has been developed and presented to potential clients. The client can then choose to apply this system. This is different from the market pull, where the client specifies what they want, and a solution that meets these requirements will be developed. Jan Pieter van Heten is of the opinion that this a more suitable way of working for large projects. The client currently specifies too much, no freedom or limited freedom occurs. This hampers the innovation.

As a side-note Jan Pieter van Heten suggested that I should take a look at the Bailey bridge. This is a bridge that has been designed and used in the second world war. It was a simple construction, by following a clear manual, everybody could construct the bridge. Also, people who did not know anything about bridges and no calculation was needed, this was all already considered in the design. Within the manual different type of possibilities were given to construct the bridge, the bridge was suitable for a lot of different situations. The bridges were developed for the army. The bridges made it possible that the troops could move faster. The success of the bridge was mainly due to the simplicity of the fabrication and assembly process, combined with the ability to erect and deploy sections with a minimum of assistance from heavy equipment. The bridge will be analysed further in the research.

c. What are the steps taking in the assembly process?

Jan Pieter van Heten starts drawing a cycle and divides this in wedges. He states that that is the basis concept of the current design. We can make the different wedges with the factory and then transport these to a land situation nearby the actual offshore location of where the windmills need to be located. On the land, the wedges are connected, and to make it one stiff/rigid whole, we deposit a layer of concrete on the top of the wedges. This is a cheaper and faster method than the current "jacking". Jan Pieter highlights here that he believe in the concept of standardisation and modularization and states that if it works with Lego, it will also work in real constructions.

4. Within literature, it has been pointed out that it is important that the standardisation of product and process has to be applied together in order to fully benefit from the standardisation. Why do you consider this to be important? (to align both process and products)

   This is because both product and process effect each other. When you change the product, this will result in changes in the processes and the other way around. Currently, there is a shift from windmills that can deliver 3 to 4 KWh, towards new innovative (and significantly larger) windmills, which can deliver 8 kWh. As this asks for a new way of working, it needs to be researched what weight the new windmills will have and can have considering the foundation and with which forces they have to cope with. Here design of the product has direct influence on the process

5. The project is significantly different from current projects of BAM Infra, where mainly a design is developed based on a list of requirements of the client. In this case, BAM has made the concept, this mean market push, not the conventional market pull. Why do you think BAM Infra decided to apply this approach?

   The researcher states that the gravity based foundation are based on market push instead of market pull strategy. Jan Pieter thinks this is a very good development and states that BAM Infra should work more on a market push level. The researcher points out that some employees of BAM Infra think this the gravity based foundations is a very simple project, as they stated that there are no aesthetic requirements, as these requirements make the infrastructural objects more complex. However, the way I see it is that still a lot of extra requirements are present. Jan Pieter agrees and stated that we may not have aesthetic requirements, there are a lot of other requirements we need to think about. For example; we need to consider the demolition of the structure, everything build off-shore needs to be designed in a way that it can be deconstructed/demolished easily without pollution. In addition, within the actual construction process, only limited amount of hindrance for the "nature" is demanded. The nature refers to the underwater life (small and large fishes, for example, blue pot fish).

Offshore windmill-parks are a new practice for BAM Infra, why do you think the management has decided that they want to expand their market?
The management of BAM Infra wanted to invest in a market where their current main competitors were not active as well, to distinguish themselves. First, it did not worked out, because the prices BAM Infra asked for the foundations was too high. The new concept had to provide more benefits that the current already known monopiles and jacking. Although the new concept has a lot of benefits, the costs of this new concept were significantly higher than the already established practices within the industry. The extra costs were higher than the benefits that occurred. Eventually, BAM Infra adapted the design, and by this making the concept less expensive.
Currently, we are working to deliver five gravity based foundations when these are successful we will continue. However, Jan Pieter states that he thinks BAM Infra is a bit late, considering the new development in the market, but still thinks it is a good design.

6. **Has BAM Infra made use of a reference considering the gravity based foundations?**
   Well, the concept of the gravity based foundation was already developed 20 years ago. But nothing has been done with it in these 20 years' time. Jan Pieter van Heten states that this is typical for BAM. He stated that we develop something like we are playing with toys. When the project is finished, we do not continue with future optimisation and innovating the build structures, as we are bored and want to go for a new challenge.

7. **Within the design, have maintenance and adaptability to future demands, and demountable of the construction taken into consideration?**
   (modularization can be beneficial considering these aspects, RWS does specify that their project should be sustainable, should be constructed in a limited time-span, and should also be deconstructed having limited hindrance and within a small time-span, and the deconstructed parts need to be recycled)
   Jan Pieter agrees and thinks the maintenance, adaptability and demountable are currently not sufficiently reviewed in a new project. The current gravity based foundation are not over-dimensioned to be able to carry a bigger windmill, as they will be bigger in the future. However, Jan Pieter thinks a totally different type of windmill will occur. And as long as the nuclear plants and coal power plants stay relatively cheap, windmills might not be profitable. When the demand for electricity increases, and/or people become more aware of their effect on the environment, building more windmills can be interesting. For now, BAM Infra starts with 5 windmills near the British coast, what can eventually become 60 till 80, when the first 5 are a success.

8. **The project is established in cooperation with Van Oord. Considering the design and development has Van Oord been involved early in the project, to share their experiences they have and to co-produce/ interfere in the design process?**
   Yes, we cooperate with Van Oord, however before we had a collaboration contract, but this ended last December and has not been expended. This means we do need to work with Van Oord considering the design and the actual process of the gravity based foundation, but this is more from a contractor to contractor basis, as the different products and processes need to be adjusted to each other

9. **Currently, the project is still in the design phase, as the actual building has not been started yet. When will this be started? And how long should the project take?**
   Next month, in June. And we planned to finish the gravity based foundation in May 2017. Then still the windmills have to be placed, but our work is then done.

10. **What are risks/barriers were mitigation measure have been taken for, and which risks/barriers are expected to have an influence on the project than cannot be mitigated?**
    There are a lot of risks, that is why we start with only 5 gravity based foundation and expand this to 60 till 80 when the first 5 were successful. Otherwise, if we would start building 60 gravity based foundations and something goes wrong, it could be the end of BAM Infra.
    The design has also been revised three times now, so it has gone through the whole process for three times. By this, we hope we have developed a good design. Additionally, the models have been tested at the Maritime Research Institute Netherlands (MARIN) and have been optimised. Considering the actual construction phase, there is a clear protocol developed about how to construct, and under which conditions this can be done, referring to the weather circumstances.

11. **Do you think it is possible for BAM Infra to choose one standard variant for the design of infrastructural objects can be chosen by the management? And then can be imposed by the management on the employees of BAM Infra to apply this standard, work with this standard as a starting point/ as a reference design.**
Jan Pieter is convinced that it is possible. But you need to consider what kind of modules you want to use and how big these have to be. A lot can be pre-fabricated, as he refers to the gravity based foundations. Here the prefab elements together form a mould, where then to make it one whole, a layer of concrete will be added.

In his opinion, it is possible to apply only prefabricated elements for the development of a viaduct. The prefabricated elements can function as a mould when the concrete is deposit will become part of the structure. The prefabricated parts are then hollow, by this, they are the relatively light weight which has benefits for the transportation. Jan Pieter states that by building this way, we can increase our efficiency.

12. **In addition, as architects can change the reference model, do you consider that are is sufficient room for change, while still be able to benefit from the repetition that occurs? (Referring to the quotation of Henry Ford; "Any customer can have a car painted any colour that he wants so long as it is black.", economies of scale, learning curve and constant optimisation of product and process)**
Considering a "basis" for windmills, there is sufficient room for change. He refers to a jeans, you have them all in different types and sizes. This is also applicable for infrastructural objects. If we want we can make it very luxurious objects, but this is not always preferred or needed.

13. **How are the knowledge and lessons learning within BAM Infra currently transferred? Do you think this needs to improvement?**
    i. *Knowledge/ experience should be shared within and the organisation in a project exceeding way*
    ii. *Innovation by constantly updating the reference model (optimisation + innovation)*
    iii. *Feedback loops are considered to be very important. By this points of improvement become clear, and as validation and verification take place, they will be better able to meet the wishes of the client.*

Jan Pieter answers this question by pointing out that innovation is something we just have to do, it is a necessary if we want to stay competitive. He stated the knowledge transfer within the organisation is very limited, as we can almost say that this does not occur. When we have a new project, the employees of BAM need get along with the project. This requires the “old” people with a lot of experience, but also the “young” people with a more open view. However, the is a “gap” between the “old “and the “young” employees of BAM Infra. They do not use the same language, the communication does not align. In addition, a bit off topic, Jan Pieter thinks BAM Infra needs more people that are willing to go foreign countries. As ABM has procured projects abroad, and the current population of employees does not want to be stationed abroad for a long period. The employees all have a wife or girlfriend, and even have small kids. For the procured projects, we need new people that are willing to go abroad. He additionally highlights that the current arrangement for working abroad are not attractive, and are conservative. They will have to be reviewed, otherwise, nobody will be willing to work on a project in a foreign country.

14. **As my research is about the implementation of a product platform for the infrastructural object, a viaduct, by applying standardisation and modularization. I am interested what your opinion is considering the concept of modularization. Here referring to the coupling relationships between the different parts and their different functions. Do you believe in the concept, and do you think it can be applied within BAM Infra, for example for the object a viaduct?**
Technically it is visible. Jan Pieter even refers to the A4, here they have developed a concrete tunnel structure, which was in his opinion modular. However, the design and/or idea of the design can be used again, this is not the case. Although we are aware that we are constantly are “reinventing the wheel”, we enjoy the search for a solution too much. We do not like to do the same thing multiple times. This, and the fact that a lot of people are sceptical and thinks it is not possible, result in the fact that we do not apply this in our projects. With the A4, nobody has investigated the possibilities for reuse and/or standardisation of the design. The drawings are documented clearly, but nobody takes a look at these. A general database might help to improve our practices, as employees can review other best and worst practices.

Jan Pieter thinks a click and screw system is possible. He again points out that you could use prefabricated elements and prefabricated mould for the development of an infrastructural object. He states that we start with some elements, additionally these will need to be reviewed and see which elements that connect to these elements, and they can also be standardised/modularized.

The biggest challenge for implementing standardisation and modularization within BAM Infra is the current viewpoint of the employees. A mind-shift will be needed.

15. **How are the different components/modules connected? By using steel cables and joint by cement?**
    Do you think it is possible to make use of a click system, instead of joining by the use of concrete (Maintenance, adaptable to future demands, demountable)
    As already state before, technical it is possible. He personally thinks a beam can be developed out of different parts, with limited couplings relations. He points out that constructing a beam out of building blocks is possible, and the transport of these parts is less complicated, considering their weight and volume.

16. **Within the design of the gravity based foundations does the design contain the application of new innovative materials?**
    No, we have not used materials we are unfamiliar with. Only established materials are used.

17. **I currently have the idea to work with other materials than the conventional concrete. And do you consider that it is possible and will be beneficial to use polystyrene (plastic) or Styrofoam (piepschuim) in combination with concrete for a viaduct?**
    However, as BAM Infra almost only use concrete and steel, applying other materials could be interesting. The researcher refers to composite. Jan Pieter stated that composite is not used because of fire safety, the structure melts when the temperature becomes too high. In addition, when a structure is collided the structure will lose it strength, and reliable anymore. The researcher points out that already a lot of innovation has occurred, considering composite, and states that these proposed problems are no longer an issue. Jan Pieter, in that case, stated that we should make use of more composite within infrastructural projects.

18. **Within literature, different opinions about the implementation of industrialisation within the infrastructural sector can be found. What are, in your opinion, the main essential success factors for the implementation of a product platform? What do you consider to be essential for the successful implementation of a product platform for viaducts?**
    Jan Pieter is of the opinion that if you obligate the project team that they will have to meet certain requirements, the implementation will become real. He thinks three or four employees of BAM Infra, just need to be given one year to develop a concept and a design in detail. He personally thing the bailey bridge out of the Second World War, is a good example that it is possible, also for infrastructural objects. This can be reviewed in the small project team.

19. **What are your tips and tricks for the development and implementation of a similar concept for viaducts? (What opportunities are there, and which difficulties did you came across?)**
    Jan Pieter things a team of three to four people are needed, to fully dedicate themselves to the development of a standard/modular design. He thinks it is important that the project team is not too large, considering effective communication and otherwise too many viewpoints will need to be combined. His advice is to combine a team of experts from diverse disciplines. In addition, he thinks it is needed to clearly formulate goals and objectives. Requirements will have to be listed, and the boundary conditions need to be clear. So that when the design is finished, it can be taking off the shelf, adapted to the situation and directly cost and planning are known.

20. **Why do you think other initiatives/projects within BAM that applied standardisation and/or modularization have not been a success? (What can we learn, what should we do differently?)**
    BAM Infra does not things forward. It is in the nature of the employees of BAM Infra to just wait and see. We do not think ahead, however forward thinking is essential. In addition, Jan Pieter states that BAM Infra is very conservative. When a new idea could be very promising, and even as the employees think it is possible, they will not apply this. They are scared and think the current practice is safer to apply, as they have experience with the current practices. Considering an innovation, they state that they have never done this before. Jan Pieter still things the main barrier for implementation of standardisation and modularization is the people, they are not open to it currently. He states that we maybe should challenge the employees, to think future. For example challenge them by obligating that concrete cannot be used any longer. In addition, Jan Pieter highlights that it is important that provinces have to be convinced, that the innovation eventually will result in lower costs. Only then they will be willing to apply the innovation.

B.1.5 Interview 5

Interview – Nicky Brieffies – 20 May 2016
Location: Amsterdam, W&R Housebuilding
Function: BAM W&R Housebuilding, Project manager

Personal Details

Title:	Project manager
Initials:	NR

Company Information

Operating Company Name:	BAM Woningbouw W&R
Working as:	Project manager and coordinator management and development
Department:	Management and development
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1. **You are project manager, where you focus is on "Beheer en Ontwikkeling". Can you shortly introduce/explain what your tasks are within the W&R concept of BAM Woningbouw?**
   Nicky Brieffies has been project manager for many years at BAM Woningbouw, for W&R projects. Two months ago he changed to a new position and is responsible for the "Beheer en onderhoud"(Management and maintenance). Here Brieffies is responsible for the estimation of the working budget, and management and administration of the BAM House-collection (Woningcollectie). By this is meant that he has to make sure all the steps taken in the different W&R project are clearly documented. Nicky Brieffies is responsible this database, that functions as a reference.

   During six to seven months a year different members of the project team (also co-producers) can do suggestions for improvement of the product or process, or just point out problems they have experienced. These suggestions are analysed, ant the commission make trade-offs if the suggestions can improve the product and process, and if this improvement is worth the time, effort and costs to implement this improvement. Nicky Brieffies here is a member of the team that are responsible for the analysing and then formulating actions for the implementation of the possible improvements. During the last months of the year, September until December the suggestions are processed, and the reference design will be adapted to the suggestions that are considered to be beneficial. Nicky Brieffies and his direct collages are here responsible for the adjustment of the drawings. By this, in the new year, the reference design is optimised. And this optimisation process continues, and will be a review at the end of each year.

2. **What are your thoughts on standardisation and modularization, by the implementation of a product platform in general? (Referring to "legolisering").**
   Nicky Brieffies thinks applying the concept of W&R in the infrastructural objects and project is possible. However, he stated that the design will need to be adjusted. He thinks that standardisation and modularization, by the implementation of a product platform is more difficult for infrastructural objects and products, than it is for the housebuilding industry. Although it still is possible, the working method is comparable.

3. **Can you tell a bit more about the W&R concept? What do you consider as the main "power" of the W&R concept?**
   a. *What are the five pillars? And how do they work?*

   In 1993 the W&R concept has been developed. Here the focus was mainly on standardisation of the construction processes. By application/have a reference design as starting-point, the W&R concept has made it possible to repeatedly build the same house but with different aesthetic requirements and room layout measurements. The concept revolves around five basic pillars which are as follows:

1. *Reference house*:
   This is a standardised product of the actual house. The reference house holds approximately 80% of all the information regarding design, planning and building processes. Nicky Brieffies hereby points out that it can be seen as a database. When a new project comes along, we use the database to combine the standardised components to develop a new design.
2. *Continuous foundation deposit process.*
   During all the projects of W&R the process for foundation deposit is continuous. Nicky Brieffies explains that if we differ from the standard, both considering product and processes, the costs will increase significantly. We need to make sure that the standard is used, and only small adaptation can be made. Within the W&R concept, we work from the process side of a project. The questions that are considered are mainly; which product is suitable for the project

and/or how can we adapt already established designs of a product so that they will be applicable for the current project.

3. *Fixed project team:*
   In the basis we always work with the same people on the construction site, the team stays the same. At the beginning of each project, a timetable is made, and the speed of development is determined. All disciplines should work on this determined tempo. By this, all the different disciplines will be done on the same time, and then the whole project team can begin on a new project. In addition, three members of the project team are fixed to transfer knowledge throughout projects. The fixed project members are the project manager, project leader and executor.
4. *Co-makers*
   From the start of the W&R concept several suppliers have been adopted as co-maker. This means the suppliers are involved from early stages of each project and no other suppliers are considered. Nicky Brieffies states that they closely work together with their co-makers, together they are optimising the design and processes. He states that they are very open-minded and help each other out. If a certain change in product or process could be beneficial for a co-producer, the other co-producers are willing to cooperate with this, although maybe not or not sufficient benefits for them occurs. When change affects the other co-producers negatively, they will be compensated by the other co-makers. Hereby Nicky Brieffies means that the different co-producers form a team. If a new innovation is proposed, this will be reviewed, and they will decide together if they want to implement this. Hereby the effect on the total concept of this innovation/change is considered as the most important.
5. *Client focused action*
   Nicky Brieffies that in all the different projects, the client is considered as important. They can provide us with feedback, and by this help with the optimisation of the processes and products. In every stage of the project, the client is informed and after every project evaluation occurs.

   b. ***Can you explain the 80%, 20% rule? And is this still applied in practice?***
   This means that for every project 80% of the design and process are fixed. This by the guidelines of the concept of W&R, but also because of the specific situation on side considering: soil, logistic possibilities etc.

   c. ***The W&R concept is market push, instead of market pull (customers have to choose from catalogues). How far dues this goes?***
   Nicky Brieffies states that customers need to choose from catalogues, and show pictures of the different established projects within the Netherlands. There are a lot of possibilities. However when the customer wants something that is not in the catalogues, wants an adjustment, this has to be discussed with BAM W&R. It will be reviewed if the adaptation is possible and how much extra this will cost the client.

In addition to this question, Nicky Brieffies highlights that: almost everything is fixed, considering both product and design. We can make some adaptations to the reference concept. However, we need the control this. When we make an adaptation that is not a standard within the design and construction process, this will be expensive. As then the project does not benefit from the possible reuse and repeatability in design. The W&R concept results in a fast construction time, and already give the client a lot of certainties, as the price and duration of the project can be determined already in the early phases of the project.

4. **Do you consider that there is continuously improvement and innovation within W&R? Referring to processes and products, small and large scale projects.**
   Yes, as stated before, the different members of the product team including the co-producers can do suggestions for optimisation. The suggestions that are considered to be beneficial are future analysed and even implemented in the new reference design. However, there we talk about small optimisation within the product and processes. Very big changes (innovation) are not applied within the W&R concept. We need to stay true to the concept, as everything depends on this concept.

5. **Within literature, it has been pointed out that it is important that the standardisation of product and process has to be applied together in order to fully benefit from the standardisation. Why do you consider this to be important? (to align both process and products)**
   Product and process are both interrelated. When you change the product, the process needs to be adapted as well. And when you change the process, the product should also be adapted to the new process. By analysing both product and process, it gives us more insight into which barriers there are for this change.

6. **How is the learning within the team transferred? And can do you consider that these principles can also be applied within BAM Infra? (knowledge is project-exceeding)**
    i. *Knowledge/ experience should be shared within and the organisation in a project exceeding way*
    ii. *Innovation by constantly updating the reference model (optimisation + innovation)*
    iii. *Feedback loops are considered to be very important. By this points of improvement become clear, and as validation and verification take place, they will be better able to meet the wishes of the client.*

    Nicky Brieffies thinks all the three aspects, listed above, and are applied within the W&R concept. In addition, he states that you do not hear about things that went well, if something goes wrong, however, you hear about it immediately. As we are with a small group and work with a fixed team, the communication is very fast. The problem will be discussed right away, and a solution is developed. In order to have a fluent process, all the different phases are documented within a database, considering a general script of what steps should be taken. We even have a list of practices that should not be applied, so that already made mistakes will not happen again.

7. **How do you implement new methods and/or techniques? As the customer rather not have the risks of a new concept?**
    The client wants that already established materials are used. This does not mean these cannot be innovative, but the new method, new technique or new material should already have been successful within another comparable project, as the implementation increases the possible risks. Nicky Brieffies states that they do apply different methods, techniques and materials, but these are already tried and tested within other projects. When we want to implement a new method, technique or materials we have to make trade-offs. If should be investigated if this is financially more attractive or that it will result in a significant increase of the quality of the building process and the end product. In conclusion, it can be stated that the W&R concept is based on a traditional conventional viewpoint, as no extra risks are taken. A change needs to be significantly beneficial, in order for BAM Housebuilding to apply this.

8. **As architects can change the reference model, do you consider that are is sufficient room for change. Or less or more design freedom/ changes are needed? (Referring to the quotation of Henry Ford; "Any customer can have a car painted any colour that he wants so long as it is black.")**
    The room for change is limited, but Nicky Brieffies is of the opinion that there is sufficient freedom/possibilities to choose from with the current W&R database. For a specific project, some adjustments can be made. However, this will only be beneficial when it will be applied to a lot of houses. If only a limited number of clients want the change, this will not be feasible, as the costs will be very high. When certain possible changes are asked by the client within different projects, we might review this, and analyse if this maybe needs to be standardised.

9. **Do you make use of a configurator for the customer, or is there still a lot of changes that are required and/ or design of new elements needed?**
    At a website, called "this is my home" the client can review the catalogue and can make choices for what they want in their new home. The website then gives a rough sketch and price of the home.
    (the Dutch website is: ditismijnthuis.nl)

10. **Can the W&R build houses easily be deconstructed, referring to the application of a "click"-system?**
    Within the design, have maintenance and adaptability to future demands, and demountable of the construction taken into consideration?
    The skeleton of the houses are of concrete and are not prefabricated, they are made on site. This makes it impossible to deconstruct the houses in parts. So the skeleton currently is not suitable for a "click"-system.
    However, so prefabricated elements are used. For example, the cavity wall is connected to the main structure by brackets and anchors. This could be changed to a "click"-system.

11. **When you have a W&R house, and after 10 years you want to expand your house. For example, add an annexe. Can this be done relatively easy?**
    Nicky Brieffies states that it is possible to expand your house in the later phases. However, this is not taken into consideration when designing the houses. Considering the concept, by making use of a concrete tunnel for the basis of the house, the house will not be easily adaptable. As the walls of the tunnel are supporting the total structure of the house, therefore a new construction has to be developed to be able to handle the forces. And some parts of the structure will need to be demolished.
    However, when you decide to buy a W&R house, there are a lot of possibilities for the annexe. This again works as the total concept works, as long as you follow the standard, stay within the boundaries, an annexe can be constructed for relatively low costs.

12. **How does the W&R concept cope with co-production? Can be very beneficial, but too much cooperation can lead to increased complexity.**
    The last 20 years, we have worked with the same suppliers. By this, a long-term, durable relationship has occurred. All the different parties are aware that they are dependent on each other. Together it is possible to deliver the projects, they need each other. Therefore a lot of contact between the co-makers with BAM Housing takes place. But also a lot of communication between the different co-makers occurs, as their products and processes need to be aligned. One in a month we have a meeting with all the different co-makers together, to make sure everybody is up to date and shares the same goals. Of course, a project becomes more complex when you work with a lot of different parties, however, if clear agreements are made, this will not be a problem.

13. **Within the W&R concept, how is made sure sufficient innovation occurs within the W&R platform? (As this is important to stay the "best", not be out competed)**
    The BAM Wooncollection was already a big innovation at the time that it was implemented. Within the W&R concept, we currently only optimise the product and processes. Continues improvement and adjustment take place. The drive is not to develop the most innovative project, but to deliver houses that meet the requirements of the client for a good price, referring to the ratio between quality and price.
    Nicky Brieffies adds the comment that he thinks there are still some points he thinks innovation could be effective. He states that we might need to rethink the way current projects are sold, maybe 3D-printing can be used and currently we use concrete for the basis of the houses, this is not very sustainable, maybe we can change these practices. But currently our approach works well, so we only optimise the product and processes.

<u>Applicability of the W&R concept within the infrastructural sector: considering a viaduct.</u>

14. **Is this concept of W&R, also applicable for infrastructural projects/objects?**
    Considering:
    a. Five main pillars
    b. Market push and market pull (currently an infrastructural object is market pull, as client specifies the requirements and a design is made)
    c. Scale of the objects and a number of objects that need to constructed (repetition)
    d. Variation needed: due to soil type, surrounding, load etc. Can, therefore, a reference be established?

    Nicky Brieffies viewpoint is that the W&R concept will also be applicable for infrastructural projects/objects. However, he does highlight that this will be more complex for infrastructural projects/objects, as more requirements are listed and less repetition occurs, as significantly more house are constructed than an infrastructural object. In addition, the states that he agrees that still sufficient variation is needed, in both cases, otherwise the concept will not work as it will not fit the requirements of the client and the different situation on-site.

15. **It has been pointed out that the current specification of the requirements of RWS are still too specific, this results in a limited amount of freedom in design although the requirements are made functional. Do you agree with the opinion that the requirements of RWS are still too specific, and therefore limited room for innovation occurs?**
    Nicky Brieffies states that within BAM Housing, we are used to high requirements and always had to meet the NEN-Norms. This does not hamper innovation, it can also be seen as a driver to increase the amount of innovation. He is of the opinion that considering infrastructural objects, this is different. He does think that the requirements limit the freedom, there is less space to innovate.

16. **Do you think the different provinces and municipalities can make an agreement for their specific requirements? As this would be the case, this will have significant positive effect on the application of a product platform.**
    Nicky Brieffies thinks this is possible. However, currently, he states that municipalities and provinces have almost none or limited communication about this matter.

17. **What do you see as risks and/or barriers, as well as opportunities in the future market?**
    Two things are seen as risks and/or barriers. First, there are a lot of competitors. This means we constantly have to optimise and innovate, in order not to stay behind on the completion. We have to keep our costs low but still, deliver high quality. Secondly, the market itself is seen as a risk and/or barrier. Here Nicky Brieffies points out that the financing of projects is not always certain. The housing market is very dynamic and changes all the time. Due to the supply and demand mechanism and the different interest rates, all have an effect on what is attractive, buying a house or renting. Thirdly, Nicky Brieffies considers the fact that the wishes of the future client are unknown. In the future, these wishes will be different from the current demand. Nicky Brieffies see that the receiving of refugees can be an opportunity for BAM Housing, as they can develop and construct standard houses for these people in a small time period and for relatively low cost. To conclude Nicky Brieffies states that for every company it is important to stay up to date with the current development, and anticipate on these.

18. **What is your opinion considering other initiatives of BAM? Small bridge? (Click and construct), Tunnel alliance, Gravity based foundations, (Why do you think it was no success? What can we learn from these initiatives and the W&R concept?)**
Nicky Brieffies did not hear of these initiatives before but refers to the utility projects and hospitals made out of modules. He thinks applying the concept of W&R to these industries can be beneficial. As utility buildings and hospitals can have a high amount of repetition considering different buildings, and as the design and construction process can be speeded up. Nicky Brieffies thinks that it is important to align both product and process. In addition, it is important to have a design that gives a lot of possibilities, sufficient variation is needed. Nicky Brieffies also points out that he thinks co-makers are needed for the concept to be successful. They all are motivated to improve the quality of the end-product. Only together you can establish successful projects, you will need each other.

19. **What are your tips and tricks for the development and implementation of a similar concept for viaducts? (What opportunities are there, and which difficulties did you came across?)**
Different points are mentioned by Nicky Brieffies. He states some tips and the difference between the housebuilding industry and the infrastructural industry, they are listed below:

- *Sceptic*
  Need to be aware that some people are sceptical, you will need to convince them. Need to invest energy, but this will pay out in the future.
- *Motivated people*
  It is important to work with motivated people that share the same vision.
- *Logistic need to be totally considered at front.*
- *RWS*
  RWS has a lot of requirements for infrastructural objects, need to consider law and regulations at front.
  Within the housebuilding sector, this is not that complicated, but in other sectors, it might be complicated.
- *Safety during construction and safety in the utility phase.*
  As infrastructural object are larger than a house, more safety risks are present and need to be mitigated at front.
- *Maintenance.*
  The maintenance has to be done while still, the road needs to keep functioning. Within the housebuilding industry, this is different, as maintenance can be done more easily.
- *Increased risks*
  When something is not constructed properly within the house-building, this can be adapted very fast. However, within infrastructural projects, one mistake will have a large impact.
- *Costs*
  Less finance is needed for the development of a house, in comparison to an infrastructural object. This also means that the housing projects are not that risky than an infrastructural project.

20. **Within literature, different opinions about the implementation of industrialisation within the infrastructural sector can be found. What are, in your opinion, the main essential success factors for the implementation of a product platform? What has been essential for the W&R concept, and what do you consider to be essential for the successful implementation of a product platform for viaducts?**
The W&R concept is not developed with the idea to develop a product platform. The idea comes from a head company office, as they have asked the critical question why there were "reinventing the wheel" all the time. Therefore, they have started to investigate if they could apply a certain amount standardisation. Then a lot of money is invested, but this has was beneficial and establish sufficient profit eventually. This could be the same for the infrastructural industry.

21. **Do you have other tips, considering the implementation of a product platform for a viaduct? Documents I need to review or people to interview?**
Nicky Brieffies states that it could be interesting to also ask RWS what their viewpoint is on this topic. (The researcher agrees and has already made an appointment with Paul Waarts. He works for the province of Noord-Holland.)

B.1.6 Interview 6

Interview – Dr. ir Paul Waarts– 24 May 2016
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1. What are your thoughts on standardisation and modularization, by the implementation of a product platform? (Referring to "legolisering").

Paul Waarts state that we can and should apply the concept of "legolisering" within all our projects. Paul Waarts thereby highlights that almost no standardisation and modularization is been applied. Considering the infrastructural sector we are missing out on opportunities.

He thinks we should look at infrastructural objects more in the way of the customer production market. The specifications need to be free, and we just have to buy what is offered. Not every time demand a total custom-made design. Here he refers to a custom-made suit. If you want a new suit, you can either choose for a conventional model that can be adapted to your specific body shape, or you can choose to have a suit designed especially for you. Eventually, both options will result in a good outcome, which fits your needs. However, the custom-made suit is more expensive. Considering a custom-made suit, we are aware of the fact that we pay double, or even more than that, in comparison to a conventional suit. Within the infrastructural sector, here there is no awareness that not all situations demand a unique solution and that a standard design could also be adapted while still having unique aesthetic characteristics.

He does state that within viaducts some standardisation is already applied, referring to standard beams that are used. However, this is the result of prefabrication, and here the suppliers have specified certain dimensions in order to have a more effective production process. Paul Waarts think that the total industry should adopt one standard, here he refers to a standard interface, where it is clear how elements/components have to be connected/are coupled. Within this interface, the elements and components can be designed freely, without restrictions. This is possible as long as the standard couplings are considered.

Paul Waarts states that you can identify two main parties that have a significant influence on the current practices within the industry, namely the government (Ministry) and manager (RWS). The ministry has a wish, they want to implement some form of standardisation and/or modularization. However, the management has to implement this with the resources they currently have. The management (RWS) will be more broad-minded than the ministry. However, they see a tension field between the budget and functionality of the new structure. Therefore, currently, most infrastructural objects are designed and constructed in a traditional way.

2. The concept already has proven itself within house building. What makes infrastructural projects different from house building? And do you consider it to be applicable for infrastructural projects/objects?

Considering the viewpoint of Paul Waarts, he states that the "legolisering" is also applicable for infrastructural objects. However, the researcher points out that infrastructural projects are different from the housing industry, where the concept of 'legolisering' has already been successfully applied.

The researcher has pointed out the different aspects that are present within the housing industry and argues if Paul Waarts can explain his viewpoint considering these aspects for the legolisering van infrastructural objects.
Considering:

a. *Market push and market pull (currently an infrastructural object is market pull, as the client specifies the requirements and a design is made)*
   Paul Waarts is of the opinion that the current market needs to change from market pull towards market push. He states that the development of a design for an infrastructural object from scratch every time, developing a custom-made solution every time, has just become a manner of habit. This is become the standard way of working within the industry, as they think everything is possible, and every design needs to be unique to be able to provide the client with the structure that meets their specific requirements. Here again, we can refer to the already explained example of a custom-made suit versus a conventional suite. When the client becomes aware, that their requirements can also be met by applying a conventional design and make adaptations to this design, they will not demand very complicated structures any longer. Because they will become be aware that the cost for this design will be significantly higher than when the conventional (reference) design will be adapted to the specific situation.

b. *Scale of the objects*
Applying the concept of “legolisering” is possible for all different scale of objects, here he refers to the automotive industry and highlights that this is also a complex product. However, the industry has successfully implemented “legolisering”. Infrastructural objects are in his viewpoint, less complex. The fact that they require big elements does not make them different from products of other industries.

Paul Waarts also highlights that the concept of “legolisering” has already been successfully applied for small bridges, which are meant for bikes and walking. He here refers to the municipality of Rotterdam. They have applied one standard for all their small bridges. Here the bridges can be chosen from catalogues. Paul Waarts thinks this is a good example of how it could also work for large infrastructural objects. If we only use, Lego-blocks, we can make a lot of different types of bridges. He points out that if we can combine the Lego-block, and by this can develop around 20 options, this can result in a cost reduction of 40%.

c. *Amount of objects need to constructed (sufficient amount of repetition)*
The research explains the W&R concept of BAM Housing and highlights that this is a very efficient process. She points out that this concept is so successful mainly because of a number of houses that are constructed every year, here a lot of repetition occurs. Paul Waarts states that this is a lot of people are sceptical when he asks them about their opinion of “legolisering” in the infrastructural sector. They state that not sufficient repetition occurs. As in housebuilding a lot of houses are constructed every year. However, he estimates that the province of Noord-Holland develops one viaduct per year, on the average over 100 years. For the managers (beheerder, RWS), this is a very small number. However, if we review all managers, a significant amount of viaducts are constructed. And if this would not be the case, the concept of “legolisering” can still be beneficial, as he refers to the opinion of professor Henk de Vries from the Erasmus University. If you make use of a design for an object two times, in steady of only once, you will already have the benefits that the design phase does not have to be fully run through. This can save a lot of costs. It is important to calculate how much cost this could save if we use one design for the development of 50 objects.

d. *Implementation of a reference viaduct possible (and what % do you think is realistic?)*
The implementation of a reference viaduct is possible, and this is something that we should do, as it can be very beneficial. Paul Waarts thinks 80% of the viaduct can be standard, and 20% can be more unique, although this can also be established by combining standard elements. The design will still give the freedom to add (toeters en bellen) specific features. By this, the object will still be “unique”. The aesthetic appearance can be adjusted to the wishes of the client (personalise). But it also will benefit from the repetition that occurs, as within the structure “legolisering” has been applied. He also points out that there always will be certain clients that want a unique project, as for example, the viaduct will be a landmark. When this is asked, a unique design from scratch can be made, however, they should then be aware of the higher costs for this structure compared to applying the standard and adapt this to the situation.

As the researcher questions what Paul Waarts would say to parties that want to have a new viaduct when they would state that they do not want a standardised object, as they pay millions for the structure, they want something unique. Paul Waarts would then offer them the standardised product and deliver this with the required features. He states that he would then just point out that the client can have the standardised design with the different specific features, for the half of the price of a design that is custom-made. However, he highlights, that in appearance both designs will be unique. The outcome here is the same. Paul Waarts highlights, if you have the drive, this concept can be realised.

e. *Maintenance, adaptable to future demands, demountable*
Considering maintenance and making the structures demountable, Paul Waarts states that this will be easier by using legolisering. This because a standard has been used, and constantly applying this standard will result in a learning curve. In addition, as all the coupling relations/connections are standardised, the different components can even be reused in new structures. The researcher hereby is sceptical if this can be done in practice. But according to Paul Waarts the different elements, for example, a beam of a viaduct, can be re-used, as he considers these elements as very robust, and the deflection and change of the form of the beam are only limited. He thinks that these beams can, therefore, be used within a new structure, and therefore do not need to be demolished. In order to make his point clear, he states that a “marketplace” (Marktplaats) can be used, where the different elements can be offered.

The researcher again asks the viewpoint of Paul Waarts considering the possibility to adapt a structure to the future demands. Currently, existing structures are mostly fully demolished when they do not fit the new infrastructural situation, for example as their capacity is not sufficient any longer (strength, adding new roadway etc.). In some scenarios, the abutment is not demolished and RWS only replaces the total deck.

However, in most situations totally demolishing the structure and construct a new viaduct, is done. As trade-offs need to be made, considering the speed of the adaptation process versus the speed of building a new structure, and also trade-offs considering the maintenance and building demountable.

f. *Due to soil type, the surrounding, different load etc., sufficient possibilities are needed. Can, therefore, a reference be established?*
As stated before, the standard (reference) design can be adapted to the different situation and features can be added to make it more of a one of a kind object. However, Paul Waarts does not think the foundation of a viaduct can be standardised. He thinks this is too hard, as he considers that putting the poles into the ground to provide a good foundation, cannot be fully know at the front, this is something that will become clear when the construction starts. However, the connection/coupling of the foundation with the abutment can be standardised. The researcher hereby asks the question if Paul Waarts hereby also considers that standardisation can result in over-dimensioning the object. Paul Waarts does not see this as a problem. The objects may be over-dimensioned as they need to fit a predefined standard. However, this will result in the fact that the object can be realised for lower costs.

3. **Why do you think the concept of “legolisering”, where this is referred to the development of a product platform considering standardisation and modularization, is not applied on in infrastructural projects already?**
Paul Waarts points out that the current way of working within the infrastructural industry is still applied, and not a shift has occurred towards “legolisering”. The main cause, why a new approach has not been accepted, is that the current way of working works for everyone. He states: Everybody is happy. Paul Waarts explains this by pointing out that a custom-made design is more expensive, this will generate higher income for the structural engineers. And maintenance and management are different for all the custom-made structures. This is a ludic market. However, the implementation of “legolisering” will change their way of working completely, and by this, they also need to consider another profit model.

In addition, engineers like working on a unique project, they like to design something special. They enjoy the process of constantly beginning a design from scratch, constantly “reinventing the wheel”. Considering “legolisering”, they only need to adapt the standardised (reference) design to the different situation. However, we do not like to do the same think twice and the engineers are not challenged. They only need to “assembly” the different components, to produce a design that will fit the requirements. This process will become boring, but it will be very efficient. This is why the “legolisering” is not adapted very fast, but they are not aware of this.

4. **Different parties within the infrastructural sector argue that although RWS has started to apply functional requirements, they still have limited design freedom. Here the employee of BAM Infra have highlighted that the also still have to deal with an anaesthetic plan; “omgevings eisen”/”esthetic programma van eisen”. What is your opinion on this manner?**
Paul Waarts states that the province Noord-Holland, gives the architect and constructing parties a lot of freedom, and thinks this is the same for RWS. He states that the requirements are functional. We try to make the listed requirements as free as possible. However, the requirements of the “bouwbesluit”, that refers to certain NEN-norms has to be considered. So, there are some restrictions, but there is still a lot of freedom. Paul Waarts states that the change from full specification towards functional specification has given more freedom in design, and more possibilities for the use of other concepts. The researcher here points out that, although functional requirements are applied, the employees of BAM Infra still experience limited design freedom. They are of the opinion that the functional requirements are a good start, but currently, the plan for the surrounding area and a sketch design are documented in the “aesthetic PVE”. Paul Waarts states that this document is not leading, it gives an impression of what kind of design is preferred by the client, what their vision is for the project. It gives an impression of how the new structures can be implemented within the surrounding. However, Paul Waarts clearly points out that this document is not leading. The “beeldkwalitietsplan” or as called “esthetic PVE”, has been implemented to give the architect and structural engineers an idea. He states that in a project he was involved the end result was nothing like the “beeldkwalitietsplan”.

5. **Do you think the different parties within the infrastructural sector are aware that they currently are working highly inefficient?**
   Yes and no, the people are not aware that their current practices are very inefficient comparing to “legolisering”. And are not aware that legolisering can be beneficial. They are accustomed/used to their current way of working and think this way of working is the right approach, as they state that this is a proven concept that works. Here they stated; why should we change a concept that has been successful for all these years.

6. **What do you consider as the main “power” of the “legoliserings” concept? What makes it successful?**
   It should be clear what the standard is, pointing to a standard for how the elements should connect together. So here, an agreement between the different parties within the infrastructural is essential.

   The concept of “legolisering”, were the researcher refers to a product platform (considering standardisation and modularization) can be very beneficial due to:
   - Quality improvement, as a learning curve occurs and elements are pre-fabricated
   - The market will be better able to focus on a specific element, and they can become a specialist in that area.
   - Saves time on site (mainly make use of pre-fabrication)
   - Fewer costs for design (design does not have to made from scratch, the reference can be adapted to the situation)
   - Sustainability: less waste, demountable and re-use of components
   - Fewer failure costs, due to repetition (learning-curve)

   The researcher asks the interviewee if he agrees that a product platform can facilitate the cooperation with other firms, without having to “protect” their innovative product or process. Paul Waarts does see this as an advantage, but he states that the different structural engineers are very conservative, and it will take a while before the product platform will be used this way.

   Paul Waarts states that there are more, as he thinks all already investigated by the researcher, but these are the main aspects that contribute to the “power” of the legolisering concept.

7. **On which level should the implementation of a product platform for infrastructural objects be applied? (Only interface, space and function?)**
   On the level of interface, space and function. It needs to have a specific dimensions and each element has a specific function.

8. **Do you consider that there is continuous improvement within the infrastructural sector? Referring to the current way of working and “legolisering”, processes and products, and small and large-scale projects. (Knowledge is project-exceeding?)**
   Paul Waarts state that it is hard to say if continuously improvement occurs, as all the different parties within the industry work in a different manner and they do not share their innovations with others in the industry. It is possible that the different parties are constantly innovating, although we do not experience this as outsiders. However, the researchers ask Paul Waarts if he thinks cooperation between the different parties within the infrastructural sector could be beneficial, as together they can optimise the process and innovate, as they share the risks and share their knowledge and experiences. Paul Waarts agrees.

9. **How do you think new methods and/or techniques can be implemented. As the customer, in your situation the Province, rather not have the risks of a new concept? And procurement is based on EMVI criteria?**
   Paul Waarts states we just have to start with implementing/applying the concept. We have to make a choice about what our standard will be. From this standard we should derive different designs, by adaptation of the standard, to meet the specific situation. He thinks the market need to be convinced. He states that change always takes time. However, if we apply the concept, we will see that it will result in less expensive projects/objects. The standardised design that is adapted to the situation, can be designed faster and will be less expensive due to time and learning curves that are established. So Paul Waarts is convinced that the standard will win on lowest price. The only thing that is needed is to get the market to work with a product platform. If they do so, the different parties will directly experience the benefits.

10. **Do you think the different provinces can make an agreement for their specific requirements, considering infrastructural objects? So that a reference object can be made, and a common interface can be developed.**
Paul Waarts strongly agrees as he is currently trying to make agreements between different provinces and municipalities. As the demand site, pointing to RWS, Provinces and municipalities all apply the same concept and have made agreements with each other considering their requirements will help to apply the implementation of a product platform. In the most optimal situation, this will also be the case between the different structural engineers in the industry. As for example Heijmans and BAM etc. together share an interface. Paul Waarts refers to a standard, as he considers a standard interface (platform) makes sure that the parts are interchangeable. The different elements can be easily coupled/ connected, because these all have the same standard connection. Paul Waarts refers to this as legolisering, were the "noppen" of the bricks are always the same and different Lego bricks can be easily clicked together. Although the interface (coupling relations) are standardised it is important the different structural engineers can still do their own think, referring to the different elements. The researcher questions if by this way there will be sufficient competition within the industry, and new innovations can occur. Paul Waarts thinks this will be the case.

11. **As architects can change the reference model, do you consider that is sufficient room for change? Or less or more design freedom/ changes are needed in order to benefit from standardisation and modularization of the product platform concept?**
Only the connection between the different parts will be standardised. The architect can still make his own design considering these different parts. Paul Waarts states; "Give me a bridge that can handle a specific capacity of traffic". Here he states that he does not care how the bridge has to look and of which materials they are made. The bridge only has to comply with the requirements of the "bouwbesluit", which refers to the NEN-norms. And it should be guaranteed that the structure will still function correctly considering a certain time-period, for a viaduct this is mostly around 100 years.

12. **Do you think the development of configurator for different infrastructural objects is beneficial and/or applicable? Or are the situations to "unique", too much different circumstances, and are there still a lot of changes that are required and/ or design of new elements needed?**
The researcher first had to explain how a configurator works, and refers to 3D programs that are used by Ikea, the client can design their desired solution based on standardised parts. Paul Waarts states that something like that will be possible to make, however, he does not see the added value of this. He thinks this is very handy within the mass-production market, referring to Ikea. However, infrastructural objects are different. The client that demands this new object is not also the end-user. It is not the same as the consumer market.

    Paul Waarts, asks the critical question of who of his colleagues (civil servants) will use this concept? He explains how the current policy works, and states that a configurator will not be applicable in the current way of working.

13. **On what level does the province specify the sustainability of the infrastructural construction. Referring to demolition, less waste, and keeping functioning of the surrounding area.**
Paul Waarts states that the province currently does not specify the sustainability of the infrastructural construction. Here states that currently specify what we call 100% sustainability. This means that there are requirements, but these requirements are so general and not specific, that it is very hard not to meet this criteria's. He thinks this is ridiculous; the requirements are just silly requirements.

    Paul Waarts however is currently working on an improvement considering the specification of sustainability. His goal is that within the construction project more focus will be on the scarcity of different raw materials. He thinks applying the Lego concept can be a good way to achieve this. In addition, Paul Waarts thinks it is more important to be able to re-use the different elements of the object than being able to demount the object. However, the researcher thinks that when a structure is built demountable, this facilitates that different elements can be used within other new objects.

14. **Why is it so important that both process and product are standardised?**
Product and process are interrelated. They are dependent on each other. When the product is changed, this process will need to be changed as well, as both product and process need to be aligned.

15. **Why do you think the initiatives that are already taken by different structural engineers have not been successful?**
Paul Waarts is of the opinion that the concept should work. However, the construction industry is very conservative. He states that in order successfully apply a product platform a mind-shift is needed. The ways the people work in the sector needs to change. Therefore, he states that he is trying to establish this by convincing important people, people that have significant influence, for example, the direction of BAM Infra. In his opinion, they will have to impose that their employees need to work with the concept, otherwise the employees will stay working the way they are used to.

The researcher also points out the parties have to invest in the concept, this referring to a small project team that are separated from others in the organisation. Here this small team will exist out of three to four people, and they will get a year to fully dedicate themselves to this project. The outcome will be a concept of how the legolisering could work. Paul Waarts agrees but stated that he also thinks it is very important that these people have an open-view, and are not biased by the current practices.

16. What do you see as risks and/or barriers, as well as opportunities in the future market?
    When there is a product platform, one of the risks that occur is that there will be an increase of competition. As the interface is standard, also parties in China can develop elements that match the interface. However, increased competition is also a good think, as it challenges the sector. Paul Waarts states, that he further does not see any big risks, but he points out he is currently looking through a pink glasses (has an idealistic view).

17. From my literature study, I have found that different parties have argued that risks occur with the increased use of standardisation and modularity, where large prefabricated models are used. They stated that currently for the whole market to apply this concept there will not be enough suitable producers of the modules, and not enough transport and heavy-lifting is available.
    Paul Waarts states that it has been estimated that change requires a process of seven years before the change actually occurs. He states that the transportation market will adapt to this changes, they will have seven years to do so.

18. What do you consider as essential elements in order to successfully apply a product platform, with the use of standardisation and modularization in the infrastructural sector?
    For the concept to be fully implemented, a mind shift will be needed.

19. Can you tell a bit more about the current study of the Bouwcampus that you participate in, considering the “legolisering” of a movable bridge?
    At the bouwcampus, we are currently researching if a moveable bridge can be made by building with building blocks, referring to the Lego concept. There only have been two sessions yet, first, the different parties needed to agree that the concept is possible. Here Paul Waarts, as he represents the province, states that we just have to start applying the concept, eventually this will become the new norm. There will be six sessions in total, and Paul Waarts thinks it would be great if we could agree on a product platform.

20. What are your tips and tricks for the development and implementation of a product platform for viaducts? (What opportunities are there, and which difficulties do you consider?)
    For the implementation of the concept, a leader is needed. If you convince the dominant coalition of BAM Infra, referring to the management team. They can impose the concept. Paul Waarts thinks you can get the attention of these people, by going “buitenom”. What is stated in the newspapers and what the opinion of different professors at the university are, is important for the management team? The concept needs to be promoted so that the management team also becomes aware that we should apply the concept of “legolisering”.

21. I currently have the idea to work with other materials than the conventional concrete. Do you work with new innovative materials? For example composite.
    Yes, we have applied composite in different small bridges within the province. The composite is strong and light weighted. Therefore, it is a very suitable material for the construction of bridges. However, Paul Waarts states that there are certain requirements, whereof we do not even know why these are specified. The requirements are in the way. He points to the fact that the deflection of a viaduct cannot be too high. However, how much the structure can bend is based on the bending of concrete elements. Composite has a bigger deflection, and therefore it is more complicated to apply composite.

22. Do you consider that it can be possible and will be beneficial to use polystyrene (plastic) in combination with concrete for a viaduct? (this is an idea I currently have)
    Paul Waarts states that were there is a drive, it will be possible to realise the idea. For this idea, he suggests it should be investigated/tested future, but it sounds realistic.

23. Do you think it is possible to make use of a “click”-system for connecting the different elements
    Here the researcher pointed out that this, in theory, could be beneficial. As current construction objects can be updated more easily, can be demountable faster and can be more sustainable. Referring to if a standard interface will be present all the different elements could be easily combined. They all can be clicked together in the same way. Paul Waarts agree with the researcher.

24. **A second question considering a "click"-system is if you think it is possible to not apply the joining of elements by the use of concrete (Maintenance, adaptable to future demands, demountable)**
Paul Waarts does think this is possible. He states that when elements are prefabricated, currently referring to concrete elements, these elements that form the bridge can be connected by the use of bolt and nuts. In this case, the structure can easily be demountable. Paul Waarts here also refers to his vision for the re-use of the elements. The researcher again questions if Paul Waarts thinks, considering the situation were bolts and nuts will be used, infrastructural objects can be easily adapted to future demands. However, Paul Waarts still remains sceptical and thinks it will not have sufficient benefits. He again states, that when infrastructural objects cannot handle the current amount of traffic (not sufficient capacity), that these structures are demolished. And a new object will be design and constructed.

25. **What is your opinion considering the maturity of BIM, how does this can affect the implementation and working of a product platform.**
Paul Waarts, states he has not considered this relation between BIM and "legolisering" before. He thinks this is an interesting question and states that is indeed something he should look into. However, Paul Waarts points out that currently there is not standard. A standard will need to be made or chosen. Currently, it is general interest, therefore nobody feels responsible. Therefore, we just have to demand to work with BIM, based on a standard, this will facilitate the implementation of a product platform.

26. **Do you have other tips, considering the implementation of a product platform for a viaduct? Documents I need to review or people to interview?**
Paul Waarts has invited the researcher to a kind of symposium, an inspirational meeting about infra-innovation, on the 9the of June in Brabant. He has helped to organise this inspirational meeting and will also present his viewpoint. Paul Waarts thereby states that a lot of important people within the infrastructural sector will be present, and this is a great opportunity to get to know these people and ask them about their viewpoint on the manner. Professor Halman will be present as well.

B.1.7 Interview 7

Interview – Leon Hendriks – 25 May 2016
Function: Senior Design leader - BAM Infra consult

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Questions focused on the N18 – design

1. **You have been the design leader for the tender of the N18. Can you shortly introduce/explain what your tasks have been within this project?**
   Leon Hendricks has been the design leader of the tender of the N18. This means he is responsible for the output from the design phases. As a design leader, you lead the different design disciplines and are you in the management team of the project. Here, five main managers were present within the tender. Kitting Lee was the tender manager. In addition, there were also managers on the execution (uitvoering), management and maintenance (beheer en onderhoud) and managing design and process considering the EMVI-criteria. Leon Hendriks here points out the tender was a DBFM contract.

   Leon Hendriks point out that this is usually the structure they work with within BAM. A small management team, but with a lot of other specialised under need this hierarchical structure.

2. **What are your thoughts on standardisation and modularization, by the implementation of a product platform in general? (Referring to "legolisering").**
   Leon Hendriks does things it is possible and is positive about the concept the researcher has put forward. He is of the opinion that a basis to apply this concept will be needed, and here refers to designing a "standard" viaduct. Leon Hendriks states that this is something we are already talking about since several years, however, we have not yet established a standard. This mainly because the employees do not think it is possible for the current market, referring to the requirements that are demanded by the client and the other regulations. In addition, although they see some form of repetition with different designs, the always have an excuse why standardisation will not work in their current project. They consider their project as unique, there are always different circumstances, which makes that no standard can be effectively applied.

   Here the N18, was a new opportunity the apply standardisation, as a new road needed to be developed that will go through meadows (grass fields), this means there was a lot of freedom for the design and the actual construction did not immediately affect the traffic as they old road still remained operating. In addition, the road needed a lot of similar type of objects (kunstwerken). Leon Hendriks hereby states, that there was a lot of freedom and there was repetition in design, so for this project, it was a good approach to apply standardisation. He stated the management team steered the project team to work on a standardised design, there were no excuses any longer. The design should be simple and less costly, and the process can be made more efficient.

   The project team have analysed which part of the different type of objects could be standardised, within this projects. Here Leon Hendriks refers to the length of the beams, the upstands (schampkanten), the edge beams and the edge elements for the finishing of the design (randbalk en randelementen). These are just examples, several other elements have been analysed. However, the members of the project team at first constantly saw conflict between the application of a certain amount of standardisation and the different situation that each object had. For example the angle of crossing(kruisingshoek), the angle of which the viaduct connects to the road. Leon Hendriks states that if the management team decides to implement the principles of standardisation and modularization, then the project team needed to step up their game. Leon Hendriks states, that he has given his design team the instruction that they have to establish a standard that works considering the different situations of the objects; "Make it work", thinks of a new solution, a new concept design, that can handle all the different circumstances. Leon Hendriks highlights that we can have a standard, as the difference between certain designs are only marginal. In addition, he states that there were a lot of similarities between the objects that needed to be designed, we should make use of this. The researcher here questions if this meant that the project team was pushed to be innovative. Leon Hendriks thinks that to innovation is not really the correct word. He states that it was more about combining already established methods and designs that could be used within different circumstances, we did not establish a new innovation, as everything was based on current practices.

3. Can you tell a bit more about the standardisation that has been applied for the tender of the N18?
    a. Considering the product (show the drawings of the N261)
        - Which elements have been standardised?
        - How is decided and/or indicated which elements/components should be standardised?

Within the N18, the most priority was given to make use of the repetition that occurs. There we did a lot of similar thinks, and we wanted to develop a design that benefitted these occurring repetitions.
Leon Hendriks state that the vision here was, that when we would completely develop each object individually this will take a lot of time, and the production and construction on the site will be expensive, will take a longer time period for the design and construction and overall the project will be more complex. In comparison, if we could build all the different objects from one main concept where you choose to apply different standards.

Leon Hendriks states that they first tried to standardise the beam heights and lengths. If this was not standardised, eventually we would end up with 24 different beams. We tried to bundle the objects considering their characteristic. For very bundle, which have been four eventually, trade-offs needed to be made of what good standard dimensions will be for the different objects. Also, considering the way the beams were connected to the other parts of the construction. These trade-offs were first mainly on price, however, the prices were based on old key features/indicators (kengetallen). Therefore, this was not representative for the project, and could not be used in this way.

A second attempted was to bundle all the different objects, considering their characteristics. Here we have identified four different groups, or as you can also say different "families". The idea was that only one specific object would be fully designed, so fully detailed. These then would be a representation of that group, and within the tender, these were used as a reference. By this, we could easily make an estimation of the budget, of how much the project will cost and in what time period the project could be established.

For the standardisation, we mostly focused on dimensions of the beams, the end beams, the upstand, the parapets, the elements for the finishing of the design (randelementen), and also other architectonic details. There we had the goal of developing one detail, which could be used for all the different object. Leon Hendriks states that only if you had really good and specific arguments, you could differ from the standard details, but this is not desirable.

    b. Considering the process
        - Referring to the tender phase
        - Referring to how the project should have been established? How was the process designed?

One of the thinks that we experience within the tender, that the different members of the project team needed to be convinced that the eventually the total project will become less expensive when you apply certain standards. However, different project team members pointed out, that absolute, a specific object would be more expensive if we use a standard beam. They argued that the standard beam is over-dimensioned, and by this will be more expensive than when we apply a beam that should be sufficient for that specific situation. However, Leon Hendriks points out that making use of repetition that occurs within the project will eventually lead to a less expensive project. He stated that a different way of calculation for the different objects was needed. The old numbers were not applicable on the standardised designs. Otherwise, we would always conclude that making objects more standardised will result in higher costs, but this is not the case as we can use the repetition that occurs. However, no data is available for what the costs are, as we have not done this before. Therefore, it hard to make trade-offs and argue and explain why we chose this specific approach/method/product.

Considering the project planning, the project could be finished 1,5 years earlier than what the client required. The researcher asks if Leon Hendriks thinks, that by using use of the repletion, the project planning was shorter than initially was required by the client. Leon Hendriks states that this had influence, of course. But also a lot of other factors have a role in this. The researcher, therefore, asked if a learning curve will result in a faster building process. Leon Hendriks states that this influence was limited. Something that did affect the planning was that permits needed. In general, we can state that you mostly can start building the road, but not yet the objects, as more permits for these objects is needed in comparison to the road. Within the N18, the project team tried to make a planning were the actual construction of the objects would not be dominant for the planning. They made a planning were all the objects needed to be built within one month. This could be done, but we had to make some concessions.

The researcher asked if within this tender there already was cooperation/ communication with suppliers in the beginning of the design phases. As the project of the N261, was used as a reference for the tender, here they did involve the suppliers from the start of the project. Leon Hendriks state that they involved the suppliers in an early phase. He points out that this is important because they have more specialist knowledge about their product, more than we have. They have done this before, and have a lot of experience. Involving the suppliers is not something we do in every project, this is a new approach. Within the tender of the N18, we involved the suppliers of the prefabricated parts and the supplier of the steel structure, already early in the project. Leon Hendriks thinks eventually this could have great benefits. Hereby, he gives an example of the N18, here the suppliers pointed out to them that if you want do make the current design (vormgeving), it will mean that the edge beams will be high. In order then, to make it one structure, the other beams will be needed to become bigger as well. This is not preferable, as it results in high costs. This is something we did not think of in that way. The supplier made us aware that this will be an issue when you would go to the actual building of the design. Therefore, we have adapted the shape of our edge beam.

In addition, Leon Hendriks states that he thinks considering the design (vormgeving) of a viaduct, this would also need to be reviewed in the first phases of the project. He thinks it is possible and important to work in a more project-exceed way. By analyse and develop a simple connection between the different elements, which can be used in more projects. The concept design will then be the same, referring to that the inside of the structure will be a standard concept and the outside, the railings etc., can be different. But the way of connecting the inside structure with the outside should be the same. However, the outside can be made specific for each phase. By this, the object still has a unique appearance but is made out of standardised components. Leon Hendriks states, and agrees with the researcher, that this could be very efficient. He believes in the concept that has been put forward by the researcher, by nailing down how components should connect to each other (interface is standardised).Leon Hendriks here refers to a project he is currently working on, for sound barriers around roads. Here RWS had developed one standard concept, and have made several options where can be chosen from, however, they are all within the standard concept. For this project, Leon Hendriks had an appointment with a supplier of steel elements, and there they also made certain steel finishing railings for viaducts. They had a concept that was totally worked out and optimised. When they go a new client, that of course wants to have a different design, they then used their concept as a starting point and developed a steal finishing railing that would fit the concept structure. So in all their projects, they work from the standard concept and used the same way of connecting the parts. Leon Hendriks thinks this is also possible for viaducts, but states that currently the designers are not aware of this/do not apply this way of working.

4. **It has been pointed out that the current specification of the requirements of RWS are still too specific, this results in a limited amount of freedom in design although the requirements are made functional. Do you agree with the opinion that the requirements of RWS are still too specific, and therefore limited room for innovation occurs?**
   Leon Hendriks states that the requirements are mostly functional, and in addition, you always see the same design trends. Currently, the client presents an ambition for the new structure, and we as BAM than have to make a translation to an actual design. If we would have a lot of freedom, then it is possible to apply the standard concept and only make the design of the outside element(vormgeving) special for the project. Referring to standardisation on the inside and standardisation of the connection. By this, it is still possible to personalise the structure.

   Leon Hendriks also refers to the W&R concept. Here they also make use of a standard concept. When a certain idea does not match with the standard concept, then they will have to make the choose to develop this design not based on the standardised concept, but the design need to be made from scratch, as it has to fit the unique situation. Again focussing on a viaduct, the project that suitable to be designed from the standard concept, here the standard concept needs to be applied. Here the architect is given the freedom in design, as long as he develops a design that is in line with the standard concept. If the architect of the client is not prepared to do so, also fine, but this means we have to develop the total design from scratch and do not have the benefits of repetition. This will result in longer and more expensive design phase, production phase and construction phase.

5. **How much freedom in design was there for the Tender of the N18, considering the specified requirements ("uitvraag") of RWS? And how did the "omgevingsplan" affect the design? (Considering how a viaduct looks, it could not be chosen anymore by the structural engineer to not make use of a column in the middle of the structure, as this had already be nailed down in the drawings of the "omgevingsplan")**

   Although RWS tries to specify their requirements in a functional way, they are also limited in their specification. This because they also have to meet certain requirements of organisations as: "welstandcommisies", municipalities and provinces. Leon Hendriks suggested it would be good if RWS cooperate more with the designers and the structural engineers, to be aware of what is possible and what the effect are of certain design choices. They then can discuss the opinion of the designers and structural engineers with the other parties. This feedback will be very efficient.
   Leon Hendriks, however, is still of the opinion that an aesthetic program of requirements contributes to the overall project. But thinks it is important that sufficient dialogue takes place between the different parties. This is hard considering the current procurement procedure, but it could result in a more effective process, and eventually the design will fit the requirements of the client, as the client is involved in the trade-offs and the certain decisions that are taken considering the design. It is hereby pointed out that when the standard concept has to be used, only once we use the concept as are main starting-point and do not changes this standard, only then a project can be delivered for a relatively low price.

6. **As I have understood correctly is the N261 has been used as a reference for the N18.**
   - What are the concepts of the N261 that have been applied in the design of the N18(Tender)
   - Are their also details that have been copied, or have been used as a reference and are only adapted on certain points?

   Considering the details, the details of the N261 were not exactly copied, but they were of course used as a reference. The approach of how we established the project, which steps did we take, was almost exactly the same as for the N261. We also have identified different families and have bounded these and applied a standard for the different families. Here, we have been looking for an optimum, a concept that could be used within all the objects, but still could be variable on a certain level. In addition, the cost estimation was calculated in the same way as in the N261. The cost per square meter of a viaduct, for example, was translated from the N261 to the situation of the tender.
   - Within the tender, Kitting Lee stated that you have made use of the same supplier of prefabricated parts as with the N261, namely RomeinBeton. Did co-production take place?
   Leon Hendriks state that is correct. For the N18 the same suppliers were approach and co-production have taken place. As we already had meetings in an early phase of the tender. Unfortunately, the further development of the design was however not needed, as the contract was not awarded to us.

7. **As architects can change the reference model, do you consider that are is sufficient room for change, while still be able to benefit from the repetition that occurs? (Referring to the quotation of Henry Ford; "Any customer can have a car painted any colour that he wants so long as it is black.", economies of scale, learning curve and constant optimisation of product and process)**
   Leon Hendriks again refers to the W&R concept of BAM Housebuilding. He is of the opinion that a lot variation is possible, but this within the standard concept. Considering the design it has to be clear which elements are variable, and how much design freedom do we have for these elements, and which elements are not that flexible and which different options do we have considering these elements. When the ambitions for the design cannot be realised within the concept a new design will have to be developed.

   Considering BAM we first need to develop a standard. Here all the ambitions have to be analysed and need to be considered how these will fit within a standard concept. The standard still should remain flexible. Then it remains interesting for different clients. Here again, a trade-off will need to be made, considering the amount of freedom (flexibility) and the amount of standardisation.

8. **Do you think the development of configurator for different infrastructural objects is beneficial and/or applicable? Or are the situations to "unique", too much different circumstances, and are there still a lot of changes that are required and/ or design of new elements needed?**
   Leon Hendriks is of the opinion that this is realistic, this is something we will have to start working with in the future. He refers to the "click and construct" initiative of BAM Infra from around 10 years ago, something like that, only then fully developed also considering the details, would be ideal.

9. **Within the tender of the N18 does the design contain the application of new innovative materials?**
   Within the N18 no new materials have been used. We mainly made use of concrete, steel for the structure and aluminium for the finishing railing.

10. **I currently have the idea to work with other materials than the conventional concrete. And do you consider that it is possible and will be beneficial to use polystyrene (plastic) or Styrofoam (piepschuim) in combination with concrete for a viaduct?**
    Leon Hendriks does think this is possible and refers to composite bridges. But notes it will be hard to implement this new material. In the beginning, not a lot is known, considering this new material. Of course, the characteristics of the materials should be analysed, and tested needs to be done, to get a better idea of how the material reacts.

11. **The N18 mainly connects the different components/modules by using steel cables and joint by cement. Do you think it is possible to make use of a click system, instead of joining by the use of concrete (considering maintenance, adaptable to future demands, demountable)**
    Leon Hendriks states that we can always make the connections between the elements in a way that the components can be easily connected, and that in an easy way the maintenance can be done. That is all possible. Leon Hendriks, therefore, states that he thinks using bolts and nuts (bouten en moeren) is possible as well. He refers to a supplier of aluminium edge profiles (randelementen). This supplier has a lot of experience with these edge profiles. Within the fabrication hall also different test considering innovations were applied. Here they were working on developing a system that could be easily constructed. The different element (edge profiles) could just be hanged on a framework that was connected to beams of the deck. The different elements did not need to be firmed to this framework, they could just be hanged up, and no additional bolts and nuts were needed. This is an innovation that could be very useful and will have benefits considering the maintenance and ability to make the construction demountable. Here Leon Hendrik points out the currently we have a lot of different systems, were a lot of different system construction are designed to be able to connect certain elements. However, as these are different, this is not handy. Considering the example he has given he states that this supplier found a more easy way to make the required connection. This innovation changed that, and of course, this can also be possible for other elements of a viaduct.

12. **Modularization (development of a product platform, and using click-system) can be beneficial considering different aspect: maintenance, adaptability to future demands, and demountable of the construction. Do you share this opinion?**
    Leon Hendriks does think it is possible to design a viaduct that can be more easily adapted to changing circumstances. However, he does note that the developments go fast and, as also the standard concept will be developed further, so he questions if the new “Lego-blocks” will comply with the old blocks. But he does think it could be beneficial. Currently, it is already applied for maintenance and construction of demountable objects. The adaptability to future demands is also possible, but here still a shift will be needed. Nowadays, the most structures are demolished and a new viaduct is constructed, instead of your idea of adapting the construction.

13. **Within literature, different opinions about the implementation of industrialisation within the infrastructural sector can be found. What are, in your opinion, the main essential success factors for the implementation of a product platform? What do you consider to be essential for the successful implementation of a product platform for viaducts?**
    Leon Hendriks states the implementation of a product platform can be done in a relatively simple way. A standard design will need to be developed, and this has to be continually updated and further developed. It is important to have on shared goal considering the standard design. As there are no clear goals, and hereby no clear standard, everybody will go their own way. This makes it important that the standard is clearly documented. When you try to develop a standard, it is important to also verify the ideas and decision that have to be made with the other involved parties, for example, the “welstandcommisie”, RWS, different suppliers etc. In addition, it is important that you make use of already established materials/products/elements. Eventually, you will then have a well-tried, proven concept. This standard then can be used in the different situations. Leon Hendriks points out that currently, we do not have a standard, so we cannot say to our project team that they should work to this standard, there will also be excuses why they think a standard is not applicable for their current project. However, when there is a standard, no excuses are left.

    In addition, Leon Hendriks points out that an innovation is only a success if both parties, the client and structural engineer , want this innovation. They have to be open-minded considering this new innovation and need to see sufficient benefits. If the constructing firm has developed an innovation that the client does not want, or the other way around, the innovation will not be a success.

14. **Do you think it is possible for BAM Infra to choose one standard variant for the design of infrastructural objects can be chosen by the management? And then can be imposed by the management on the employees of BAM Infra to apply this standard, work with this standard as a starting point/ as a reference design.**
    Considering the viewpoint of Leon Hendriks, the actual implementation of a standard can be established in different ways. First is developing a standard design from scratch. The second could be that within the organisation you choose one project, for example, the N261, and further develop this design, making it more standard. Thirdly, considering the tender process, the tender team just have to choose between three standardise concepts of already established projects, and only small adaptation can be made. Eventually, the goals will be to combine these three concepts to one, but you have to start somewhere. However, Leon Hendricks does think this has to be 'forced', otherwise the employees of BAM will not change their current practices. The researcher then questions if he thinks her idea of dedicating a small project team to the development of a standard will be a good approach. Leon Hendriks thinks this will be a good approach and refers to the W&R concept. It is important that somebody is responsible for the concept, and that the concept will be further developed in a project exceeding way.

15. **Do you think the employees of BAM Infra are open for this new development of implementing a standard? As people are sceptical and do not like changes.**
    Leon Hendricks does think people will be open for the concept, but not all people. Every change proposed, will get critics and not everybody will be willing to cooperate. Therefore, it is important that you show how the concept could work. Leon Hendriks here refers to developing a standard concept that will be starting point, and by this convince the people that the working with a standard concept will be beneficial. Your team needs to also see potential in this new approach. The implementation of working with a standard will not be easy and it could help if the management of BAM Infra would impose the concept. But still, it is more important that the employees understand why the change is needed.

B.1.8 Interview 8

<u>Interview – Aad van der Horst – 26 May 2016</u>

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1. **What are your general thoughts on standardisation and modularization, by the implementation of a product platform? (referring to "legolisering")**
   Aad van der Horst stated that he has doubts about standardisation, but has no doubts about modularization. He is of the opinion that when there is a mechanism that regulates/organise the different modules, this can lead to the optimal solution. He thereby states that you can choose for a standard viaduct, but when we choose for that approach this will affect our organisation, as through away our flexibility. As we develop one standard. Choosing a standard is:
   a. Unequivocal (Eenduidig)
   b. The tender phase is simple.
   c. Within the realisation, you have a high repetition factor at your different projects, as every time the same viaduct will be constructed. Here you take a design that you have applied before as starting-point. And no surprises during the construction phase occur, as you are familiar with the design and the process.

   The repetition that occurs in design and construction, result in fewer costs. Aad van der Horst explains here that this standard viaduct can be very beneficial because it offers the possibility to build the viaduct for the lowest price and in a fast way. However, by choosing one standard, you will lose your flexibility to adjust/cope with different project-specific circumstances. And as you lose your flexibility, by this you also lose your creativity. This is the price you pay for choosing one standard.

   Aad van der Horst, states that he is not convinced about standardisation, although he does think it could be effective and possible to standardise processes. He states that he does believe in Modularity. But points out that then we have to have something that makes sure the combination of modules will be an optimum. This is very complicated and it is not likely that you will figure this out. Aad van der Horst implies that if you want to develop such mechanism, you will need to know how the different modules affect each other. When a delta in one of the models changes, what will this change in the other modules? Combining the different modules can result in 1) Less expensive (intrusive less expensive), 2) Or should result in an increase of the value for the client. As procurement is based on EMVI-criteria. The price vs quality ratio is essential. However, the point where the clients want extra attention for (EMVI-criteria), are not the same for different projects. The different criteria also result in a different optimal combination of modules/different optimal solutions.

   Aad van der Horst here points out that criteria can be having a limited amount of traffic-delay-hours. But Van der Horst highlights that it is not a synonym for building fast. He states that if we want to build fast, we can still choose different construction methods. But when the traffic-delay-hours are important, it could be interesting to apply a construction method that does not require lifting from the existing road. He states that this could be developing the viaduct from the abutment, and jack a prefabricated/constructed module in place. Hereby the road underneath can keep functioning. As a reflection of what the researcher has pointed out, considering a product platform, to optimise and innovate. He asks the question if a product platform will help the optimisation and innovation. Optimisation can be different for the different projects. He points out that it is important to give the definition of optimisation. Aad van der Horst points out that this can even mean that a standardise solution, is not considered optimal for the specific circumstances. But that a totally different solution will be optimal. Procurement is based on lowest price, in combination with the specific EMVI-criteria. These criteria represent, what the client thinks is optimal. But this collides (wringd) with a standard product. But standardising the processes can be applied.

Aad van der Horst states that he believes in modules, referring to the combining of the different modules to form one whole. And to be able to choose the combination of the modules, so that an optimum can be established for the specific circumstances and the specific contract circumstances. But this makes modularity very complex, as the specific contract circumstances; vary from cheapest to optimisation of the value. However, a standard process will be one of the first things you will consider, this process can be taken into consideration when combining the modules. It is important to choose a motive. You can develop a module for fast building time or a module for minimal traffic-hindrance-hours or a module for less CO_2. It is important to do an analysis, to get to know the motive.

Within the tender phase, there are two strategies to choose from. In scenario 1, we know the solution and find alternatives on the way. During the design phases, we have to choose one alternative as we cannot work out all the different alternatives. We have to make a choice. In scenario 2, we do not know what the solution will be. Therefore we compare different alternatives. And eventually, make a combination of these different alternatives. Aad van der Horst hereby is of the opinion that for making a choice for a tender strategy and the future working out of the design, modularity can help. But he also highlights that a standard process can help as well. He, therefore, thinks it would be a good idea to analyses the “uitvraag” (listed requirements), what are the characteristics of the project. Based on these requirements and characteristic a choice for a tender strategy then can be made.

The researcher asks if Aad van der Horst is of the opinion that process and products need to be aligned. He agrees but points out that a lot of variables are of influence on the process and the products. However, although we have to deal with a lot of differences, we can apply a guideline. Every situation is unique, but this does not mean we cannot choose a focus, as we can focus ourselves on the most plausible option. With the experience and analyses of the situation, we can make a choice in the beginning. We then do not have one standard viaduct but have multiple types that are suitable for the different type of circumstances. The process, of what to choose based on the characteristics can be standardised. Decision models can be made.

The researcher questions if the decision models that are developed within master thesis projects are eventually used within BAM Infra. Aad van der Horst states that not a lot is done with this. Here the human factor is crucial, as there is too much resistance of the employees. He gives an example about the development of a knowledge platform for excavations (bouwputten). The management is of the opinion that it should be possible to standardise the processes. However, in practice, this was difficult, as an agreement of what the best standard is had to be made. Everybody has his own motives and vision considering this standard. This makes it hard to make one agreement considering a standard, as everybody sees different chances.

Standardisation means in definition: limiting of flexibility. Aad van der Horst hereby points out that the main question is if under these different circumstances standardisation is feasible. Different modules will need to be developed that meet the listed requirements and the specific situation. Modularity is feasible, but then we have to apply a mechanism, to come to the optimal solution. This mechanism can be evaded (omzeilen) by already work-out different designs that can be used as a starting-point. This is not totally modular, as different routes are pre-sorted. Different variable designs can be developed. Then product sheets can be developed. Considering the specified demand, we then can go through our product sheets to find a design that is the most suitable solution for that specific demand (wishes and requirements). Aad van der Horst thinks this is possible, but notes it is substantially different than when you make a viaduct modular, based on “de-component”-level. By this, the components can be combined and need to coincide together as a concept. Here a mechanism will be needed so that the right modules will be coupled.

Considering the development of the concept, it can be interesting to first analyse the specified demand. What are the characteristics of this demand? What is the focus of the client?
Analysing this for different specified demands, we will find a “line” within all the different specified demands. Certain characteristic will come back in the different specified demands. Based on the characteristics that come back all the time, we can make basic concepts that match these characteristics. When a new tender process starts, we then can question which concept that is developed already will best match the specified demand. A concept then has to be chosen but still can be changed/ adapted to the specific circumstances. This is a preselection of solutions, instead of fully developing a design out of modules.

The researcher questions if Aad van der Horst thinks that if we make a preselection of concepts where can choose from, this will be a good approach. He does think this could be a good approach but points out that he was convinced that if we know four different variables of the new viaduct (span, crossing angle, imposition and the traffic load), would be enough to come to one optimum, considering the estimated budget. A research has been conducted. Within this research, however, we did not succeed to develop/point out one optimal design. All the different project that were analysed, estimated in different ways. The available dataset was not sufficient to come to one univocal (eenduidig) standard. Aad van der Horst states that no solution was found, because every time there were different criteria's for the end design. He states that if we want to establish a limited amount of basic concept, we will have to look future

than just the characteristics. It has to be analysed how different choices are made, and hereby what is the definition of the optimal solution in this case. If we are aware of what the focus of the demand is, for example, initial costs, maintenance, sustainability (considering people, planet and profit) etc., we can combine modules together to form a concept. We then can make a spreadsheet and/or flowcharts, here the characteristics and the requirements are listed, and it can be easily seen which concept is suitable to use as a starting-point. Aad van der Horst points out that this can also be considered by reviewing the past. However, he doubts if there will be sufficient data available to come to conclusions, to find out what has been determinative.
When conducting an interview it is, therefore, important to ask critical questions. As, what is the definition of optimisation in this project, and what has been the criteria to concluded that this was the best solution? Additionally, we can ask which other alternatives have been reviewed, and why were these not chosen?

Aad van der Horst states that he thinks it will be hard to make conclusions based on the past, as the data is too general and not always available. If you want to draw conclusions by analysing the past, you will need to know for certain that the past is representable for the future. In addition, sufficient amount (N) will be needed to back up your conclusion.

2. How do you think new methods and/or techniques can be implemented.
As Aad van der Horst has already pointed out before, the employees of BAM are resistant to change. In order to implement the concept of modularization, a mind-shift will be needed. And the management team should fully support the new approach. The researcher hereby questions how the idea/concept of modularity can be implemented within BAM Infra. Aad van der Horst states that there has to be sufficient support from the employees. The concept first needs to be developed on the workplace and will need to be realised step by step. However, creating support is not always possible. It can mean that the proposed idea is not realistic or that people are not open to the new concept, as they stay with their own experiences. In a “normal” research you will have to come up with numbers (facts) to convince everybody. Aad van der Horst, points out that this can also work for implementing a new approach. If you show them the concept is possible, the people will also see this and start to believe in the concept. Demanding to work in a new way by the management team can help, but this is not something we do often, and still sufficient support for the concept is needed to implement the concept.

Aad van der Horst is of the opinion that the implementation of innovation should develop independently of the tenders and development of designs. The contract forms are too complex and too specific, to experiment with innovations. Based on established and current projects, we can identify and draw a conclusion about where the potential to innovate lays in the current market. We then should develop an innovation, and test this by a pilot.

3. Do you think an individual project team that is responsible for a new innovation, would be a good approach?
The researcher hereby explains here viewpoint, of a project team of four till five people that will work a year individual from the other projects within the organisation, to investigate and develop the concept. Aad van der Horst here refers to “Speeltuin”, a playground. He thinks this could be a good approach. Within BAM Infra, there now is one employee that manages the innovations within the organisation: Ad van ‘t Zelfde.
Aad van der Horst points out that if you want to design a new concept, it has to come from the current situation and the future circumstances. Just developing a new innovation without analysing the current situation and the future situation will not be successful.

4. Do you think the different provinces can make an agreement for their specific requirements, considering infrastructural objects? So that a reference object can be made, and a common interface can be developed.
The researcher here refers to the interview with Paul Waarts, as he is trying to create one demand for all provinces and municipalities. Aad van der Horst, thinks it would be fantastic if his idea could be realised. But thinks this will not happen in the coming years.

5. What do you consider as essential elements in order to successfully apply a product platform, with the use of standardisation and modularization in the infrastructural sector?
Aad van der Horst here states that if we want to apply the modularity, the contract forms should change. The current contract forms do not motivate to innovate. He points at the HSL. Here different tests were done, considering the foundation. The test results were very positive, and it was clear that applying this innovation could be very beneficial. However, eventually, RWS listed their requirements and even added a penalty description. This penalty description did not allow the new innovation. The risks for the contractors were too high, if they would construct the HSL and something goes wrong, they will be bankrupted. By this, the innovation was not applied, although this was a great change in the Netherlands. As an innovation is a substantial part of the project, then the risks for the contractor are too high. Aad van der Horst states that you then cannot take the gamble, the projects are too large and the contract conditions are too strict.
If we want to stimulate innovation, it is important to have a dialogue about reviewing what the impact/consequences will be for certain requirements listed and decisions made. Aad van der Horst hereby points out that the oil and gas

industry apply a procedure/contract that makes it possible to innovate. Here they agree on a certain relationship. Within the contract, specific arrangements are listed. This cooperation is based on a concept in the early stage. This allows the parties to work together, as this contract allows that things can be adjusted, however, conform to the contract. Here they can develop something together, within the agreed price range. Here less risk occurs for the structural engineer as well as the client.

6. What are your tips and tricks for the development and implementation of a product platform for viaducts? (What opportunities are there, and which difficulties do you consider?)
   In order to get more innovation with the application of modularity, a different procedure for the contract is needed. Considering the idea of Paul Waarts, the different parties are prepared to make one demand. However, there is a tension field between wanting to innovate and controlling the budget that is available. The public client, as RWS, cannot afford to procure in a broad way. For them, it has to be clear what the eventual costs will be. Therefore, this will stay limited to the innovation that offers sufficient added value.

7. What is your opinion considering the maturity of BIM, how does this can affect the implementation and working of a product platform.
   Currently, BAM Infra is not mature enough considering BIM to facilitate the concepts of standardisation and modularization. Aad van der Horst points out that there are two ways we can use BIM. It can be used for communication, as a tool for information management. And as a simulation tool to make chooses in tenders. But it is still difficult to create a mechanism for this in BIM.

   Modularity could eventually be implemented in BIM. Here the BIM-model will become an attribute that contains all the knowledge and experience of a design and its components. The ambition is that in 2020 all designs are designed with the use of BIM. This is mainly with the vision to use it as an information management tool. In 2020 we will not be ready to use BIM as a decision tool. If we want to use BIM as a knowledge tool that can simulate, referring to an attribute that contains all the knowledge and experience, the organisation has to have a higher level of maturity. Aad van der Horst thinks this will take around 5 till 10 years before BAM will be mature enough to use BIM as a knowledge tool with simulations. Everything has to be built into BIM, this will take some time. However, when we are further with this process, this will stimulate the application of a modular structure. Within projects, BAM Infra is currently already simulating different components, but here a lot of work still has to be done. The different components are not standard documented within BIM.
   Aad van der Horst points out that the coupling of calculations techniques (considering forces within and on the design) is also not yet developed within BAM Infra. BAM Infra is currently working on the development of a database for the cost calculation. But here we still have a long way to go, and this is complicated. If we want to use BIM as a calculation tool for the costs, we have to agree on to which abstraction level we want to use the calculations. If we want to apply BIM on a high detail level, then every little screw has to be put into the BIM-catalogues. However, the indirect costs cannot be implemented within BIM. The result is that we should make a cost estimation for all the different components. These estimations also need to contain the indirect costs. This is almost impossible. We can measure the amount of cubic meter concrete we have, but what this cubic meter actual cost is not unequivocally. This depends on different things, for example, the moulds that are needed, if the concrete is for an abutment or for a deck and which method is used etc. This makes an estimation of the costs very complex. If we want do the cost estimation in this way, we need to implement all this data in BIM. This is too complex, and not realistic to do. However, if we look at it from a high level of abstraction, we know the price per square meter of the different concept. Then this will make us able to compare the costs of the different option in a fast and effective way.

<u>Question focused on the design of a viaduct</u>

8. **I currently have the idea to work with other materials than the conventional concrete. Do you work with new innovative materials? For example composite.**
   Aad van der Horst points out that composite is a material that is already been used by BAM Infra. He is of the opinion that applying composite can be very beneficial. Currently, BAM Infra has applied this material in different small projects. We have to get experience with the material first on a small scale before we start to apply the new innovative material in all our projects. We are currently in the beginning of using composite. We do not know sufficient about how the material will change in time, and how it will react to different circumstances. Here a lot is still unknown. First, we need to control the material before we start using in on a broad scale.

   If we want to apply a new material, we first have to test the material. I will not get awarded the tender if I cannot prove that this new material will work. And second, when the contract is awarded, and I have not tested the material, I will not know what the exposure will be for the future.

   Steel and concrete are also a combination we currently apply. And Aad van der Horst things censoring, will make us able to think in terms of life-cycle, this is also an interesting development.

9. **Do you consider that it is possible and will be beneficial to use polystyrene (plastic) in combination with concrete for a viaduct? (this is an idea I currently have)**
   Aad van der Horst does think this is possible. But this first needs to be proven in theory and practice.

10. **Do you think it is possible to make use of a "click"-system for connecting the different elements? And do you think it is possible to not apply the joining of elements by the use of concrete (Maintenance, adaptable to future demands, demountable)**
    The researcher here refers to faster and easier building process, adaptability of the construction by changing circumstances (for example increase of the amount of traffic), maintenance and building demountable.
    Aad van der Horst states that around 50 years ago building demountable was a big hype. So this concept was applied in practices, but currently, we do not focus on this anymore. He points out that making a construction demountable conflict with the constructive performance of a structure and the different components. However, Aad van der Horst thinks that building demountable could become more important considering that sustainability is becoming more important. He thinks re-use of the different parts, combined with new information technology as censoring, has great potential. Considering a "click"-system and less joining by the use of concrete, Aad van der Horst state that he thinks the is a good critical view. But he points out that when you build something demountable, after several years this still has to be demountable. This means if you bolt the different elements of the structure together, then you will have to conserve these connections. This to make sure the bolts can be easily unscrewed, and no grinder is needed. Aad van der Horst hereby states that considering building demountable this has not reached a breakthrough, but is used for specific construction as temporary constructions.

B.1.9 Interview 9

Interview – Johan Bolhuis – 1 June 2016

General questions about the application of the principles of standardisation and modularization, and questions considering the Tunnel-alliances.

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1. **How long have you been the head of the department for Civil Design Regions, and can you explain what the work field contains?**
   Together with Chris van der Zwaard, Johan Bolhuis is responsible for the projects within their compartment. Together they manage around 50 people, mainly structural engineers and designers. Johan Bolhuis is here responsible for the different design regions. These are the relatively smaller project, until 30 million euros.

2. **What are your general thoughts on standardisation and modularization, by the implementation of a product platform? (referring to "legolisering")**
   Johan Bolhuis is optimistic about the concept. At his previous employer (Heijmans) Johan Bolhuis was involved in a project that had a goal to develop a standard viaduct that could be built in just four weeks. Johan Bolhuis, therefore, think it is possible to apply standardisation and modularization on the object, a viaduct. However, he states that "doorpakken" is needed. He states that a lot of researches considering this topic have been conducted. Most of these researchers concluded that applying standardisation and modularization is possible, and even fully specified designs are suggested. The next step is to implement this. BAM Infra has not applied this jet, but Johan Bolhuis also points out that the competition, referring to Heijmans, also has not implemented their standard viaduct.

   In the research of a standard viaduct that could be constructed in within four weeks, mostly prefabricated elements are applied. Johan Bolhuis states that design of that elements as the columns and deck are standard prefabricated elements. Even an abutment is prefabricated. The abutment is delivered in three parts, and these parts are combined by pouring concrete. The researcher hereby questions if he then thinks a prefab mould can be used, that eventually becomes part of the structure. Johan Bolhuis states this is the case in this standard design. The three elements, which consist out of the moulds and the reinforcement steel, will be transported to the site and connected. By pouring concrete we eventually get an abutment that is partly prefabricated and partly in-situ. This is applied by Heijmans for a viaduct by Culemborg, but BAM also has applied this, in the project for the Klaproosweg.

3. **Why do you think the concept of "legolisering", where this refers to the development of a product platform considering standardisation and modularization, is not applied on in infrastructural projects already?**
   Johan Bolhuis states that the client always wants something different. The standard will not match each situation. Considering the infrastructural sector, the way how products are purchased is different (market push vs market pull) in the infrastructural sector we do not just sell a product, we design a product that meets the requirements listed by the client. The client here is mainly RWS. If we want to apply the concept of standardisation and modularization, the requirements should become less specific.

   When there is more freedom for the contractors, a standard can be applied. This can be beneficial because the standard is fixed. This standard concept is applied within other projects before, therefore a learning curve is established. By working from this standard, constant optimisation of the concept is possible. Additionally, Johan Bolhuis points out that for the standard concept, the logistics are already worked out. Overall, the 'doorlooptijd' of the process will be shorter, than if we develop an individual design for each situation.

4. **Do you think the implementation of product platforms can be beneficial for BAM Infra? What do you consider as the main "power" of the use of a reference design that can be adapted to the specific situation? And what makes it successful?**
   Johan Bolhuis has a short answer to this namely: "Proven technology".

5. **What do you think is the end-goal for BAM Infra/ what is their vision, to apply standardisation and modularization through the implementation of a product platform?**
   (Faster design and building time, reduce failure costs, having more time left for other objects with the tender phase.)
   A Johan Bolhuis point out eventually everything is based on money. Johan Bolhuis hereby gives examples; the longer a road cannot be used, the more this will cost; learning curve will result in less failure + optimisation product and process, reducing costs.

   If we want to increase our profit, the more projects we do, the better. The more projects there are, the more tenders, resulting in the procurement of the contract, resulting in more revenue, which eventually all comes done to making more money.

6. **Considering modularization, combining the different modules together, designing an optimum for the circumstances, the rules and the current contract forms is difficult.**
   This is on the lowest price or the most optimised value.

   What do you consider as a main focus for the optimisation? (CO2, minimal impediments)
   a. **General**
      In general, Johan Bolhuis, again points out that the costs are the focus. Everything is interrelated with the costs.
   b. **Tunnel alliance**
      Within the tunnel alliances, the focus was on the cheapest design. It is a Design and Build contract, here for BAM only considers the initial costs. They are only responsible for a guarantee period of 5 years. In addition Johan Bolhuis points out that the structures are made out of concrete, it is a combination of concrete and steel. Concrete is maintenance free, so Johan Bolhuis also thinks almost no maintenance will be needed.

7. **What is the definition of optimisation (through the application of a product platform) within your viewpoint? What have been the criteria to conclude that this was the best solution?**
   Within the tunnel alliances as stated before it is all about money. Johan Bolhuis also points out that ProRail already worked out what should be build. Here, almost non-freedom in design occurs for the contractor. Therefore, Johan Bolhuis states that his vision to work more standard. By making use of standard products and processes, the fewer mistakes will be made, resulting in fewer costs.

8. **How do you think new methods and/or techniques can be implemented.**
   a. **Within the current market**
      Within the tunnel alliances, we try to invest now, so that eventually we will benefit from these designs, as a lot of railway underpasses needed to be constructed. Johan Bolhuis thinks the current contract forms do not give sufficient freedom for innovation, as the risks for the construction firm are too high. Here he refers to the government vs the private market. In the private market, you can discuss options, however, when you work for the government you are bounded to certain rules. The tender has to be made public, and the procurement is based on EMVI. Johan Bolhuis states the clients are risk-minded, and specify everything to decrease their risks.

   b. **Within the company BAM Infra**
      Johan Bolhuis is of the opinion that the requirements should not be a contractual demand, but should function as guidelines. Otherwise, it is not possible to apply a standard. Within the tunnel alliances, we have standardised the process, and are constantly optimising. Currently, we mainly focus on having less 'waste", referring to the transfer of knowledge and experience for one project to the other project (reinventing the wheel).

      In addition Johan, Bolhuis thinks innovation is needed. But here the costs are also very important. We innovate, to stay ahead of our competitors within the market. This means we have to reduce our costs, offering the best solution for the best price (price vs quality, considering the EMVI-criteria). Johan Bolhuis is of the opinion that if you innovate, the other construction companies will copy this. If we would have a patent for our design, we would be ahead of the other construction firms, but this is not a realistic scenario, currently the procurement is based on lowest prices versus quality (EMVI).

9. **Do you think the different provinces can make an agreement for their specific requirements, considering infrastructural objects? So that a reference object can be made, and a common interface can be developed.**
   Johan Bolhuis is of the opinion that this will not happen. Not now, but also not in the nearby future.

10. **As architects can change the reference model, do you consider that there is sufficient room for change? Or less or more design freedom/ changes are needed in order to benefit from standardisation and modularization of the product platform concept?**
    Johan Bolhuis does think there is still sufficient room for change. He points out the currently the beams of the deck already have standardised shapes and measurements. This can also be applied to other parts of a viaduct. We just have to choose a standard, for example, have three types. He hereby notes that the more possibilities there are, also the more expensive the structures will be.

11. **Do you think the development of configurator for different infrastructural objects is beneficial and/or applicable? Or are the situations to "unique", too much different circumstances, and are there still a lot of changes that are required and/ or design of new elements needed?**
    The interviewee does think this is also suitable for different infrastructural objects. Johan Bolhuis here refers here to the "click and construct" bridge, a project from around 10 years ago. He highlights that although the situation is "unique", it is almost always possible to construct a design out of standard pre-fabricated parts. He is not concerned about the end-result as well, as still, a lot is possible considering the design. The edge elements can be completely different for the same standard design.

12. **Why do you think the initiatives that are already taken within BAM Infra have not been successful? For example the click and construct the bridge, the research for the development of a reference viaduct etc.**
    The W&R-concept of the housebuilding department of BAM is a good example of an initiative that is successful. However, this is a concept for the private market. The government is the client of infrastructural projects and the project is tendered. The list of requirements for the tenders are very specific. The requirements, therefore, do not give a lot of freedom in design. The contractor is limited by these requirements. Due to these regulations, it is almost not possible to innovate. The construction company just has to build what is listed in the requirements.
    In addition, Johan Bolhuis states the "click and construct" bridge was a good tool, but it was focused mainly on technique, and therefore eventually failed.

13. **What do you see as risks and/or barriers, as well as opportunities in the future market?**
    A risk Johan Bolhuis considers is: That the standard will not fit within the requirements listed in the tender. The researcher asked if he thinks it could be a risk that there will not be sufficient suppliers to deliver the pre-fabricated parts, or not sufficient heavy-lifting will be available. Johan Bolhuis does not see this as a risk, it maybe will take a while, but eventually the "market mechanism" will level this. Johan Bolhuis is clear about that he does not see this as a problem.
    Johan Bolhuis does point out that he thinks that the review committee (welstand commissie) can have significant influence. They can hold up the projects for a long time, sometimes this also means the project will not be developed. In addition, Johan Bolhuis thinks that the architect should be more aware of how to construct their design. He states that we need architecture with respect to the logistics of the building processes.

14. **What do you consider as essential elements in order to successfully apply a product platform, with the use of standardisation and modularization in the infrastructural sector?**
    The standardised model should be applicable in every situation. Here Johan Bolhuis refers to soil conditions and the situation of the surrounding area. He states that we should have only limited types. We should have one standard that we can change by parametric modelling and the way components connect should be fixed. Johan Bolhuis points out, in his opinion, a standard with different options will need to be developed. He states that everything is possible, but if you want something different than the standard can provide, you will have to pay a bit more.

    The researcher question if it would be an idea to already involve the client in the early design phase. Johan Bolhuis thinks this would be very beneficial. But within the current regulations, this is not possible. Working together with the client is not legal. (concurrentie vervalsing).

15. **What are your tips and tricks for the development and implementation of a product platform for viaducts? (what opportunities are there, and which difficulties do you consider?)**
    First, a budget needs to be made available. And the approach needs to be promoted within the company. The employees need to be motivated and should share the goal. Then we still have the uncertainty that the new approach will not be taken up by the current market. It is, therefore, important to have sufficient support within your own organisation, as support from other stakeholders in the market.

16. **What is your opinion considering the maturity of BIM, how does this can affect the implementation and working of a product platform.**
BAM is not ready for this. Johan Bolhuis estimates that in 2018, BAM will have the maturity of BIM that will be high enough to facilitate a product platform. BAM is currently working on applying and implementing BIM within all their practices. BAM already make use of the coupling between different models, but there still is a lot of room for improvement. Currently, BAM Infra does not go further than 4D (schedule), but we want to go to 5D (costs) and eventually 6D (assets management /maintenance).

Question focused on the design of a viaduct

17. **I currently have the idea to work with other materials than the conventional concrete. Do you work with new innovative materials? For example composite.**
Johan Bolhuis states that composite is indeed an innovative material. We already make use of this material in combination with concrete (vezel versterkte kunststoffen), within different projects. He refers to an Eco duct, at the Grebbelberg. Composite is very sustainable (will stay functioning for many years). And it is very light weighted. The total construction, therefore, can be dimensioned lighter than when only concrete is applied.

    For most projects working with this new material is too expensive, and as the projects are procured based on price. However, EMVI has changed this situation. When there an EMVI criteria that can be scored on, by applying composite, it becomes interesting for the construction firm to consider this.

18. **Do you consider that it is possible and will be beneficial to use Styrofoam (piepschuim) in combination with concrete for a viaduct?**
Johan Bolhuis thinks that is a good idea and is familiar with the flour that is constructed out of styrofoam and concrete for utilisation buildings. However, points out that we currently do not know enough about this method. And therefore do not know how the material will react. We cannot give a guarantee. Johan Bolhuis states that he has once analysed if a “bubble-flour” (bollenvloer) could be possible for a viaduct, referring to weight savings. But this was too expensive, as we could only apply this one time because the next contracts did not wanted these new decks.

19. **Do you think it is possible to make use of a “click”-system for connecting the different elements? And what is your viewpoint considering a “click”-system? Do you think it is possible to not apply the joining of elements by the use of concrete (Maintenance, adaptable to future demands, demountable)**
Johan Bolhuis thinks it is possible but is of the opinion that this is too expensive. Maybe that eventually, considering the total life cycle, applying a click-system can be cheaper than our current practices. But the initial costs, to start working this way, are very high. The client (RWS) should specify this, otherwise, the construction industry will not see a need to develop a click-system.

    Considering making a viaduct demountable, Johan Bolhuis thinks that a click-system could make this process easier. And thinks the different components of the viaduct can be re-used for a new structure. The researchers point out to Johan Bolhuis that the system needs to be developed in a way that the click-system still can easily be disconnected. In the situation of bolts and screws, this can be a problem, as these connections are affected by the weather conditions. Johan Bolhuis does not think this is a problem, as these bolts and screws can be replaced every 25 years (maintenance period). Additionally, Johan Bolhuis points out that he thinks adapting a viaduct to the new circumstances, for example, weighting the deck, is possible. He states that this is already applied, here a trade-off is made considering if the existing structure has to be demolished and a new viaduct has to be build, or if the viaduct can be partly used and expended. Johan Bolhuis states that the expansion of a viaduct is mostly not a problem (increase spreading of the current structure)

    To concluded Johan Bolhuis again points out that this is something the client will need to specify. A viaduct is designed for around 100 years. The person who builds it right now is not concerned with how we should deconstruct the structure in 100 years. They are of the opinion that a lot of changes in the market will appear as technology is developed further, you cannot know what the future will bring. They consider their current situation and go for the situation that will result in the highest profit.

B.1.10 Interview 10

Interview – Ad van 't Zelfde – 20 June 2016
Function: Advisor Innovation - BAM Infra consult

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Introduction

Ad van 't Zelfde first asked the researcher about what the topic of your research, and how are you going to approach this? The researcher explains here research field. Ad van 't Zelfde finds it an interesting topic, and mainly considers the coupling relationships as an interesting way to analyse standardisation and modularity. He thinks it will indeed give a good insight in how different components interact and have an influence on each other.

1. **Your function is advisor innovation, within BAM Infra consult. Can you shortly introduce/explain what your work field contains? (What are you working on currently, tasks, responsibilities)**

Ad van 't Zelfde explains that his work field revolves around innovation of BAM Infra. By this he states that he is involved in the innovation from inside the company towards the market, the innovations from the market to the company, innovations from departments of the companies to other departments of the company, the trends occurring in the market and he also meetings with clients about the innovation policy and with suppliers considering their new innovations.

2. **What are your thoughts on standardisation and modularization, by the implementation of a product platform in general? (Referring to "legolisering").**

Ad van 't Zelfde states the projects and constructions that BAM build are 80% standard. The materialisation and how projects are realised is standard. It is important for the standard products and processes to optimise. Ad van 't Zelfde points out that this has to be done within different boundary conditions. The perception of the construction industry is not that far yet. Ad van 't Zelfde state that he things industrialisation has great potential for the construction industry. The costs can decrease, different parties can develop certain ideas and concepts further, optimisation of the product and process occurs due to the learning curve. By this we will eventually have more time left to focus on the other important areas of a project, referring to the influence of time, costs, sustainability and planning etc. Ad van 't Zelfde states that it is strange that we are not working in this way currently. It cannot be stated that it is not possible. The shipbuilding industry has adopted the idea of standardisation and modularity around twenty years ago. For BAM Infra it should be possible as well.

3. **Do you think the different parties could increase their efficiency by implementing a product platform? Do you think the implementation of product platforms can be beneficial for BAM Infra?** (As continual optimisation and innovation is facilitated/ easier to establish by application of a platform)
   Ad van 't Zelfde immediately responses that this is possible. He states that some years ago he has made a comparison between an object that you construct 5 times separately, and the costs for the objects when you construct the five objects after each other. In the first approach, all objects will cost the same. In the second approach, due to reuse of the design and planning from the first object significant time and money can be saved. Additionally, a learning curve will be established and the object will be continually optimised. The outcome of the comparison was that when the objects were constructed after each other, there was a significant decrease of costs. The fifth object was 30% less expensive than the objects that were constructed individually.

4. **Why do you think the concept of "legolisering", where this refers to the development of a product platform considering standardisation and modularization, is not applied in infrastructural projects already?**

This is because of the current viewpoint within the industry. The industry is very conservative. When we want to implement the principles of standardisation and modularity a mind-shift is needed. In addition, within BAM Infra it was not possible to work project-exceeding and together innovate. The total company was divided into departments: BAM Regions, which all had their own responsibilities and therefore designed their own constructions not considering the practices of other departments. The knowledge and lessons learned were not shared between the departments. Ad van't Zelfde is of the

opinion that if you want to apply the principles of standardisation and modularity this means that the company and their processes must be organised in a different matter. The new way of working should facilitate the loop that occurs, referring to the learning curve and optimisation. However, when this loop does not occur, optimisation and hereby cost-reduction will not be established.
The researcher states that the organisation structure has changed, this gives opportunities. Ad van't Zelfde agrees but states that it has not changed, and still remains an issue. He does think the different parties within BAM should work together on this, as it is a great opportunity.

5. **What do you consider as the main "power" of the use of a reference design that can be adapted to the specific situation? And what makes it successful?**

The main power of a reference design is that it is already fully specified. Only some adaptations to the standard reference need to be made, to establish a design for a different location. This can save time and costs. Ad van't Zelfde states that therefore it is important to analyse the step and decisions made considering an object. Some steps that we take and decisions that we make are not based on analyses of the most optimal solution. We do not think about this, as we feel it is the best approach. However, if we would analyse certain decisions and steps, we will see that the way we currently design is a not always optimal and other possibilities maybe lead to a better result for lower costs.

6. **Do you consider that there is continuous improvement within the infrastructural sector? Does BAM works in a project exceeding manner?**

Ad van't Zelfde states, implicitly this is the case. This means learning takes place at the level of the individual employee, but this learning is not documented and transferred to the entire organisation. So we do learn, but this process is not optimal. Explicit, we are currently working on several projects within our new cost-leadership program, for example, the railway underpass. However, this is still in the first phase of the development.

And what do you think is the cause (knowledge is not transferred throughout the organisation), or what will be needed to work more project exceeding and establish a "better" learning-curve?

That the knowledge and experience of the employees are clearly documented and documents are available/ assessable for all the employees of BAM Infra.

7. **How do you think new methods and/or techniques can be implemented.**
    a. **How are innovations implemented currently? (process of implementation)**

Only a few innovations become project exceeding, but in general, an innovation stays within the project and is not transferred to a new project. Then we also have innovations, as the X-block, this is a completely new concept, with one goal. But the implementation of little innovations is more difficult. As long as nobody reviews the innovations before they start with the design, the innovation will not be applied in the new projects. The innovations then will not be optimised.

   b. **Within the company BAM Infra**

The ideal would be that we can constantly optimise. But currently, the employees are sceptical and see a lot of risks. It is important that we look at both the risks as the opportunities.

   c. **Within the current market (As the customer rather not have the risks of a new concept? And procurement is based on EMVI?)**

Here it is important that a good analysis has to be made. What is already applied and what does the client demand? The key here is to be flexible.

8. **Why do you think the initiatives that are already taken by different structural engineers have not been successful? For example the click and construct bridge, the research for the development of a reference viaduct etc.**

Ad van't Zelfde again highlights that this is again related to how the organisation is structured. Although process and technique have been fully elaborated, this does not mean the concept will be successful. A dedicated team is needed. The team should be aware of what goal they are working on. Ad van 't Zelfde states that if there are no clear boundary condition the team will not be able to come in the "loop" to develop the concept further and start using it in their current practices and optimise the concept. He highlights that when it is decided that we are going to focus on certain concept, it is important that we stick with this for a significant amount of time and consider the concept from the perspective of different disciplines. In addition, Ad van't Zelfde states that apparently currently there is now big driver to decrease costs. Otherwise, the initiatives would be developed further. The gap between the costs of the project and the incomes of the project apparently is not big enough at the moment. The need currently is too low.

In addition, Ad van 't Zelfde thinks the employees are not aware of the initiatives and new innovation. And states that you will always have people that are stubborn. They just want to do a project in their own way. Why the initiatives also are not taking future, is because the client has to specific requirements. Therefore, the solution space is limited, as it is bounded by the requirements. If the market would work different, referring to the situation where BAM Infra would offer a certain product, they would have more design space. But then you can raise the question if this will work in practice. Ad van 't Zelfde concludes with that the organisation cannot manage the freedom needed, and the client thinks given this freedom is too risky for them. Ad van 't Zelfde points out that BAM Infra always points at the client for why the new innovation or optimisation on the base of standardisation is not possible. The employees always have an excuse, why they are of the opinion that it is not possible. It is important that we look and approach the design of these projects, not considering the things that are not possible, but focus on the things that are possible in the current situation. Reviewing what elements are almost always the same in the different constructions. In addition, already have contact with the architect from the beginning of a project can highly contribute to this. Here he refers to having catalogues of different variations/options that can be chosen by the client would be ideal. The client could then just pick the option that suits them best. However, when the client wants something different this is also possible, but not with the standard design. Then a new design will have to be made, but this will be more expensive.

Ad van 't Zelfde states that the essence is that you have to be flexible. Of course, there are constraints, but this does not mean it is not possible.

9. **There is a tension field between product and process. How do you cope with this when a new innovation is established? (Product and process are interrelated)**

There is tension field between the product and the process. When BAM Infra wants to implement a new product innovation, this is possible. But when the product innovation also has a significant impact on the current process, this is much more complicated. This means that the innovations that currently are established within BAM Infra, are within the boundary conditions of the current way of how processes are organised. If we want to implement an innovation what will have a significant effect on the current working process, the way of working within the organisation has to change. Ad van 't Zelfde states than we are dealing with a different playground (speeltuin). By this, there will be more space/potential for innovation and optimisation.

<u>Question focused on the design of a viaduct</u>

10. **I currently have the idea to work with other materials than the conventional concrete. Do you work with new innovative materials? For example composite.**

Ad van 't Zelfde states that BAM Infra has worked with composite in some projects, however, there are risks considering composite. A lot is still unknown and we currently do not construct viaducts only out of composite as it cannot handle large forces that occur when the viaduct is smashed by a car. But he is of the opinion that it has potential and thinks it will be used more often in the future.

11. **Do you consider that it is possible and will be beneficial to use polystyrene (plastic) in combination with concrete for a viaduct? (this is an idea I currently have)**

Ad van 't Zelfde thinks a lot is possible. He states, "Why not?"
In addition, Ad van 't Zelfde points out that he sees a lot of possibilities in 3D-printing. But there are a lot of developments that could change the world.

12. **Do you think it is possible to make use of a "click"-system for connecting the different elements? And by this to not apply the joining of elements by the use of concrete (Maintenance, adaptable to future demands, demountable)**

Ad van 't Zelfde answers this question with: "Why not?" The researcher points out that currently, constructions are one stiff whole, due to the pouring of concrete.
Ad van 't Zelfde response to this is that this requires analysing the possibilities. He, as innovation manager, thinks it is a challenging question. He thinks it is possible. But there are more options to investigate. Here Ad van 't Zelfde points at making use of glue or using bolts, there are a lot of possibilities.

Ad van 't Zelfde states that three questions need to be asked: does the concept fit within the requirements, is it a good solution, and what is the benefit of using this concept?
However, he is of the opinion that making a structure adaptable and demountable is not something he sees happening in the coming period. We are already struggling with standardising the elements in our current way of working, also considering to deliver constructions that are adaptable and demountable will only make this process more complicated. We can only deal with all these different elements at the same time. In addition, he points out that a viaduct is an object that is constructed for 100 years. In 100 years a lot can happen, so there is a significant amount of uncertainty. It will also be more expensive, as the concept needs to be fully developed. The government will not be willing to pay for this.

Concluding questions

13. **What do you see as risks and/or barriers, as well as opportunities in the future market?**

Ad van 't Zelfde is of the opinion that the organisation BAM Infra is the biggest risk. He states that "We", referring to the organisation itself, are the biggest risk. This is because of our current view. We only see the problems that occur when we want to implement something new. And the current ways of working does not facilitate innovations. Ad van 't Zelfde is of the opinion that there are certain components/aspects of a viaduct where a standard could be developed as the client does not have to be involved in the decisions that need to be made about certain components/aspects.

14. **What do you consider as essential elements in order to successfully apply a product platform, with the use of standardisation and modularization in the infrastructural sector?**

Here Ad van 't Zelfde refers again to the previously asked question. The biggest risk are we, as the company BAM Infra. It is essential that we stick to our plan, and develop a concept into detail and then implement it in our current way of working. However, there will be resistance to this new innovation, therefore the implementation will not be easy. But we have to stick to our plan, be dedicated and not quit when things get hard.

The researcher states that she thinks that the sharing of data is also an essential element. Ad van 't Zelfde agrees but still thinks the current viewpoint of the employees of BAM Infra is the most limiting factor. They always have an excuse why the principles of standardisation and modularization cannot be applied.

15. **What are your tips and tricks for the development and implementation of a product platform for viaducts? (what opportunities are there, and which difficulties do you consider?)**

It is important that the employees of BAM Infra become aware of the benefits. The best thing you can do is analyse the costs and point out that your idea is economically more attractive, as it will decrease the costs. Your approach of the coupling relations of the different components is a good approach. Ad van 't Zelfde is of the opinion that the design of project/object has a very big influence on the development and construction. It is important that the architects and the design team are aware of what effect their decision will have, considering time, costs, quality etc. You will have to show the architect and the team that we can develop viaducts on lower costs. Therefore you should set up a program to develop your idea future. A group of employees (entity) needs to be appointed that investigates and develops the idea future. Someone has to take this responsibility. This team then becomes responsible for this goal.

Additionally, Ad van 't Zelfde states that the management team should be convinced that a new way of working is needed to establish a different innovation-loop. And they should obligate their employees to apply this new way of working. For example Ad van 't Zelfde points out that it will not work if the different Regions of BAM will still work individually. Then, they are still constantly "reinventing the wheel". It is important that when a viaduct needs to be constructed in a specific region, that the Region contacts the team that is responsible for viaducts. As they are the experts and will design these viaducts for a relatively low price. They can constantly improve their design, as they have to deal with more of the same structure: a viaduct. Here ad van 't Zelfde refers to "BAM Asphalt", this could be a good approach also for viaducts.

16. **What is your opinion considering the maturity of BIM, how does this can affect the implementation and working of a product platform.**

Ideally, BIM should become a knowledge carrier. Here Ad van 't Zelfde refers to the idea of the researcher to investigate the coupling relations. If the couplings relations are clear, we can make use of a BIM Library. However, it is important that the platform is flexible. As different circumstances and wishes of the client will occur. We do not want to build viaducts the way houses were built in the DDR.

Concluding remarks

17. **Do you have other tips, considering the implementation of a product platform for a viaduct? Documents I need to review or people to interview?**

Ad van 't Zelfde states that it is very important that the process and the product will have to be adapted and have to match. Currently, we are not reviewing the problem in a systematic way and we do not collect the data. Therefore, if you have no data, you also will not be able to prove your viewpoint. Everybody is right in this way. Therefore, you need prove. Ad van 't Zelfde thinks, therefore, this research will be very hard.

B.1.11 Interview 11

Interview – Liona Lim – 13 July 2016
Function: Specialist Business Development - BAM Infra consult bv

Personal Details

Title:	Specialist
Initials:	L

Company Information

Operating Company Name:	BAM Infraconsult bv
Working as:	Specialist
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Introduction
Liona Lim has started on the first of April as specialist business development at BAM Infra consult bv. Liona knows a lot about the company BAM Infra, as she is working there now for 3 months and has established here master thesis at BAM Infra consult. She, therefore, had the chance to analyse the practices of BAM from the sideline and now is experiencing how everything works in practice. The research topic she investigated was about the standardisation of processes. Here Liona Lim investigated how to implement a more standard way of working within the current way of working of BAM Infra. Here the theory of lean and agile are combined with scrum. After finishing here master thesis, she directly started to work for BAM Infra consult. The company created a new function for here, within their new program: Cost-leadership. Cost-leadership is a new initiative. The aim of this new initiative is to lower costs of the project by eliminating waste and optimise product and processes by increasing their efficiency.

1. **Your function is specialist business development, within BAM Infra consult. Can you shortly introduce/explain what your work field contains? (What are you working on currently, tasks, responsibilities)**
Liona Lim is specialist business development. Within this function, she supports the cost leadership program, by helping to find ways to reduce costs. This can be of any kind, considering very different projects. Liona Lim states that this comes down to that we create the circumstances for other people to be able to lower costs. For example, we analyse certain practices, arrange cost leadership sessions, or just connect the right people so that they together can make a plan to decrease the costs. Liona Lim explains that within BAM Infra there are four improvement programs, cost leadership is one of these programs. Within the cost leadership program, there are ten improvement projects. Within each of the projects, we analyse what we can do to decrease the costs. How can we change current practices, and start working in a more structured way? It has to be effective and has to decrease the costs.

2. **What are your thoughts on standardisation and modularization, by the implementation of a product platform in general? (Referring to "legolisering").**
Liona states that she thinks the concept of standardisation is great. As a client in this way will be more aware of where they are spending their money on. This is difficult in the infrastructural sector because in this way you will have to ask your client to think about the project in a different way. A platform would be very favourable for the contractors, but not for the client. It will, therefore, be hard to convince the client to cooperate with this new approach. The client does not experience the same benefits as the structural engineer . In the infrastructural sector, the projects are based on demands and wishes of the client. However, when we change this approach when you implement a product platform, the client one of a sudden has to explain and justify exactly where they spend their money on. Liona state: "We do not sell a bridge, we only provide an offer when there is already a request for a bridge, and also which requirements, demand and wishes of the client, need to be met. The researcher questions if hereby she means that the market-push versus market-pull will change. Liona agrees and states it will not be easy to shift to a more market-pushed approach.
3. **Do you think the different parties could increase their efficiency by implementing a product platform? Do you think the implementation of product platforms can be beneficial for BAM Infra?** (As continual optimisation and innovation is facilitated/ easier to establish by application of a platform)

   Liona Lim states she definitely thinks it could increase their efficiency. But points out that a viaduct is a difficult object to industrialise (as she refers to). A viaduct is a public work, the provinces and municipalities are the clients. They do not have the goal to make profit, and only build a viaduct once in 10 years. The whole idea of industrialisation revolves around the repetition, however for the province and a municipality there is not sufficient repetition for them to benefit from, as they can only spend their money once. The learning curve is not important for them. However, this does not mean that a platform is not a good approach for large constructions works. Liona refers to windmill parks, which is a commercial market, with private clients. These private clients will be more tended to establish a platform than public parties.

The researcher explains that she agrees with the viewpoint of the interviewee. But explains that she also has spoken to people of the province of the North of the Netherlands, and they are of the opinion it has potential for the infrastructural sector as well. They are currently focusing on functional requirements, this is a first step in the direction to industrialise. Aside from the functional requirements, there are also a lot of norms and regulations that limit the solution space. But the main problem lays in the aesthetic requirements document. Liona Lim agrees and states she is very frustrated about this. Although the provinces state that they work with functional requirements and that by this the construction companies have a lot of freedom, this is not true. The aesthetic requirements document is still a leading document and puts further constraints on the design of the project.

4. Why do you think the concept of "legolisering", where this refers to the development of a product platform considering standardisation and modularization, is not applied in infrastructural projects already?
   Liona Lim considers three main reasons why standardisation and modularization are not applied within the infrastructural sector:
   a. *People do not see the benefits that the industrialisation can bring and mainly think about the negative aspects.* Liona is of the opinion that this also has to do with how the construction industry functioned before. People in the industry were used to work with the RAW approach and try to make more profit by deviations and extra work.
   b. *The maturity of the new contract forms: people within the industry still have to get used to this new way of working.* Liona highlights that people have to go through the learning circle. When we do something for the first time, it is logical things will go wrong, but we have to learn from these mistakes and take them to the next project.
   c. *The client does not have an "open-minded" view.*
      Liona here refers to ProRail, as she currently is working on the tunnel alliances within the cost leadership program. ProRail here is the client, but they again also have the municipalities as clients. ProRail started the project with the vision that they wanted to standardise, but at the same time, there are already so many requirements and rules that the solution space is limited. This makes it almost impossible for BAM Infra to develop a design. In addition, it even is more complex, as within every project they design also has to conform the requirement the specific municipality demands. Liona highlights that this is a very strange situation. During the course Legal and Governance, that she had to do for her master degree, she learned that within a Design and Construct contract the contractors had to bear the risks, as the client is not allowed to be involved in the design. However, in this case, ProRail has already delimited the design. Although they provide functional requirements, they also have a lot of technical and aesthetic requirements that are also binding.

   Liona points out that she does not know how the ideal approach should look like. In her opinion, it would be great if all stakeholders could be involved at the beginning of the design project. However, currently, this is not possible as it is not legal to have conversations with the client in the procurement phase.

5. What do you consider as the main "power" of the use of a reference design that can be adapted to the specific situation? And what makes it successful?

Liona states that see thinks creating a reference is not a good approach, as each situation is different, not one design will fit all the different circumstances. The researcher here elaborates and explains the application of the principles of standardisation and modularization and where the theory comes from. And explains that establishing a product platform, which in the core has one main reference design, has to seen as a product that has basic and different add-ons can be put on this basis to expand the functions of the product. Different types of components are compatible or interchangeable with each other, as their interfaces are standardised. The idea is that you can take construction apart, and can put it back together so that it still functions properly. Or the different modular components can be used in another structure that has the same interface. The researcher here refers to the Pax- closet of the IKEA. Considering this point of view Liona thinks it has great potential. She states that the reference design should be based on As-Built documentation of different successful projects, so based on best practices. It is important that as-build documents are used for the design, as they can differ from the drawing of the definitive design. Once we have a reference, we can then adapt this reference to the situation occurring. Means, we only have to deal with the deltas, only adapting deviations. This means you do not have to do design everything from scratch again but can use already applied/proven practices.

6. **The ideal situation would be if we would develop a configurator. Do you think the development of configurator for different infrastructural objects is beneficial and/or applicable?** (Only have to define parameters, and rate the importance of different aspects as sustainability, building time, hindrance, safety etc.).
Liona Lim thinks that a configurator is not a good approach considering the market of the infrastructural sector. The public sector is not ready to choose from a catalogue. And points out that a product platform for the whole infrastructural market is not of the interest of BAM Infra. The researcher agrees and explains that here idea is to develop a configurator for within the company itself. A configurator tool that can be used by the employees of BAM Infra. The employees have to fill in certain characteristics of the location of the to-be-designed structure and other parameters that the structure should conform to. Referring to a viaduct ,for example, have to put in the local circumstances as a type of soil, the length of the span needed etc. And the employees have to give weight factors to the aspects of the viaduct they consider their importance. Within the regions of BAM, delivering the project for the lowest price will be the most important criteria. For the large projects, the lowest price will be important, but also the EMVI-criteria's. By making these choices, the configurator will provide an outcome of the most optimal design for that specific situation. Liona Lim states that, if possible, it would be great. However, she notes that this program will be very complex and will have to be updated all the time as the market is constantly changing.

The researcher explains that it will be hard to find a standard and to identify the best solution for different circumstances. There is no clear documentation about why certain choices are made within the different projects. Therefore, the coupling relationships will be investigated, and the researcher thinks the advice to BAM Infra will be that they need to start labelling their projects and documenting their choices. Knowledge management is important and will be essential if BAM Infra wants to improve their current practice. Liona Lim responses to this by pointing at data-mining. Data-mining is what is needed. And this in combination with BIM would be needed for the development of a configurator that takes everything into consideration. The researcher agrees.

7. **Within your thesis, you describe six criteria that a standard concept has to conform with to be successful. Can you explain these criteria briefly? And how did you identify these criteria?**

The activities' characteristics are set in a fragmented structure, one-of-a-kind production, on-site production and temporary project teams. Furthermore, it is not clear at the beginning what the outcome of a standard concept will be. This has resulted into six criteria which are as follows:

o *Continuous improving processes* (Perminova, Gustafsson, & Wikström, 2008).
This means the concept should evolve with the time.

o *Use of standardisation where it is found suitable* (Giezen, 2012).
Do not apply standards for things that are not suitable. Sufficient repetition has to occur. And for the aspects/components were a high amount of repetition occur, the concept of standardisation will have to be applied, so that we do not have to do everything again (reinventing the wheel each time).

o *Functional project description and scope* (Van Goudzwaard, 2015) (Bertelsen, 2003).
There has to be sufficient freedom in design, otherwise, the project team will get stuck on the technical aspects. Too many requirements will make the design to complex.

o *Transparent information exchange* (Thiry & Deguire, 2007) (Davies, Gann, & Douglas, 2009).
Important that all members of the project team have asses to the different data and that this data can be a review in an efficient manner. The sharing of data should facilitate the communication within the team.

o *Redundancy, resilience and multiple alternatives* (Priemus, Bosch-Rekveldt, & Giezen, 2013).
A robust concept is needed. The concept should not be "star" (inflexible) but should be flexible, be able to be adapted to different situation.

o *Self-managing project teams* (Gann & Shalter, 2000).
The processes have to continue autonomously. This means the management team has to give order once, and then the approach will be adopted and taken further by the employees. This requires independence of the employees.

8. **Do you consider that there is continuous improvement within the infrastructural sector? Does BAM works in a project exceeding manner?**
Liona Lim states that this depends on, this is different for the different kind of people within the company. In the departments that are responsible for large projects, the people are more focused on performance and are constantly sharing their knowledge and experience. They already think further and try to learn from their practices. Here there people are challenged to design and deliver a project in a way to meets the client's demands and wishes. This also considers the EMVI-criteria. However, within the regions, the projects just have to be developed in a limited amount of time and on a tight budget, as procurement is on lowest price. These people, therefore, take a more practical approach and are more result-focused. Meaning they will every time apply the "proven" concept within all their projects. Liona states: "It just has to be done". They are not concerned with the optimisation when their current way

of working still is applicable. Liona points out the within the large project people question themselves, how do we do it currently, and how can we even become better? And within the region people question themselves, is how we currently work right or wrong? They do not think in terms of improvement.

9. **What do you think is the cause (knowledge is not transferred throughout the organisation), or what will be needed to work more project exceeding and establish a "better" learning-curve?** (that the knowledge and experience of the employees is clearly documented and documents are available/ assessable for all the employees of BAM Infra).

   Liona Lim is convinced that people want to improve, but this is not always possible. There is not always time to put effort in optimisation. People have certain responsibilities and have to spend their working hours on the projects they are responsible for. If an employee wants to optimise a certain process, this will demand time and effort. However the time is not always available, and the employees have to justify the hours they work. If they work on an optimisation that is not directly linked or is not only suitable for one project, there is no post to decelerate these hours to. In addition, Liona states that employees are not triggered to improve their practices, the rewording system does not trigger the people. Only in the larger project, the people are triggered because it is worth to be/pays of to be distinctive. Within regions it is only based on lowest price, there are no EMVI-criteria's, innovating here will result in higher costs and therefore is not an option.

10. **How do you think new methods and/or techniques can be implemented.**
    a. How are innovations implemented currently? (process of implementation)

   At first, Liona Lim points out that BAM Infra does innovate, for example with the development of asphalt. BAM Wegen (roads) is constantly innovating and is leading in their specific market. The way new ideas and innovations come together in the department BAM Wegen is also possible for the other departments of BAM Infra. Liona Lim hereby thinks it is important that the knowledge is transferred within the organisation, but also the way this is transferred is important. The researcher points out that she has talked to several people who worked on the new A4, two concrete tunnel structures had to be constructed. The first tunnel was made in a traditional manner. The second tunnel, however, was different and a new technique (innovation) was applied. After the finishing, it became clear that this innovation worked very well and solved a lot of issues that occur when the traditional method is used. At that moment people were very enthusiastic about the innovation. However, until now nobody has applied the innovation again. The researcher here thinks that the innovations are not been taken further, and BAM Infra here misses out on an idea that has a lot of potential. Liona Lim agrees and states that there are two thinks why innovations are not put through with. The innovation mostly stays within the project that it was designed for. This means the idea is not transferred to the organisation. And if people do not know about the new innovation, they will not apply it in their projects. And additionally, if people are aware of the new innovation, they will not always apply it. This is because the people have one goal: the project they are currently working on. They together have to make sure their projects are a success, and at that time the innovation does not matter. The researcher agrees and points out, the first time you will apply a new innovation it will be more expensive than when you would go for the known traditional approach. Only when the innovation is applied within more projects, eventually the cost will be lower than the traditional design. So, with view/pressure of winning a tender, there is no room for the application of this innovation. As this will result in higher costs, and the procurement is on mainly on price.

   Liona Lim points out that the way projects are organised also highly contribute to the fact that new ideas are not been taken further. The communication between the tender team and the team that eventually continues with the project when the project is awarded do not exchange sufficient knowledge, only limited communication between these teams occurs. As when a tender or project is finished the different members of the project team go to a new project. Here they do take the things they learned at their previous project with them, but the knowledge gained is not documented and transferred within the organisation. The knowledge stays with the employee itself.

   The researcher here states that a database would be useful, but this is not the solution. When a database is applied this does not mean employees will actually use this database to look at other projects. The researcher here questions how Lion thinks this problem can be solved. Liona Lim is of the opinion that first knowledge-groups need to be set up, to improve the transfer of gained insights. Cause the first step is that all people within the company get familiar with the new innovation in process or product. I people do not know about the innovation, then it will not be applied again.

11. **Why do you think the initiatives that are already taken by BAM Infra have not been successful? For example the click and construct bridge, the research for the development of a reference viaduct etc.**

   (Need to be flexible)

   Liona Lim states that already a lot has changed in comparison to when she started here master thesis at BAM Infra. The whole company was in reorganising at that time. A lot of people were dismissed and the total company has been restructured. In these times, meaning times where the company have difficulties to stay competitive, the management team has to choose where they want to put their money in. It is logical that the management team will put their money in practices that keep providing income. This means there is not money left for innovation programs, and they will put on hold. This is also what happened with the reference viaduct. But when there is sufficient time and money available, the ideas are not always put through. People are sceptical and see too many barriers. The researcher questions, why Liona thinks the click and construct initiative failed, as this has been fully worked out. Liona states that it is important that the innovation is reviewed within a broad perception. Here, she refers to the five piles, which are form the base for the concept of W&R. It is important that all these five pillars are considered, and applied within the new initiative. Within the tunnel alliances, where Liona is working on currently, they also take these five pillars as a base. Liona is of the opinion that only if these five pillars are realised in a concept, the concept will be a success. But this is not easy. The researcher states the currently the feedback loop of System Engineering is not applied or only applied limited, this has to change. Liona agrees and states that constantly evaluation is also an important factor in this total cycle.

12. **There is a tension field between product and process. How do you cope with this when a new innovation is established currently and what is your vision for the future. (Product and process are interrelated)**
    Liona states that it is important that people become aware that process and product cannot be considered independently, there are interrelated. In every project, both product and process need to be considered. How you approach these depends on what your driver is for this project. If these are developing a design with low costs, or if you want to establish an innovative design, these ask for different approaches. Therefore, it is important to think about what your drivers are before starting the project. And what in the process or in the product contribute to this driver.

<u>Question focused on the design of a viaduct</u>

13. **I currently have the idea to work with other materials than the conventional concrete. Do you work with new innovative materials? For example composite.**
    Liona Lim points at composite, this is concrete combined with polystyrenes (vezelversterkte kunststof). She knows BAM applies this for small bridges. But she does not really have other ideas about this.

14. **Do you consider that it can be beneficial/possible to use polystyrene (plastic) in combination with concrete for a viaduct? (this is an idea I currently have)**
    The response of Liona is; “Is that strong enough?” The researcher here explains that there have been tests with polystyrene (piepschuim) in combinations with concrete, to make beams. The outcome was that the combination was able to handle large forces. However, if we would like to apply this within out viaduct more research will be needed and thinks the regulations in the Netherlands will not allow this. Liona states that this is always difficult with innovations. A current innovation that is also now coming to the infrastructural industry is 3D-printing with polystyrene or concrete. She thinks this is a very promising innovation, and thinks it can have a big effect on the total construction industry, including the infrastructural sector. Liona here suggests that if you make a design in BIM, you can print it out, and transport it to the location needed. Ideal this would be if the construction would be light weighted for transport. Additionally, the work on the side will be reduced, and by this, a number of lost vehicle hours will also become small.

15. **Do you think it is possible to make use of a “click”-system for connecting the different elements? And by this to not apply the joining of elements by the use of concrete (Maintenance, adaptable to future demands, demountable)**
    Or make the moulds part of the structure. By prefabricating moulds made out of concrete, the form the outside shell of the construction. And finishes the structure on site by the pouring of concrete
    Liona thinks the ideas are all great, and if you really believe in something it is worth to investigate the idea and develop it future. However, as with all new and innovative ideas, it will clash with the requirements listed. For example in the tunnel alliances, it is already settled that the structure has to be made out of concrete, by this, no new and innovative materials can be applied, this is not conform to the listed requirements. In addition a new innovation demands an investment, however, for the first projects, this will mean a higher price or the organisation should be willing to contribute, with the idea that the third project will be much lower than the first. But this is a gamble. And you will always have to explain and justify the money you spent. If the innovation becomes a great success you will get promoted, but if the innovation fails you will maybe lose your job.

Concluding questions

16. **What do you see as risks and/or barriers, as well as opportunities in the future market?**

Liona thinks the biggest barrier is:

a. The client: How the client currently specifies to what requirements the design has conformed to. The constructions companies need more freedom in this.

The biggest risk is:

b. The uncertainty. When you start with something new, you will not know where it will eventually end up. There is no guarantee that the innovated idea will work and be a success. But a company needs to innovate, as it needs to adapt to the changing market conditions and new technologies. If BAM does not innovate, they will lack behind other construction companies. This will mean that eventually they will be out competed.

The biggest opportunities:

c. Other commercial markets: Here you can go to the client with a fully worked out design. This is the opposite of how we currently work in most of our project. However, the gravity based foundation is an example of where we are active on the more commercial market. But this is a completely different market compared to the market of a viaduct. Within the commercial market, the parties spent a lot of money on the project and eventually expect profit, therefore they are very willing to cooperate and think along with the constructing parties. Infrastructural projects are financed by the government, there are public projects. The governmental organisation need to consider all the different stakeholders, as they are spending public money, and need to justify all the choices they make to the public. In theory, it would be possible to establish a product platform for a viaduct, but in practice, this can be hard to establish. Currently, it already goes wrong on the most simple and stupid things. There are too many general interests that need to be considered. Liona here concludes that a product platform can be a great opportunity within the commercial market, but she is of the opinion that it is not suitable for the public market.

17. **What do you consider as essential elements in order to successfully apply a product platform, with the use of standardisation and modularization in the infrastructural sector?**

Liona thinks some elements are essential, such as:

a. The product platform must be visible for everybody. People need to be aware of the existence to the platform
b. The platform has to be easy and has to be open and accessible. Otherwise, people will not start to use the platform.
c. Technical the development has to be based on as-build documents. So that the optimisation is based on facts, not on estimations.

18. **What are your tips and tricks for the development and implementation of a product platform for viaducts? (What opportunities are there, and which difficulties do you consider?)**

Liona Lim thinks it is important that when you develop a product platform, you first need to talk with the people that are your target. You have to be very specific about what the problem is. A product platform is more a solution, but it is important that you find out what the actual problem behind this is. Is there a problem, or am I just making thinks nicer? Hereby Liona means that it is important that the problem that the client has is the main focus. A constant feedback loop here is needed. Here Liona refers to SCRUM. It is important that during a process you always check if you are still working on the problem and if your solution contributes to solving the problem

19. **What is your opinion considering the maturity of BIM, how does this can affect the implementation and working of a product platform.**

Leona here responses very quick, with: No. She does not think BIM is mature enough for the implementation of a product platform. She does believe in the idea. But the organisation is not ready for this. The researcher hereby points out that it is so hard to get access to data, that it is almost impossible for employees to review other projects. Liona agrees and states that this is why a general database will still take a long time. For the outsiders BAM is one company, however internally we still work in a fragmented manner as we are a combination of 40 different companies. However, we are working on that, to become one company. Eventually, it would be ideal if we would have one database that is clearly structured and is continually updated. But there is still a long way to go before we will reach this point.

B.1.12 Interview 12

Interview – Kees Quartel – 24 Augustus 2016
Works at Spanbeton (supplier of prefabricated concrete components)
Function: Head of sales department
Phone number: 06-22 97 52 35

<u>Introduction</u>
Kees Quartel is head of sales of the company Spanbeton. The researcher and Kees Quartel have met each other before. This was during an excursion to Spanbeton, arranged by the student association for civil engineering (Concept). This was a good change for the researcher to see how big the concrete components are, and how they are produced. Later on in the research, the researcher has asked Kees Quartel for an interview.

1. **Your current position on Spanbeton is head of the sales department and projects. Can you shortly introduce/explain what your work field contains? (What are you working on currently, tasks, responsibilities?)**
Kees Quartel is head of the sales department of Spanbeton, a supplier of prefabricated concrete components mainly for infrastructural objects. Not long ago the function of Kees Quartel was head of sales department and projects. This means Kees Quartel did the sales and also the project management of different projects. However, within the organisation, they decided that these functions needed to be split up, because the workload was too high and more specific attention to both processes were needed. Kees Quartel explains that he is responsible for the sales and by this bringing in new projects. In addition, his job is to make new and maintain old relationships and he is also closely involved in the establishment of innovations. The researcher here asks if Kees Quartel can explain a bit more about the kind of innovation. Kees Quartel explains that this is innovation on process, system or product- level. Innovations mostly originated from wish/demand of the client. These wishes and demands of the client are a starting point for generating new innovations. These wishes and demands are almost always project specific, but when we have developed these ideas further, mostly it appears that the concepts are applicable to other projects as well. It can, for example, function as a basic solution for different projects, becoming a new standard. Because the demand of the market is so closely related to the innovation, this is also part of my function. It is important that the demand, wishes and trends occurring are known by the designers and the resource and development team. Innovation alone is not a goal in itself; it is always a reaction to the current market. Because I have a close relation with the client, I am responsible for transferring the demands of the client towards the team of designers. Innovations cannot be considered separately from the demands of the market, they have a direct relation. Kees Quartel highlights that innovation requires cooperation with the client, Spanbeton is very client focussed as only together you can establish great things.

2. **What are your thoughts on standardisation and modularization, by the implementation of a product platform in general? (Referring to “legolisering”).**
Kees Quartel is of the opinion that “legolisering” is a great concept and a great way to apply a standard. The vision behind the concept is that as much as possible, current developed/designed standardised building blocks need to be applied when a new structure has to be developed. The new structure has to be made out of the standardised building blocks. However, Kees Quartel things also that this is the point where there is friction. Each viaduct is designed for a specific unique situation/surrounding. The standard building blocks need to be combined to develop a solution. This means that you will have to be able to adjust these building blocks, so a solution can be designed that fits within the specific circumstances. Here, Kees Quartel explains that in his opinion Spanbeton does not apply a standard, but applies three concepts (solid deck beams, inverted T- or I-beams, box beams), that are suitable for the different situations occurring. These three concepts are three standards concept, but when these concepts are applied to the different projects, the concepts are fully adjusted/fitted to the situation occurring. Kees Quartel here points out that he thinks this is the same idea of what the researcher calls: modularization. And refers to what the researcher said about standardising the interfaces, meaning standardising the way the different components are connected: modularization. Kees Quartel states that Spanbeton is trying to nail down how different components should be connected to each other for quite some period, and by this thinks they already make use of the principles of modularization.

3. **What are your thoughts on standardisation and modularization specifically for the infrastructural object; a viaduct.**
Kees Quartel does think the application of the principles of standardisation and modularization can be very beneficial for infrastructural projects. Standardising is not always the best strategy. However, applying three standard concepts is not full standardisation, as it still provides room for change and can be adjusted to fit the specific situation. Kees Quartel highlights that every infrastructural structure is unique, so just one standard will not work. We need to provide multiple options.

4. **Do you think the different parties could increase their efficiency by implementing a product platform? Do you think the implementation of product platforms can be beneficial for Spanbeton and BAM Infra?** (As continual optimisation and innovation is facilitated/ easier to establish by application of a platform)
   The researcher hereby points out that she had an interview with Paul Waarts. He works for the province of South-Holland and together with others in the infra sector he has launched a new initiative, a platform called Infra-innovation Network (Infra-Innovatie netwerk). Kees Quartel thinks it would be great if the different parties involved in a project would come to a more general list of requirements. The earlier all different parties are involved in the project, the more efficient this will be. The ideal would be if the designer is involved right from the start. In the current situation, a plan for the aesthetic appearance of the infrastructural structure is developed by the architect of the client. In this phase, no market parties are involved. When the market parties would be involved already at the beginning of the project, both parties can explain their point of view, the constraints and the effect of possible ideas can be discussed. This gives great insight for both parties, and together they can make trade-offs considering the specific project. Currently, this is a bottleneck, but when the different parties are involved early this can be avoided, and more accumulation (afstemming) about the different aspects and components of the structure can be agreed on already in the beginning.

5. **Why do you think the concept of "legolisering", where this refers to the development of a product platform considering standardisation and modularization, is not applied in infrastructural projects already?**
   Kees Quartel thinks BAM is currently in the same process as Spanbeton. Spanbeton is analysing the different components, tries to clearly document, make trade-offs, draw conclusions and nail down how the different components should connect. Three main solutions for prefabricated decks are: 1) Solid deck beams, 2) Inverted T-shaped or I-shaped beams, 3) Box beams. In a project, you have to choose between these three options. The options that you choose, means that directly you also make a choice for how the different elements are connected and form a stable whole. Here, three aspects are important: the connection between different elements/components, the bearings and the expansion joints.

   There are three main factors that influence the application of these three concepts, from the perspective of Spanbeton.
   a) *The Deck - demanded design*
      In a project the aesthetic appearance of the viaduct is important. Before the construction company is involved, the aesthetic appearance has already been nailed down and clearly documented. The construction company has to meet these demands and wishes of the client. The deck highly influences the appearance of a viaduct, and the client prefers a thin deck. One of three different concepts for the deck can be chosen, but still, adaptations will be required to meet the specific demands and to fit within the boundary conditions. Adaptation to the standard design of the concept needs to be made for the deck beams and the edge beams. Because the deck and the edge beams greatly contribute to the appearance of a viaduct, these are very client specific demands, and therefore are different in every project.
   b) *The substructure – demanded design*
      In addition to the design of the deck, also the wishes for the design of the substructure (columns, capping beam, wing walls etc.) influence the structure. The client wants an exciting and challenging design. And the complications that occur within the deck have to be solved within the substructure.
   c) *The connection between the abutment/bank seat with the total structure.*
      For the connection between the abutment/bank seat and the deck an increasing trends is currently that this connection has to be very tight. This is preferred by the architect, but Kees Quartel doubts if the architects are aware of the effect of their design choices. As this means that the standard details have to be adapted.

   To conclude, Kees Quartel states that the demands and wishes of the client, considering the aesthetic appearance of a viaduct, increase the tension field for the application of the three concepts.

6. **How do you think new methods and/or techniques can be implemented? (considering Spanbeton)**
   Kees Quartel explains that this is not something Spanbeton cannot establish on his own. Cooperation between the different parties involved is needed. Developing a platform can be the first step. This will give a clear signal to the other parties involved, that there should be awareness about the boundary condition present. If you want to develop viaducts in an economic and effective way, it is important that all parties are aware of the boundary conditions, make agreements with each other, but also stay within these boundaries. Therefore, in order to develop a good platform, the boundary conditions that are of influences need to be agreed on by the different parties involved and need to be clearly documented. Kees Quartel points out that for the design of the aesthetic appearance of the viaduct, this means that the designers need to be aware that they have a lot of freedom in design, but some boundary conditions are in place.
   In addition, it also will be great if the clients (Province, municipalities) could agree on one basis. And take this basis (list of basic requirements) as a starting point for all their projects. The different market parties can develop different building blocks and catalogues can be developed. The client can then choose from this catalogues. Kees Quartel states:

there are no other types or flavours the client can choose from. If they want something completely different this will not be based on the standard concepts. A unique solution needs to be designed, but this will also mean that the viaduct will be more expensive than when the standard concepts are applied.

Kees Quartel asked if the researcher is familiar with the “click and construct” initiative. The researcher is familiar with this initiative. It was an application where the client could easily put in their demands and the constraints of the specific situation in, for the constructing of a new small bridge in suburban areas. The program then made a design for the situation, based on standards available (catalogues). However, this initiative has not been successful. This had to do with the demands of the market, the fact that the initiative was still very abstract and the reorganisation that took place within BAM. Kees Quartel is of the opinion that something like this can be established for a viaduct as well. He hereby points at the idea of the researcher for a configurator and is convinced that this will work. And highlights that to establish this cooperation between the suppliers with the construction firms is needed.

7. What position should Spanbeton take considering the implementation of the principles of standardisation and modularization within concrete viaducts? How do you think that this can be established?
As supplier, Kees Quartel thinks it is important that the possibilities and the constraints of a project need to be clear. With this knowledge, the proposed configurator can be applied and has to be run- through in a logic way. At the beginning of a project a choice will have to be made, this by considering references, demands of the client and specific situations, location constraints and design aspects.

   Kees Quartel is convinced that developing a configurator for viaduct is very realistic. The different building blocks are already available. The requirements and boundary conditions need to be put into the configurator, and the configurator will do the rest of the work. The outcome of the configurator will then be a design, based on standard components. By this, the structural engineer will have more time for the more unique structures, and Spanbeton can specialise themselves in a specific area. It is important for market parties to distinguish themselves from their competitors.

8. Do you think more cooperation and together development of new concepts can be beneficial for both parties? (Innovation program)

   a. Are you open for this new approach? (Or is there nothing to win?)
   Yes, I am. We are already working like this with other big construction firms. It would be great if we could also do this with BAM Infra. But within BAM Infra the culture is still an obstacle.
   b. Do you think it is realistic, referring to the procurement and the awarding of the contract?
   Kees Quartel agrees there are some risks. But when two parties trust each other, this will not be a problem. Both parties are responsible, you are in it together. This is something all parties within the construction industry have to deal with; it is part of the construction market. We should cooperate with and think with the client. Otherwise, they will go to another company. There is a risk, but we are used to this risk, this is the same for BAM Infra. If BAM Infra does not invest in a tender, they will not be awarded the contract
   c. Will require a long-term relationship. This can be a risk, as the company will have to commit to one client and cannot share the innovative product developed with other clients. What is your opinion about this?
   Having cooperation with one company does not mean that you cannot also have cooperation with another company. Why should we focus on just one partner? It does not have to be so black and white is we just trust each other.
   d. Not sure if the together developed innovation will be a success. BAM Infra will get compensated for the work they have put in the tender. However, this will not be the case for Spanbeton.
   Kees Quartel states that Spanbeton currently also has to tender, this also gives risks. The effort you put in will not always be rewarded. This is the same for BAM Infra. But this does not mean we should not innovate together. By cooperating, we can even establish more.

In addition, Kees Quartel points out that you will always be dependent on the client, in this case, RWS. In addition, you have a lot of competitors. Every construction firm or supplier knows how to build a viaduct, and they will all be able to construct this structure for relatively the same price. Therefore, it is important to distinguish themselves from their competition. But a constant struggle is that something you have developed within a partnership cannot be applied for other clients as well. Because both parties will not be willing to share their innovation, that distinguishes them from the competition. However, in the current way the market works, referring to the procurement (“aanbestedingsprocedure”) the client will need to be informed about the innovation, this before the work is rewarded. This means these companies have to share their innovation, but the construction companies will not be willing to share their innovation. These innovations distinguish them from their competitors. Therefore, Kees Quartel thinks it is interesting to think about a market shift, as the researchers had put forward. A shift from current situation; market pull, towards market push. When the client can only choose from standard concepts, referring to market push, this will be economically very attractive. But Kees Quartel is of the opinion that involving market parties in this process is essential. Kees Quartel states, that if we do not cooperate and think with the client, we will not get work.

The current culture in the construction industry is very result oriented, and all parties try to postpone agreements with suppliers, so that they can benefit from a decrease in price due to the working of the market. However, although this is a good approach for an individual project, it is based on short-term thinking. We should consider the long-term. This means we have to trust and cooperate with different parties active in the market. Together we can improve our practices. But, trusting each other is essential.

9. Do you think that by working with a standardised interface (how different components are coupled is nailed down and clearly documented) it will become easier to improve and innovate components individually?
   Kees Quartel states that if we agree on a standard way how different components are connected, in theory it can become easier to improve and innovate. But it has to note that still the components that need to be connected have to be analysed. Independent parts are not something I see as realistic.

10. As a supplier, you will have a good view of how innovative the current construction industry is.
    a. Do you consider that there is continuous improvement within the infrastructural sector?
       Kees Quartel states that it is clear that compared to other industries, the construction industry is lacking behind. And it is important to learn and innovate more.
    b. And what do you think is the cause (knowledge is not transferred throughout the organisation), or what will be needed to work more project exceeding and establish a “better” learning-curve?
       Kees Quartel states that the ideas of the researcher for developing labels, and eventually develop a configurator, will be a very good approach for establishing this.

11. Can you tell a bit more about the standardisation that has been applied within Spanbeton?
    a. Considering the product
       This has been discussed earlier in the interview. Spanbeton has three standard concepts they deliver. These concepts can be adapted to the specific demands and locational constraints.
    b. Considering the process
       Considering the process Kees Quartel explains that Spanbeton tries to work in the same (systematic) way in every project. And the client is the most important (central) in this process.

12. What would be an ideal situation for Spanbeton? (To be able to fully benefit of the repetition that occurs in projects and within different projects (project exceeding)).
    The ideal would be that all parties would collaborate already in the early stages of the project. And that the market will change, so that the client can choose from a catalogue.

13. Do you think the development of configurator for different infrastructural objects is beneficial and/or applicable? Or are the situations to “unique”, too much different circumstances, and are there still a lot of changes that are required and/or design of new elements needed?
    Kees Quartel already explained his vision about a configurator earlier in the interview. He believes in the idea to develop a configurator, but also states that we need to keep innovating. This is something we maybe will forget, but it remains important to listen to the client and innovate as a reaction to the demand of the client. In addition, Kees Quartel also points out that regularly brainstorm sessions with other big companies and clients (RWS, province, municipalities) are arranged. This is on a very high level of abstraction, but it is very useful. It gives great insight into the different demand and wishes and the how the market is currently developing. Here again, Kees Quartel, points out that trust is essential, and by cooperating with each other a lot more can be accomplished than developing on your own.

Question focused on the design of a viaduct

14. I currently have the idea to work with other materials than the conventional concrete. Do you work with new innovative materials? For example composite.
    Spanbeton does apply innovative materials within their products, but we still mainly use concrete for our components. However, you should be aware that there are lots of different types of concrete. So we still have a lot of possibilities to innovate. Considering the example composite, we do apply composite, but this is mainly for the secondary components, not for the basic constructive components. A lot is still unknown about composite, and the regulations are very strict.

15. **Does Spanbeton have a Research and Design department? And are new designs only developed based on demands and wishes of the client, meaning for a specific project? Or are new designs also developed outside the scope of a project?**
    Spanbeton does do research and create innovative ideas. We do not have a special research and design department, but the designers and structural engineers are also part of an innovation team. Here they get the time and space to develop new concepts. However, Kees Quartel highlights that the innovation within Spanbeton is a response to the demands of the market. He as head of sales should communicate with the designers and structural engineers about what the market trends are and what does the client wants? This means that sometimes an innovation team will focus on a new idea, which is not directly applicable to a project. But, it also means that sometimes innovative solutions are developed within projects. These new innovative solutions can also be applied to other projects. By this new innovations are created within the projects of Spanbeton.

    In addition, Kees Quartel states that they are currently working on how they can design their beams so that they are very thin. They are investigating self-healing concrete and try to experiment with different types of high strength concrete. And they currently also do a research with TUDelft, about smart bridges. This means bridges that have sensors, which tell when the structure needs maintenance.

16. **Do you think a market shift can occur? Change from market pull, towards market push?**
    If we look back 10 years in time, you will see that a lot in the construction industry has changed. In a period of 10 years, a lot is possible. So a change towards market push can appear. The past two to three years the different parties in the construction industry are having dialogic with each other, here referring to RWS and big construction companies. RWS has more requirements than 10 years ago. For example building demountable, having less hindrance for the surrounding area etc. A good design has to be smart, has to consider the surrounding and has to be sustainable. Kees Quartel states that the way the construction industry works can only be changed by RWS. If RWS specifies certain aspects, the construction parties have no other option than design structures that also meet these new aspects.

17. **Do you consider that it is possible and will be beneficial to use polystyrene (plastic, piepschuim) in combination with concrete for a viaduct? (this is an idea I currently have)**
    Yes, of course, this is possible. We already apply this in our box beams. This is a material that has a lot of potential.

18. **Sustainability is becoming more important, and the requirements of RWS considering sustainability are becoming higher. How do you deal with this as prefab-supplier?**
    Building demountable is something that is increasingly asked by RWS. But building demountable is something that already needs to be decided on at the beginning of a project. If the client does not specify this, a construction company and suppliers will not apply this in the projects. We do have solutions for this, but these solutions are more expensive than the traditional practices. Because procurement is mainly on the lowest price, this means we will not apply these solutions. However, if we continue to build viaducts on the way we have the past 50 years, this will mean that we have to demolish most viaducts after 20 years, as they do not fit/meet the demands any longer. This is not sustainable. The researcher points out that RWS currently does not specify that viaducts have to be designed in a way that makes it relatively easy to expand a viaduct. Kees Quartel responses to this and states that if RWS does not specify this, the suppliers and construction companies will not consider this, as the procurement is on lowest price.

19. **In a current project of BAM Infra, it is investigated if the beams of a current structure can be re-used in a new structure.**

    a. **Do you think it is possible to re-use the beams in a new structure? (considering how the beams are currently made and connected)**
       Yes, Spanbeton in currently is investigating this approach with BAM Infra for knooppunt Hoevelaken. Here a lot of viaducts have to be adapted, and some need to be demolished. The idea is that the beams of the viaducts that need to be demolished can be used for the expansion of viaducts that need to be adapted, or the beams can be used within totally new viaducts.
    b. **In order to re-use the deck beams the structure will have to be demountable (not be demolished), do you think it is realistic that concrete structures will become easier to deconstruct? And what would/ how can Spanbeton contribute to this?**
       To be honest, we have tried to reuse beams before. This was in for the A4 at Schiphol, here a temporary viaduct needed to be constructed. Therefore, building demountable was demanded by RWS. The structure had to be easy to deconstruct, without causing a lot hindrance for the traffic. The beams from the viaduct were later used as beams for a bus-line, and some beams were again used in the new viaduct that had to be constructed. However, although this sounds great, we bounced into a lot of obstacles. Most beams needed to be repaired and the parts were the connections were needed to be cleaned to assure the new connection would be strong enough. As a result, the costs were very high, but this was the risks of the client, luckily for Spanbeton. But this project makes clear that very tight organisation is needed and most beams still need a lot

of work before they can be directly reused in a new structure. And not all beams can be reused because they do not conform to the current regulations.

20. **Do you think it is possible to make use of a "click"-system for connecting the different elements? And by this to not apply the joining of elements by the use of concrete (Maintenance, adaptable to future demands, demountable)**
When the researcher asked this question to Kees Quartel, he immediately response that this is something he greatly believes in and is very excited about this. Kees Quartel states within Spanbeton they have investigated how this could be developed considering the technical aspects. Here we investigated the concept of Ikea could also be possible for a viaduct, referent to the pax-kast. The conclusion was that it is technically feasible. It will not be easy to develop viaducts where a "click" system will be applied, but the main concern of Kees Quartel is the regulations. When you construct a viaduct based on "click" systems with the vision to be able to adapt the viaduct and demount the structure effectively, where the different components can be used in other new or old structures, you will have to deal with the increase regulations. Norms and other regulations are constantly changing. To make sure that the reused components will conform to the current regulations, the components should be inspected and a lot of difficult calculations need to be made. In addition, it also requires significant effort to demount the structure, clean the connection points of the components, repair damage, transport the components and temporary store the components. Kees Quartel is not sure if this will be beneficial, as he already has put forward in the interview considering the experience he has with the A4.

<u>Concluding questions</u>

21. **What do you see as risks and/or barriers, as well as opportunities in the future market? For the construction industry in general and for your company: Spanbeton?**
For Spanbeton, Kees Quartel does not see big risks or barriers. The big changes that will occur are that SpanBeton will work more closely together with construction companies or other parties. To together develop new innovations. This means partnership agreements will need to be made. But, we cannot have an agreement with a lot of different parties. We have to make a choice. When this choice is made, it should be self-evident that cooperation with this company is needed. Kees Quartel does not see any dilemma considering the partnerships. If the constructing company is afraid that Spanbeton will ask the highest price for their products, then they do not understand the concept of working together. The construction companies do not have to be afraid that this will happen because there will always be a certain amount of competition and market function. If a company will behave opportunistic, the other parties in the market will not trust them any longer. And there are no reasons for partners to take advantage of the partnership, only on the short-term this could mean profit, but on the long-term, this will mean the company will not survive.

22. **What do you consider as essential elements in order to successfully apply a product platform, with the use of standardisation and modularization in the infrastructural sector?**
Kees Quartel again points out that trust is essential. The different parties involved should make clear agreements, only then we can develop product platform. However, this is still a very long process. We will not be able to establish this the coming years. However, we can make a start to standardise the bearings, standardise some details that are always coming back and start using more forms of digital communication.

23. **What are your tips and tricks for the development and implementation of a product platform for viaducts? (What opportunities are there, and which difficulties do you consider?)**
Sufficient space needs to be created for the different parties involved to apply the idea of standardisation and modularization within construction projects. Because the current market is based on lowest price, the different parties within the industry have to be strategic. They should cooperate with each other in the form of partnerships. Together trade-offs will need to be made. It is important that the expertise of the different companies is shared. The parties should learn from each other. In Kees Quartel opinion cooperating with other parties is essential for a firm to stay competitive.

24. **What is your opinion considering the maturity of BIM, how does this can affect the implementation and working of a product platform.**
Kees Quartel is of the opinion that application of BIM-software is not sufficient. The application of BIM should be improved by all parties in the construction market. But this is also limited by the software that currently is available. The software has to be developed future. This will facilitate the processes we have discussed.

<u>Concluding remarks</u>

25. **Do you have other tips, considering the implementation of a product platform for a viaduct? Documents I need to review or people to interview?**
You should also talk to the people of the sales department of BAM Infra. This will give you good insights into how BAM Infra currently operates.

B.1.13 Interview 13

Interview – Frank van Geijn – 25 august 2016
Function: BAM Infra consult – Engineer Construction technology

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General questions

1. **You have been involved in the project of the A12. Can you shortly introduce/explain what your tasks have been within this project? And what your current work field is?**

Currently, Frank van Geijn is project leader for BAM Infra Regions Nord-West in the Netherlands. Before the reorganisation that took place within BAM, Frank has been working as project leader for BAM Civil Central Projects at the department project control. For the project A12 Frank van Geijn was work preparatory (werkvoorbereider).

2. **What are your thoughts on standardisation and modularization, by the implementation of a product platform in general? (Referring to "legolisering").**

Frank does believe in the theory, to apply the principles of mass customization within the infrastructural sector. He is convinced that there is potential. However, Franks has been a member of the conducted in-house research about a reference viaduct. Due to this research, he has become more sceptical about standardisation. Frank van Geijn states that; within current projects, there are many constraints and it is hard to make a design that takes these constraints into account and still deliver a project that meets the demands and wishes of the client. In addition, the design has to be the economic most valuable investment. All big contractors are struggling with this, BAM Infra as well.

A good approach will be needed to apply the theory of mass customization in practice. But it is hard to make a specific plan for this. BAM Infra does already apply a form of standardisation within their large projects. A lot of almost the same/comparable structures need to be constructed. There is sufficient repetition to apply a standard. However, in comparison to mass customization product, there is less repetition, and we cannot predict the future. It is hard for a construction company to make estimations of how many of a specific type of viaduct will need to be built within the coming years. We do not know how the market will change and how infrastructural object will be designed in twenty to thirty years from now. Frank van Geijn states that there are too many influences and unknowns. We do not have a glass bowl that will provide us with this information, and if we would it still would be very complex.

The researcher explains the idea behind the application of the principles of mass customization in the infrastructural sector. Frank agrees with what the researcher has pointed out. Not all components can be standardised. When standardisation is not possible/appropriate modularizing the components has to be considered. Frank van Geijn states that he understands the idea, that if you cannot standardise the object, you should standardise the interfaces (raakvlakken) with other components.

3. **Do you think the implementation of product platforms can be beneficial for BAM Infra?** (As continual optimisation and innovation is facilitated/ easier to establish by application of a platform)

Implementing a product platform for viaducts should be possible. Within current large projects were around 15 viaducts or more has to be build, standardisation is already applied. Here the listed specifications are the same. And the standardisation is very successful. However, this is not applied to the smaller projects. In theory, this is also possible, but in practice, you will see that there are always people that claim that the specific project they are working on has significantly different circumstances. It is too "unique", no standard can be applied.
Frank van Geijn thinks people are just stubborn. If we adopt a standard for different components, it will eventually be more beneficial than our current practices. However, before you can apply this, a standard has to be chosen. This is not easy. All the employees have an own way of looking at the design and are not willing to give their viewpoint up. If a standard would be chosen and applied within all the project, it eventually can be more beneficial for BAM Infra due to the repetition.

4. **Do you think that it possible and will be beneficial for BAM Infra to work with a script (draaiboek)? The processes are then standardised/prescribed and this line should be followed within all the different projects.**

Frank van Geijn states that a first step towards more standardisation could be to standardise processes. He personally is struggling with how the principles of standardisation and modularization can be implemented within BAM Infra. Standard processes are something that Frank can imagine and thinks this will be beneficial.

5. **Do you also see potential in the bundling of information in a structured manner, to learn from this data and increase efficiency?**

The researcher has explained her idea of labelling projects, with the vision to establish a configurator that is based on the created database by the labelling of projects. Frank van Geijn does think this can be a good way to collect data in a structural manner. And for this it will be needed to work with standard processes, as a line within the project will then become visible.

Frank is of the opinion that when a standard process is applied within all projects, and this data is collected in a structured way that chance that a specific "uitvraag" matches with the requirements and circumstances of an already established project will be bigger. The database has to be big enough and should be easy to use. Frank states that a lot of effort needs to be put into this database before it will be a good tool for BAM Infra to use.

6. **How should this database be established? Considering established projects and new projects. Not all the knowledge about the established projects will be available, as it has not been clearly documented and a lot of people who work on the project do not work at BAM Infra any longer. In addition, people forget why certain decisions are made.**

Frank van Geijn states that we should just start. The older projects, referring to around 10 till 15 years ago, will need to be analysed and reviewed. The characteristics of these projects will need to be put into the database. These characteristics will result in the selection criteria for the configurator (the researcher mentioned). We should definitely consider the older projects as well. It should not be that hard to document their basic concepts and drawings. For current projects, a format needed to be filled in during the different phases of the project. These characteristics again will give the input for the selection criteria for the configurator. Because the projects that are currently been developed or constructed, the characteristics and the trade-offs made can be documented in more detail than the already established project. If we clearly document our current projects and make it visible by the application of a framework, a great database can be established.

Frank van Geijn thinks this database will be a tool that will be used by the employees of BAM Infra. He, for example, points out that for the A12, a project he was involved with, they analyse and reviewed other projects. This to see what they could learn from these projects and if the applied method/product could also be beneficial for their project. However, Frank agrees with the researcher that the data that can be collected from the previous project will not that as valuable as we compared this data with the data that will be collected within current projects. Frank hereby points out that first sufficient data has to be collected to be able to create a database and configurator that can be of value for the employees of BAM Infra. If the database is not very large, and the employees try to search in this database or use the configurator for input in their current project, it could be that no or limited number of matches are found. The employee will not use this tool again in other projects. The database needs to be large enough/ mature enough to be of value, and by this to be implemented within BAM Infra. "If you do not put data in the system, nothing will come out of the system".

Frank van Geijn points out that the selection criteria of the configurator need to be very specific. The standard designs and or methods applied in already established projects are only of value for projects that are comparable.
There are certain aspects that need to be a selection criterion for the configurator. If the selection criteria not specific enough, the outcome of the configurator will only be of limited value. Therefore, during the development of a database and hereby configurator the project team should identify what the specific characteristics of the project or component are. When the characteristics of a new project will be comparable to already established projects, a match will be found in the configurator. It then would be great if it would be easy for the different disciplines working on a project to analyse and review the projects. And reuse the design, idea, concept etc. from the already established projects.

Frank van Geijn gives an example of the current situation within BAM Infra. In his holidays he got an e-mail from a colleague that was looking for data and specific drawing of the A12. This to analyse and review this data to see if the designs and concepts applied could also be suitable for his current project. When we would have a configurator, this process would be a lot easier. Now I needed to search within the files of BAM Infra to find some data for him. The researcher points out that this is something that she also experiences within here research. She constantly has to ask people about who participated or was responsible for certain projects. And also collecting drawings or other documents is not easy, as it is hard to find where the data is located, and it is hard to get permission to get access to this data. This also means people do not know about certain innovative ideas that have been applied within projects. And are dependent on their network within the organisation to get to know these practices (be aware of the existence and be able to get access to data to review and analyses the project/component)

7. **Product and process are interrelated. If we would implement a standard step by step approach (a script where certain steps are prescribed, and needed to be followed). And apply this in all our project. Will this eventually not mean that the product (referring to the different components) will be/have to be standardised as well?**

Frank van Geijn does not think a standard process will lead to a standard product. However, he does agree with the researcher that when information about current projects would be documented in a structured way, a database can be set up. All the different designs will be available within this database. The database will grow/develop further, and the chance that the "uitvraag" of a project will match with a project in the database will become bigger. Because we apply the design in more projects, learn during these projects and adapt the design, a more optimal design will be established. This could become a standard. However Frank van Geijn is of the opinion that, applying a standard process does not mean the product needs to be standardised as well.

8. **Do you consider that there is continuous improvement within the infrastructural sector? Does BAM works in a project exceeding manner?**

Frank van Geijn does think there is continuous improvement within BAM Infra. However, there is a difference between improving a design by the learning that takes place when the design/concept is applied in new projects. Or innovating, meaning totally design something different. The questions here are; how can I design it differently? Frank van Geijn points out that this is in conflict with applying a standard. At the one end, we as an organisation need to innovate. But on the other hand, we want to work with standardised processes and products/components. It is important that we find a balance between continuously improvement and innovation. In addition, it is important that the successful innovations should be further developed, so that they can be applied to other projects as well. Currently, this is not the case; most innovations are project specific and are not applied in new projects.

9. **What do you think is the cause or what will be needed to work more project exceeding and establish a "better" learning-curve?**

The researcher states that she came to the conclusion that knowledge is not transferred throughout the organisation. However, it is important that the knowledge and experience of the employees are clearly documented and these documents should be available/ assessable for all the employees of BAM Infra. Frank van Geijn does agree but point out that innovations are mostly developed for a specific project (specific situation). Mostly this specific situation will not also occur within a new project within a relatively small amount of time. This means there is no need for this innovation, there is no project where the new innovation can be applied again and be improved. In addition, this is also very different for projects of BAM Infra Regions or projects of BAM Infra multidisciplinary projects. Within the Regions, only limited time is available for the design of the structure. And the procurement is mainly on lowest-price. Therefore, it is not interesting to innovate. Already known, proven technology will be used. A new innovation requires a lot of time and effort. The amount of time that is available for the design of the structure is limited. And implementing a new innovation will not be without risks. Innovating within these projects is almost impossible. However, projects of the department BAM Infra Multidisciplinary contracts, are very large project. Here more time is available, and the project team can think the design through. In addition, the risks the innovation brings and time needed to invest in this innovation can be spread over the total project. Within these projects, we should work more project-exceeding.

<u>Questions considering the A12</u>

10. **Can you tell a bit more about the standardisation that has been applied within the A12?**
    a. **Considering the product (show the drawings of A12)**

- Which elements have been standardised?

The edge element (finishing) – concrete elements covered with plates that looked like brickwork were applied.
Abutment – In the A12 integral viaduct have been applied. The shape and dimensions of the abutment have been standardised. These were always the same and are made by an in-situ process on site.
Columns – the columns were standardised: shape and dimensions. These were mainly made by an in-situ process. But some columns have been prefabricated. This at the locations where it was not possible to apply an in-situ process, because of the roads around the location of the column had to keep functioning.
Approach slap – Standard solution was applied. The dimensions and shape were always the same.
The connection between of the foundation piles with the Abutment or foundation pad (the piles were "snelle" instead of boechaderen).
The deck – For the deck box beams have been chosen for all the different structures within the A12. This has also been concluded by Avinash Gangaram-Panday as the best option. For these specific box beams, no pre-tensioning was required and only a small strip needed to be poured with concrete. This type of box beams has been applied, because it could save us a lot of time, due to the different phases of the project. No pre-tensioning was needed, this meant that old viaducts could be adapted/totally transform will keeping one side of the viaduct functional.

- How is decided and/or indicated which elements/components should be standardised?

Within the A12, and also within other projects, the decisions considering the design are made by the project team together. This is mainly done by making trade-offs and other calculations.

b. Considering the process

- Referring to the design and realisation (construction) phase

Within the A12 we tried to work in a systematic order, both in the design and in the construction phase. In the design phase, this means we searched for repetition of certain aspects. This to benefit from this repetition and make a solution that would fit in various situations. For the construction phase, the way the viaducts have been constructed are almost always the same, as in their basic design the viaducts were the same.

- Have optimisation within the project been established? For example, when placing the 4th viaduct, the process was adapted to not make the same mistakes that have been made when viaducts 1, 2 and 3 were constructed

For the process, this was possible till a certain limit. We could not reschedule, or change to a new design. But within the processes on-site some adaptations on the level of the construction team could be made. However, these are only small things.

- Has the design been optimised within the project?

The design has not been optimised within the project, no big mistakes occurred and the contract did not allow us to change the design.

For more information considering the standardisation and modularization applied within the A12, it is suggested to read section 3.4.

11. How much freedom in design was there for the design of the A12?

Within the A12, the architect already made a lot of design choices before the contractor had contact with him. For example in the beginning of the project the architect had already decided that all the structures had to be finished with brickwork (meaning esthetical). In addition, the "omgevingsplan" and ""vormgevingsboek" were also leading.

12. If I have understood correctly, is the A12 the first project where standardisation has been applied, on a large scale.

- What has been the "need" to standardise within this project?

The project team found a significant amount of repetition and by this of optimisation within the contract. Frank van Geijn states that after the project of the A12, the designs/concepts were taken further in the project of the N33.

- What have been the 'opportunities" that made it possible to standardise?

The repetition, because it was a very large project, standardising certain parts was beneficial.

- For the A12, which project or projects have been a reference, or inspiration to also apply standardisation

Frank van Geijn does not know which project have been used as references. But for the N261 the A12 was used as a reference.

<u>Questions considering a viaduct</u>

13. I currently have the idea to work with other materials than the conventional concrete. And do you consider that it is possible and will be beneficial to use polystyrene (plastic) or Styrofoam (piepschuim) in combination with concrete for a viaduct?

Frank van Geijn thinks it is a very interesting idea. Research will be needed

14. The N18 mainly connects the different components/modules by using steel cables and joint by cement. Do you think it is possible to make use of a click system, instead of joining by the use of concrete (considering maintenance, adaptable to future demands, demountable)

This should be possible. Currently, prefabricated elements are connected to each other by injecting concrete mortal in the gain. These are relatively small but long pipes/holes that are located at the end of a certain component. Steel reinforcement pipes that come out of a component, for example, the top of a column are connected with the capping beam. The capping beam is lifted over the reinforcement steel pipes at the place the holes are located. The room between the reinforcement steel and the holes is then injected with a certain concrete mortal. This makes sure the two components have a stiff connection. This has been applied within the N261. A few years ago not a lot of people were positive that it could actually work. A click-system might be possible as well.

Frank van Geijn points out that he is not sure if a click-system will be beneficial for maintenance, adaptation or demounting a viaduct. There is friction between building demountable and durability of a structure. When you want to build demountable this will require a lot of changes. There will need to be invested in a new way of connecting components and expensive solutions will be the outcome. Currently, it will not be beneficial. Frank van Geijn can although imagine that if we apply other materials than concrete, referring to lighter materials, it would be easier and more realistic to design a demountable viaduct. Composite is an example.

General questions

15. **As architects can change the reference model, do you consider that if BAM Infra implements a reference model, there be sufficient room for change, while still be able to benefit from the repetition that occurs?** (Referring to the quotation of Henry Ford; "Any customer can have a car painted any colour that he wants so long as it is black.", economies of scale, learning curve and constant optimisation of product and process)

Frank van Geijn explains it would be preferred to have more room, but it also has to do with how you approach a project. Within the A12, the esthetical design was already locked down when BAM Infra as a contractor was involved. The architect wanted certain dimensions for the edge elements (finishing) so that all the viaduct had the same aesthetical appearance. This meant that around 300 different edge elements needed to be constructed. As in all project the architect and the construction company came together to discuss how the design should be build and possible concerns are explained. This has also been the case for the A12. Because of the contact/cooperation between the construction company and the architect the architect became aware that the dimensions of his design meant that 300 different edge beams were needed. Frank van Geijn states that in the project they had around one kilometre of edge element. Therefore, Frank van Geijn thought of a solution how to benefit of the repetition, to makes the edge elements the same for all the structures. He proposed applying standardised dimensions of the edge elements. This way the amount of "unique" edge elements, referring to elements with different dimensions, was lowered to 50 instead of 300. By this, the elements could be prefabricated for a lower price and could be assembled on the site more quickly. Therefore Frank van Geijn point out that it is also a manner of communicating and explaining your viewpoint.

16. **Do you think the development of configurator for different infrastructural objects is beneficial and/or applicable? Or are the situations to "unique", too much different circumstances, and are there still a lot of changes that are required and/ or design of new elements needed?**

Frank van Geijn does think it is possible to develop a configurator, but there are limitations. The construction market does not function as the markets of mass customization products. An architect or the client will not be happy if he can only choose out of a catalogue. However, he states that he does not agree with the people who say everything is unique, and therefore no standardisation can be applied. He is of the opinion that there is always something that can be standardised. Frank van Geijn here refers to what the researcher has told him about the tender of the N18. Only five different lengths/dimensions of the beams of the deck were applied. This meant some beams were over-dimensioned, but the application of five standards eventually was less expensive.

17. **Modularization (development of a product platform, and using click-system) can be beneficial considering different aspect: maintenance, adaptability to future demands, and demountable of the construction. Do you share this opinion?**

This has high potential, but currently, the client does not ask for these specific thinks, and the added value is only limited. Appling modularization is currently not beneficial. The modular structures will be very expensive, and from the budget the client has we cannot realise this.

18. **What do you consider as essential elements in order to successfully apply a product platform, with the use of standardisation and modularization in the infrastructural sector?**

There have to be sufficient people that support the idea of implementing standardisation and modularization within the infrastructural sector. In addition, it requires discipline from all parties. The total sector has to be involved. As a start Frank van Geijn thinks the client (mainly RWS) should give the construction companies more freedom.

19. **What are your tips and tricks for the development and implementation of a product platform for viaducts? (What opportunities are there, and which difficulties do you consider?)**

Maybe we should ask ourselves why we spend so much money on the esthetical design of infrastructural structures. In France, Switzerland and many other countries viaducts are very simple objects.

B.1.14 Interview 14

Interview – Maryia Smahlei – 19 February
Specialist BIM – BAM Infraconsult bv

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Although I had prepared questions to ask Maryia Smahlei, we did not follow this list of questions. We just started talking about here research and my research. Below is a short documentation of the conversation.
Smahlei is currently working at BAM Infra, at the department Infra consult as a BIM specialist. The reason to have an interview session with Maryia is because she has conducted a PhEng two years ago at BAM Infra. Here research was about standardisation of tunnels and the development of a BIM application for these tunnels. She is very positive about the potential of standardisation and has highlighted that in “Wit-Rusland”, where she is from, a lot of standardisation occurs, due to the Soviet-union. Therefore she learned that everything is possible.

Most ideally would be to have one large module catalogues that have modules that can be used in the different project, even for a variety of different products. All the modules (structured parts) are then mapped in a library, and the developers can choose out of this library the correct/suitable parts. In this case, the designer’s first look inside the library to see which components are available, and combine these into a design for a new product, in our cases civil construction works.

In her opinion, the start to having standardisation is by implementing a common framework for processes and products. First, make an architectural plan and create the modules -- > all based on one grid. The modules must meet the grid (the product platform). It is like LEGO. By reviewing what has already been done, what suppliers can deliver without making big investments, the cost can be safe. First, it speeds up the design process. Secondly, the suppliers do not have to adapt their work and the benefits of improving quality, due to more experience because of the repetition. -- > Fast construction + Cheaper

Maryia considers 4 types of standardisation levels in her report, this is on page 35. She tried to make a Tunnel design, conducted out of prefabricated parts, this was for relatively small tunnels. -- > Investigated the use of a standard process (protocol) + the using of the same parts (the standardised elements)

In the research, she struggled between the wishes of the University of Delft and the wishes of the company BAM Infra. There was no clear goal. Eventually, she made a Revit model for parametric design and analysed what good dimensions were for this model.

Talking about the coupling index, that I would like to use in my research, she pointed out that System Engineering is important. It enables us to assess the priority -- > identify parts + functionalities -- > What to standardise.

My research will be focused on the product, a viaduct. Maryia sees however that first a change in the process is needed before the design can be standardised. They are closely related. When there is a standard way of working (framework) the design will eventually also become standardised, due to the repetitive way of working.

BAM has established a project where they create a configurator for small bridges. This eventually failed -- > went wrong because at the start they focused on the details (the technical details), without considering if it was something that the market asked for. Eventually, nobody was interested. Therefore, she gives the advice to look at the market. -- > What is important for the market, who is the targeting group -- > Why is this interesting for them. For example, a municipality will want to have very nice architecture, a tailored product, standardisation is less applicable here. So consider who your customer is.

In addition, to reviewing the market, she makes the suggestion that I should start by investigating what types of viaducts there are. There will be elements that are “standardised” -- > Are design the same as previous projects.

But viaduct can still be completely different -- > lot of dependencies. Different in shape, the place they are built, their size, the span distance etc.
It is hard to find the right documents. BAM is a big organisation and works fragmented. Not all the documents are shared or accessible for everyone within the company. -- > Advises to try to get access to the folders by asking ICT, this will save a lot of time.

As major benefits/driver/added-value of standardisation, she considers are the cost-savings. By simplifying the process (develop standard procedures), and establish a learning curve. -- > Optimisation will occur -- > will result in lower building costs, less failure and the products will be of higher quality (already made a big step by using prefab elements instead of making the total construction on site)

Standardisation becomes interesting when there is a limited budget. If the client has a large budget, they want a tailored product, like civil structures with very nice architecture.
Standardisation is a way to make construction works cheap(er) -- > but still need to consider does the client need this? -- > the standardised modules will not be useful for all projects.

Also, Maryia has experienced that the employees of BAM are sceptical when it comes to standardisation. As they say, we have been working like this for years and it has always been successful, the do not see the need to adopt a new way of working. -- > Need to understand in which cases it is needed/can be applied. -- > No all situations ask for standardisation. They need to ask themselves: Why are we doing this + in what circumstances should we apply standardisation -- > Important that the staff becomes more open to different solutions.

From Maryia's point of view, the smaller projects are the most suitable to standardised. -- > You will find a lot of common thinks in their designs -- > Almost the same for all projects + mostly small projects are more common (for example Ikea), it is a matter of quantity.
Large projects are not always suitable for standardisation -- > these mostly have a specific, unique architecture, where the client is a big company and money is not that limited.
But knowledge also needs to be used for larger projects -- > reviewing them. Adjustment of the standard concept is always needed, every environment is different.
Within the company BAM, they already have the same way of working. -- > Big company, so it is hard to see this through, but in processes, repetition occurs, and people learn in the organisation. BAM is fragmented still, even after the re-organization.

If BAM starts using the reference viaduct, it still would give sufficient room/ flexibility in design. It does not have to be a limiting factor, still, a lot is possible.
As BIM expert, I asked Maryia the question; how far BAM Infra is considering BIM, how mature are they? -- > Have a good position in the market -- > They are one of the leading companies in this field and they try to use this in all their products.

BAM already has made a big step by working in a multidisciplinary team, instead of splitting it up in departments (disciplines). I asked if she thinks there are also risks of using BIM, considering a product platform. Maryia stated that see does not see risks, Dutch people like to communicate, they will keep communicating, using one platform will not change this, it only helps/enhances the processes. The interfaces can be checked + make it able to communicate in a more effective way.
The Ideal situation would be a product "configurator" -- > Mix and match + Plug and play.
It is easier to develop this configurator "in-house" (within the company BAM). If other parties are involved, it will be hard to agree on one standard interface, as they all have different interfaces currently.
One of the first steps is more cooperation with suppliers, although Maryia thinks this is an essential step, she thinks I can take a long time before this will be established. But she highlighted that we need to combine and share knowledge.

Major challenges -- > always challenging to adapt your process, starting to use a new way of working, this is even harder in large companies, because the "system" is embedded within the companies structure.
+ People will not be open and are redundant to apply the standards (process + product) + Hard to make it known throughout the company + the staff of BAM will remain sceptical.

B.1.15 Interview 15

Telephone call – Cor Notenboom – 12 May2016
“Click and construct” project for a small bridge.

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On 12 May 2016, a phone call conversation with Cor Notenboom took place. Cor Notenboom was found after a long search for data and people who have participated in the initiative of the so-called “Click and Construct”. In this initiative, a configurator has been developed for a small bridge.

Cor Notenboom is currently working for BAM Build and Technic, for large projects. He is the only member of the initiative of the “click and construct” project that is still working for BAM. Cor Notenboom was the developer, or as he mentioned, the architect of the development of the idea.

First, I have asked Cor Notenboom if he still has some documentation about the click and construct the project. Although he has no documentation about the project anymore, he proposes that I could contact the innovation manager Ad van ‘t Zelfde), as he will have access to the old BAM Civil documentation. He points out that a small brochure has been developed for the project, and thinks this will still be available somewhere in the organisations as the click and construct initiative has been rewarded with an innovation award.

Cor Notenboom explains that the idea of the development of a tool for small bridges comes from the W&R-concept of BAM Woningbouw. As BAM Woningbouw makes use of a configurator, here customers can design their own house by the choosing between different options the model gives. Here it is a product platform for the house-building. The click and construct project was before called the W&R bridge, referring to the W&R concept of house-building. Cor Notenboom states that the idea of the project lies in the same scope as the W&R concept, only then this tool is for the infrastructural sector, considering a bridge. The click and construct project was a serious initiative to introduce in the market.

The basic idea behind the development of a configurator (tool) for simple small bridges, was to provide civil servants of municipalities and provinces, and architects and urban planners with a tool that could give a conceptual idea for the small bridge. A 3D-model and estimation of cost and building time are the output of the configurator. A web application, therefore, has been created, namely www.bouwjeeigenbrug.nl, however, this is no longer active. Within the web application key figures of the small bridge can be entered, for example, how long and width the bridge has to be and which functions does the bridge has considering the forces that the bridge will have to be able to handle. In this way, it is proposed as a fast and efficient tool to get an insight how this small bridge would look like, the costs and building times .

Although the web application has been completely developed and the site has been lounged, the initiative has not been a success. The tool was mainly developed for a very early stage of projects. Cor Notenboom states that it is a good tool for a rough estimation and concept idea of the small bridge. However, during the development of the web application, it became clear that in practices the situations for the construction of the bridge were significantly different. The roads needed a different angle and the slope of the embankment was different within the different situations. Cor Notenboom pointed out that the main difficulty the project team of the click and construct initiative was that they have to deal with different soil types. The small, but significantly differences and the different soil types made the initiative not commercially achievable. The web application gives an indication, but not more than this. When the directors that were the mainspring behind the initiative left the firm, the imitative has not been developed further.

The name, “click and construct” refers to the construction of a bridge by applying a kind of click system to connect the different components. However, this is not the case, as it refers to the mouse-clicks when using the web application to by this way design your own bridge. However, maybe this will be possible considering new technologies.

Cor Notenbooms viewpoint on the development of a product platform for a viaduct is positive. He states that he still thinks the click and construct initiative is a good idea. He thinks standardisation and the use of a product platform can be beneficial. Within the click and construct initiative, they have struggled with making a 3D-model, as the project was in 2005. However, technology had changed, and making 3D-models is not that complicated anymore. He, therefore, thinks that the development of a product platform can be a success.
Below the result of the developed web application has been given. The illustrations give a good insight into the project.

B—1 Web application: click and construct

B.2 QUALITATIVE ANALYSIS INTERVIEWS

For this qualitative analysis, the interviews of Appendices B.1 are used as input. These interviews have been conducted with different employees of BAM Infra, with different backgrounds and functions. In addition, also an interview with the province of North-Holland and an interview with a supplier, SpanBeton, is conducted. By these interviews, the researcher got many insights into the problem, current practices and various viewpoints on the application of the principles of standardisation and modularization in the construction industry.

B.2.1 Qualitative analysis interviews conducted

Category	*Comment*	*Abbreviation*
General view on application of the principles of standardisation and modularization		
Kitting Lee does see much potential in the application of the principles of mass customization and development of a product platform: It will make us able to faster develop and construct projects, and it will result in higher level of efficiency. In addition, it can also speed up the tender process. Kitting Lee highlights that we should not just consider standardisation and modularization, he thinks it is a "must". If BAM wants to stay one of the biggest construction companies in the Dutch market, they will have to apply this concept to stay competitive. If BAM does not start using this, they will fall behind and will be outcompeted.		KL
Paul Waarts think that the total industry should adopt one standard. He is enthusiastic about the idea of the researcher for a standard interface, where it is clear how elements/components have to be connected/are coupled. Within this interface, the elements and components can be designed freely, without restrictions. This is possible as long as the standard interface for coupling is considered.		PW
When there is more freedom for the contractors, a standard can be applied. This can be beneficial because the standard is fixed. This standard concept is applied within other projects before. Therefore a learning curve is established. By working from this standard, constant optimisation of the concept (product and process) is possible.		JB
Ad van 't Zelfde things industrialisation has great potential for the construction industry. The costs can decrease, different parties can develop certain ideas and concepts further, optimisation of the product and process occurs due to the learning curve. By this we will eventually have more time left to focus on the other important areas of a project, referring to the influence of time, costs, sustainability and planning, etc. It is strange that we are not working in this way currently. It cannot be stated that it is not possible, the shipbuilding industry has adopted the idea of standardisation and modularity around twenty years ago. For BAM Infra it should be possible as well.		AZ
Paul Waarts argues that we should look at infrastructural objects more in the way of the customer production market. The specifications need to be free, and we just have to buy what is offered. Not every time demand a total custom-made design. He refers to a custom-made suit. If you want a new suit, you can choose for a conventional model that can be adapted to your specific body shape, or you can choose to have a suit designed especially for you. Eventually, both options will result in a good outcome, which fits your needs. However, the custom-made suit is more expensive. Considering a custom-made suit, we are aware of the fact that we pay double, or even more than that, in comparison to a conventional suit. Within the infrastructural sector, here there is no awareness that not all situations demand a unique solution and that a standard design could also be adapted while still having unique aesthetic characteristics.		PW
Within current projects, there are many constraints, and it is hard to make a design that takes these constraints into account and still deliver a project that meets the demands and wishes of the client. In addition, the design has to be the economic most valuable investment.		FG
Within infrastructural projects, there has to be dealt with a lot of different stakeholders, within the house-building the number of stakeholders is significantly lower. Due to this, an infrastructural project is more complex, but still, standardisation should be possible.		CZ
The people are a major barrier. Chris van der Zwaard states that a mind-shift will be needed. Moreover, points out that it should be demanded by the management and the project leaders. If this is not the case, the employees of BAM will not adopt the concept.		CZ+AGP
If we want to apply the modularity, the contract forms should change. The current contract forms, do not motivate to innovate.		AH

The main cause, why a "legalising" has not yet been accepted, is that the current way of working works for everyone. He states: Everybody is happy. Paul Waarts explains this by pointing out that a custom-made design is more expensive, this will generate higher income for the constructors. Moreover, maintenance and management are different for all the custom-made structures; here a ludic market has occurred. However, the implementation of "legolisering" will change their way of working completely, and by this, they also need to consider another profit model.	PW
Although functional requirements are applied, the employees of BAM Infra still experience limited design freedom. This is because they consider the aesthetical program of requirements and the "beeldkwalitietsplan" as a leading document. Paul Waarts states that this document is not leading, it gives an impression of what kind of design is preferred by the client, what their vision is for the project.	PW
The main driver for BAM for applying a product platform is the learning curve, to optimise and not "re-inventing the wheel" constantly.	CZ+AGP
The "mix and match" of components can be very beneficial. However, we must be aware that then only a limited amount of standard components need to be applied, as otherwise, the effect of the standardisation is missing.	JPH
Product and process are interrelated.	
Developing standards can be very beneficial. However, first, changes in the processes are needed before the design can be standardised. They are closely related. When there is a standard way of working (framework), the design will eventually also become standardised, due to the repetitive way of working.	MS
Major challenges: It is always challenging to adapt your process, starting to use a new way of working, this is even harder for large companies because the "system" is embedded within the company's structure.	MS
Standardisation of processes will eventually lead to standardisation of the product; they are interrelated	FS
Various variables are of influence on the process and the products. However, although we have to deal with many differences, we can apply a guideline. Every situation is unique, but this does not mean we cannot choose a focus, as we can focus ourselves on the most plausible option. With the experience and analyses of the situation, we can make a choice in the beginning. We then do not have one standard viaduct but have multiple types that are suitable for the different type of circumstances. The process, of what to choose based on the characteristics can be standardised. Decision models can be made.	AH
There is tension field between the product and the process. When BAM Infra wants to implement a new product innovation, this is possible. However, when the product innovation also has a significant impact on the current process, this is much more complicated. This means that the innovations that currently are established within BAM Infra are within the boundary conditions of the current way of how processes are organised. If we want to implement an innovation what will have a significant effect on the current working process, the way of working within the organisation has to change. Ad van 't Zelfde states than we are dealing with a different playground (speeltuin). By this, there will be more space/potential for innovation and optimisation.	AZ
Cooperation: Co-makers and early involvement of all disciplines and client	
It would be great if all stakeholders could be involved at the beginning of the design project. However, currently, this is not possible as it is not legal to have conversations with the client in the procurement phase.	LL
When the market parties would be involved already at the beginning of the project, both parties can explain their point of view, the constraints and the effect of possible ideas can be discussed. This gives great insight for both parties, and together they can make trade-offs for the specific project.	KQ
The N261 could be constructed relatively fast, and the project was delivered 1,5 year earlier than required. This was partly because the municipalities, provinces and architect were already involved in the first phases of the project.	CZ+AGP
More awareness is essential: the architect should be more aware of how to construct their design. He states that we need architects that design with respect to the logistics of the building processes.	JB
If you want to develop viaducts in an economical and effective way, it is important that all parties are aware of the boundary conditions, make agreements with each other, but also stay within these boundaries.	KQ
Trust is essential, and by cooperating with each other, a lot more can be accomplished than developing on your own.	KQ
One of the first steps is more cooperation with suppliers, although Maryia thinks this is an essential step, she thinks it can take a long time before this will be established. But she highlighted that we need to combine and	MS

share knowledge.	
Co-production is needed. Van der Zwaard refers to Toyota, as they have long-term relationships with their suppliers. Here the suppliers also are motivated to innovate, as Toyota demand them to develop the product further, for example, they will have to develop components further, to decrease the cost of this component by 10%. If this innovation is not established and by this, the goal has not been reached, Toyota goes to another supplier. This driver for innovation is important.	CZ+AGP
Co-makers are needed for the concept to be successful. They all are motivated to improve the quality of the end-product. Only together you can establish successful projects.	LH
Market demand: client	
It will be hard to convince the client to cooperate with this new approach of a product platform The client does not experience the same benefits as the constructor	LL
The whole idea of industrialisation revolves around the repetition, however, for the province and municipalities, there are not sufficient repetition for them to benefit from, as they can only spend their money once.	LL
Client is the biggest barrier	LL
The click and construct initiative went wrong because at the start they focused on the details (the technical details). However, they did not question themselves if it was something that the market demands. Eventually, nobody was interested.	MS
The municipalities pay for the product (railway underpass). Who pays, is mainly in charge of the design. The municipalities can demand a (unique)design that meets their wishes.	FS
The clients always want something different. The standard will not match each situation.	JB
Innovation is only a success if both the client and constructor want this innovation. They have to be open-minded considering this innovation and need to see sufficient benefits. If the constructing firm has developed an innovation that the client does not want, or the other way around, the innovation will not be a success.	LH
Reference, apply a standard	
Once we have a reference, we can then adapt this reference to the situation occurring. Means, we only have to deal with the deltas, only adapting deviations. This means you do not have to do design everything from scratch again but can use already applied/proven practices.	LL
Every infrastructural structure is unique, so just one standard will not work, we need to provide multiple options.	KQ
If a standard would be chosen and applied within all the project, it eventually can be more beneficial for BAM Infra due to the repetition.	FG
There is always something that can be standardised. In the tender of the N18, only five different lengths/dimensions of the beams of the deck were applied. It meant that some beams were over-dimensioned, but the application of five standards eventually was less expensive.	FG
If BAM starts using the reference viaduct, it still will give sufficient room/ flexibility in design. It does not have to be a limiting factor. Still, a lot is possible.	MS
If a client has very specific requirements, this will also result in more unique, custom made solutions, the consequence here is that the price will be higher compared to choosing a more standardise design.	CZ+AGP
The standard design needs to be relatively simple. If the design is too complex, it will not be used by the employees of BAM Infra and too much adjustment needs to be made in the design, this means it will not benefit from the repetition that occurs.	KL
It is important to have a design that gives many possibilities; sufficient variation is needed.	NB
The repetition that occurs in design and construction result in a decrease of costs. Aad van der Horst explains that this standard viaduct can be very beneficial because it offers the possibility to build the viaduct for the lowest price and in a fast way. However, by choosing one standard, you will lose your flexibility to adjust/cope with different project-specific circumstances. Moreover, as you lose your flexibility, by this you also lose your creativity. This is the price you pay for choosing one standard.	AH
The main power of a reference design is that it is already fully specified. Only some adaptations to the standard reference need to be developed, to establish a design for a different location. This can save time and costs. Ad van 't Zelfde argues that it is essential to analyse the step and decisions made considering an object. Some steps that we take and decisions that we make are not based on analyses of the most optimal solution.	AZ

We do not think about this, as we feel it is the best approach. However, if we would analyse certain decisions and steps, we will see that the way we currently design is not always optimal, and other possibilities maybe lead to a better result for lower costs.	
A lot variation is possible, but this within the standard concept. Considering the design it has to be clear which elements are variable, and how much design freedom do we have considering these elements, and which elements are not that flexible and which different options do we have considering these elements. When the ambitions for the design cannot be realised within the concept, then a new design has to be developed.	LH
Knowledge management and transfer (database)	
Data-mining is what is needed. Moreover, this in combination with BIM would be needed for the development of a configurator that takes everything into consideration.	LL
Frank is of the opinion that when a standard process is applied within all projects, and this data is collected in a structured way that chance that a specific "uitvraag" matches with the requirements and circumstances of an already established project will be bigger. The database has to be big enough and should be easy to use. Frank states that much effort needs to be put into this database before it will be a good tool for BAM Infra to use.	FG
Projects have to be documented and reviewed, to learn from them. This is currently missing within the organisation. In addition, in the situation when verification and validation do occur, and the project is documented correctly, the big problem is that the employees of BAM Infra do not (insufficiently) take the successful project as starting point. Or even worst it is very hard to get access to the documents and drawings of the different projects.	CZ+AGP
For the documentation and efficient data sharing within the company Chris van der Zwaard thinks this has to become easier, we cannot only say to our employees that they should adopt standardisation, we also have to provide the tools that are required to accomplish this; This by choosing standards.	CZ+AGP
For the implementation of standardisation/modularization and, thereby, the development of a product platform, the documentation needs to be improved. The different project member should clearly document their process so that the project can be understood by the other employees of BAM Infra. Based on the documentation, it should be clear why certain decisions have been made, what trade-off did occur.	KL
A general database might help to improve our practices, as employees can review other best and worst practices.	JPH
Learning takes place at the level of the individual employee, but this learning is not documented and transferred to the entire organisation. So we do learn, but this process is not optimal.	AZ
Communication	
The communication between the tender team and the team that eventually continues with the project when the project is awarded do not exchange sufficient knowledge, only limited communication between these teams occurs.	LL
For the successful implementation of a product platform, Kitting Lee considers that clear communication and documentation will be needed. However, also a point out a mind-shift has to occur, this is essential.	KL
Knowledge transfer within the organisation is very limited, as we can almost say that it does not occur. When we have a new project, the employees of BAM need get along with the project. This requires the "old" people with much experience, but also the "young" people with a more open view. However, there is a "gap" between the "old "and the "young" employees of BAM Infra. They do not use the same language; the communication does not align.	JPH
Configurator	
A configurator will be very complex and will have to be updated all the time as the market is constantly changing.	LL
It is important to keep updating the platform so that the companies can keep up with the developments within the dynamic and fast changing market. Constant validation is important to make sure the design still meets the changing requirements.	LL
Kees Quartel is convinced that this will work. Moreover, highlights that to establish this cooperation between the suppliers with the construction firms is needed.	KQ
By combining various modules, an optimum can be established for the specific circumstances and the specific contract circumstances.	AH
Standardisation means in the definition; limiting of flexibility. Aad van der Horst argues that the main question	AH

is if under these different circumstances standardisation is feasible. Different modules will need to be developed that meet the listed requirements and the specific situation. Modularity is feasible, but then we have to apply a mechanism, to come to the optimal solution. This mechanism can be evaded (omzeilen) by already worked-out different designs that can be taken as a starting-point. This is not totally modular, as different routes are pre-sorted. Different variable designs can be developed. Then product sheets can be developed. Considering the specified demand, we then can go through our product sheets to find a design that is the most suitable solution for that specific project.	
Having catalogues of different variations/options that can be chosen by the client would be ideal. The client could then just pick the option that suits them best. However, when the client wants something different, this is also possible, but not with the standard design. Then a new design will have to be made, but this will be more expensive.	AZ
Why not successful/What makes it successful	
There is not always time to put the effort in optimisation.	LL
It is important that all these five pillars(of BAM Woningbouw) are considered, and applied within the new initiative.	LL
Client is the biggest barrier	LL
a) The product platform must be visible for everybody. People need to be aware of the existence of the platform *b)The platform has to be easy and has to be open and accessible. Otherwise, people will not start to use the platform.* *c) Technical the development has to be based on as-build documents. So that the optimisation is based on facts, not on estimations.*	LL
Apparently, BAM does not push through. This is because BAM still works as different firms that are work together. However, they should work as an integrated team. Currently, still, the culture of individual firms is present, although we are one big organisation right now. We should work together, also on the level of innovations. Together we have to invest in this.	CZ+AGP
Using the principles of W&R from development until production will result is successful projects.	FS
Need to stay true to the concept, everything depends on this concept	NB
In essence, it is vital that the platform is flexible. As different circumstances and wishes of the client will occur. Of course, there are constraints, but this does not mean it is not possible. However, we should remain flexible; we do not want to build viaducts the way houses were built in the DDR.	AZ
Every structure is "unique."	
Province and municipalities have certain requirements for the design; these are different within all projects.	FS
Although all projects are unique, the building blocks (referring to the Lego-blocks) are not unique.	KL
Paul Waarts argues that the current market needs to change from market pull towards market push. He states that the development of a design for an infrastructural object from scratch every time, developing a custom-made solution every time, has just become a manner of habit. This is become the standard way of working within the industry, as they think everything is possible, and every design needs to be unique to be able to provide the client with the structure that meets their specific requirements.	PW
Although the situations are "unique", it is almost always possible to construct a design out of standard pre-fabricated parts. The design can be customised. Still, a lot is possible considering the design, and the edge elements can be completely different for the same standard design (for the construction underneath).	JB
Culture	
Three main reasons why standardisation and modularization are not applied within the infrastructural sector: 1) People do not see the benefits that the industrialisation can bring and mainly think about the negative aspects..2)The maturity of the new contract forms: people within the industry still have to get used to this new way of working. 3)The client does not have an "open-minded" view.	LL
The current culture in the construction industry is very result oriented. Moreover, all parties try to postpone agreements with suppliers, so that they can benefit from a decrease in price, due to the market mechanism. However, although this is a good approach for an individual project, it is based on short-term thinking. We should consider the long-term. This means we have to trust and cooperate with different parties active in the market. Together we can improve our practices. However, trusting each other is essential.	KQ

Frank van Geijn thinks people are just stubborn. If we adopt a standard for different components, it will eventually be more beneficial than our current practices. However, before you can apply this, a standard has to be chosen. This is not easy. All the employees have an own way of looking at the design and are not willing to give their viewpoint up.	FG
The construction industry is a very conservative industry. When an innovation is implemented, the process or product does not work optimally right away. Always something will go wrong, the pessimistic people involved will then argue that the new approach has failed. The resistance can be high, as within this business limited amount of innovation occurs in comparison to other industries	FS
Jan Pieter emphasises that if BAM Infra develops something, it is like we are playing with toys. When the project is finished, we do not continue with further optimisation and innovation of the build structures. We are bored and want to go for a new challenge.	JPH
The industry is very conservative. When we want to implement the principles of standardisation and modularity a mind-shift is needed.	AZ
Engineers like working on a unique project, they like to design something special. They enjoy the process of constantly beginning a design from scratch, constantly "reinventing the wheel". Considering "legolisering", they only need to adapt the standardised (reference)design to the different situation. However, we do not like to do the same think twice, and the engineers are not challenged.	PW
The construction industry is very conservative. To successfully apply a product platform, a mind-shift is needed.	PW
Project specific innovation (not project-exceeding)	
Within regions it is only based on lowest price, there are no EMVI-criteria's, innovating here will result in higher costs and therefore is not an option.	LL
The innovation mostly stays within the project that it was designed for. This means the idea is not transferred to the organisation. Moreover, if people do not know about the innovation, they will not apply it in their projects. In addition, if people are aware of the innovation, they will not always apply it. This is because the people have one goal: the project they are currently working on.	LL
It is important that we find a balance between continuously improvement and innovation. In addition, it is important that the successful innovations should be further developed, so that they can be applied to other projects as well. Currently, this is not the case, most innovations are project specific, and are not applied in new projects.	FG
Innovation is mostly developed for a specific project (specific situation). Mostly this specific situation will not also occur within a new project within a relatively small amount of time. This means there is no need for this innovation. There is not a project where the innovation can be applied again and be improved. In addition, this is also very different for a project of BAM Infra Regions or projects of BAM Infra multidisciplinary projects.	FG
Chris van der Zwaard had/has the idea to make a small book for every type of project, object and even processes about the standard of how the project teams should start, referring to the considered standard. From the established standard that has already been applied and has proofed to be successful, a new design can be established. By a process of optimisation and innovation of the standard. By this constant improvement occurs, and a learning curve occurs.	CZ+AGP
Other countries	
Why do we spend so much money on the esthetical design of infrastructural structure? In France, Switzerland and a lot of other countries viaducts are very simple objects.	FG
In Switzerland, viaducts have been standardised. The municipalities can choose from around five designs. These designs are a starting-point (reference) for future development of a design on the specific location.	FS
People are sceptical	
People are sceptical and see too many barriers	
They need to ask themselves: Why are we doing this and in what circumstances should we apply standardisation? It is important that the employees of BAM Infra become more open to different solutions.	MS
People will not be open or redundant to apply the prescribed standards (process + product). It will be hard to make it known throughout the company, and the staff of BAM Infra will remain sceptical.	MS
The benefits of product standardisation are not clear within the company; the employees do not see how standardisation could be beneficial.	FS
A mind shift is needed, this is essential.	KL

The biggest challenge for the implementation of standardisation and modularization within BAM Infra is the current viewpoint of the employees. A mind-shift will be needed.	JPH
The current viewpoint of the employees of BAM Infra is the most limiting factor. They always have an excuse why the principles of standardisation and modularization cannot be applied. It is important that the employees of BAM Infra become are aware of what effect their decision will have, considering time, costs, quality, etc. Moreover, become aware of the benefits. The best thing you can do is analyse the costs and point out that your idea is economically more attractive, as it will decrease the costs. You will have to show the architect and the team that we can develop viaducts on lower costs.	AZ
We have not yet established a standard. This mainly because the employees do not think it is possible for the current market, referring to the requirements that are demanded by the client and the other regulations. In addition, although they see some form of repetition with different designs, the always have an excuse why standardisation will not work in their current project. They consider their project as unique, there are always different circumstances, which makes that no standard can be effectively applied.	LH
Design freedom	
Although the provinces state that they work with functional requirements and by this that the construction companies have a lot of freedom, this is not true. The aesthetic requirements document is still a leading document and puts further constraints on the design of the project.	LL
Although the new contract forms and more functional requirements give BAM more freedom, this also means more responsibilities. Chris van der Zwaard highlights that new detail design needed to be developed. However, he states that this also brings possibilities to consider safety, which he considers as very important.	CZ+AGP
The client needs to trust the contractor; this is essential. Moreover, the client should give us more freedom in design. With the current level of specifications/requirements, there is almost no room for innovation, as a lot of requirements are demanded.	CZ+AGP
Currently, they are more functional than before. However, this does not mean there is more freedom. There still is an aesthetic program of requirements; this is a leading document.	KL
Current contract forms do not give sufficient freedom for innovation, as the risks for the construction firm are too high. He refers to the government vs. the private market. In the private market, you can discuss options. However, when you work for the government, you are bounded to certain rules.	JB
Johan Bolhuis is of the opinion that the requirements should not be a contractual demand, but should function as guidelines. Otherwise, it is not possible to apply a standard.	JB
Building demountable	
Building demountable is something that already needs to be decided on at the beginning of a project. If the client does not specify this, a construction company and suppliers will not apply this in the projects	KQ
There is friction between building demountable and durability of a structure. When you want to build demountable, this will require many changes. There will need to be invested in a new way of connecting components, and expensive solutions will be the outcome. Currently, it will not be beneficial. Frank van Geijn can although imagine that if we apply other materials than concrete, referring to lighter materials, it would be easier and more realistic to design a demountable viaduct. Composite is an example.	FG
Maintenance, adaptability and building demountable are currently not sufficiently reviewed in a new project.	JPH
Designing a construction that is demountable conflicts with the constructive performance of a structure and the different components. However, the demand for building demountable will increase, considering the increasing demand for sustainable structures. Re-use of the different parts, combined with new information technology as censoring, has great potential.	AH
This is something the client will need to specify. A viaduct is designed for around 100 years. The person who builds it right now is not concerned with how the structure can be deconstructed over 100 years. They are of the opinion that many changes in the market will appear as technology will be developed further. You cannot know what the future will bring. They consider their current situation and go for the situation that will result in the highest profit.	JB
When you build something demountable, after several years this still has to be demountable. It means if you hold the different elements of the structure together, then you will have to conserve these connections. This to make sure the bolts can be easily unscrewed, and no grinder is needed.	AH

How to implement	
Standardisation can be implemented with BAM Infra by clear documentation of standards. Standards have to be chosen and then imposed on the organisation. He refers to his idea of a "standard reference book". For the current situation, he thinks a group of experts of the different projects where standardisation has been applied have to form a discussion group, to figure out what a good standard will be. A standard has to be chosen and shared within the organisation that this standard needs to be used within all new projects. *Chris van der Zwaard suggests that we have to start with a focus group. However, when these people are busy with projects, their department will not let them go for this. BAM needs to work more like one organisation, helping each other out and learning from each other. By implementing a standard, the idea can constantly be improved, as it is applied in different projects.*	CZ+AGP
A dedicated team is required. A team that wants to take the best out of the situation, delivering a successful project is essential. Modification and innovation are processes that take a lot of time, and many obstacles have to be overcome. However, when you really believe in a new concept, you should do your best to establish the concept, although this will not always be easy.	FS
Kitting Lee states that it can help to already nail down and distinguish the different modules, at the beginning of the design phase. This can be applied by analysing the practices of different projects. Currently, we are trying to implement this. The project teams have contacted the project team of the N18. To see what they have designed, and use what they had already investigated, to build forward on these concepts and the trade-offs that have been made. This is a very good development; it will help us to optimise both product and process. We do not have to "reinventing the wheel" all the time.	KL
Determine a clear goal and budget, and use projects/tenders as a pilot to set up and adopt the product platform. Besides, learn from other industries how such platform are realised.	KL
It is important that first research about what has already been established will be conducted. The different member of the project team will need to ask themselves the question; "Which lessons learned within other projects, can I use as a starting-point considering this project?".	KL
Combine a team of experts from diverse disciplines, to fully dedicate them to the development of a standard/modular design. In addition, it is needed to formulate goals and objectives clearly. Requirements will have to be listed, and the boundary conditions need to be clear. So that when the design is finished, it can be taking from the shelf, adapted to the situation and directly cost and planning are known.	JB
If you want to apply the principles of standardisation and modularity, this means that the company and their processes must be organised in a different matter. The new way of working should facilitate the loop that occurs, referring to the learning curve and optimisation.	AZ
Ad van 't Zelfde highlights that it is very important that the process and the product will have to be adapted and have to match. Currently, we are not reviewing the problem in a systematic way, and we do not collect the data. If you have no data, you also will not be able to prove your viewpoint.	AZ
The biggest risk is BAM Infra. It is essential that we stick to our plan, and develop a concept into detail and then implement it in our current way of working. However, there will be resistance to this innovation. Therefore the implementation will not be easy. However, we have to stick to our plan, be dedicated and not quit when things get hard.	AZ
It is important that the architects and the design team are aware of what effect their decision will have, considering time, costs, quality, etc. You will have to show the architect and the team that we can develop viaducts on lower costs. Therefore you should set up a program to develop your idea future. A group of employees (entity) needs to be appointed that investigates and develops the idea future. Someone has to take this responsibility. This team then becomes responsible for this goal.	AZ
We just have to start with implementing/applying the concept. We have to make a choice about what our standard will be. From this standard, we should derive different designs, by adaptation of the standard, to meet the specific situation. Currently, the market needs to be convinced. Change always takes time. However, if we apply the concept, we will see that it will result in less expensive projects/objects.	PW
Paul Waarts points out that currently there is not standard. A standard will need to be designed or chosen. Currently, it is general interest. Therefore nobody feels responsible. Therefore, we just have to demand to work with BIM, based on a standard, this will facilitate the implementation of a product platform.	PW

Considering BAM, we first need to develop a standard. All the ambitions have to be analysed and need to be considered how these will fit within a standard concept. The standard still should remain flexible, to stay interesting for different clients. Again a trade-off will need to be made, considering the amount of freedom (flexibility) and the amount of standardisation.	LH
A standard design will need to be developed, and this has to be continually updated and further developed. It is important to have on shared goal considering the standard design. As there are no clear goals and no clear standard, everybody will go their own way. This makes it important that the standard is clearly documented. When you try to develop a standard, it is important to also verify the ideas and decision that have to be made with the other involved parties, for example, the "welstandcommisie", RWS, different suppliers, etc. In addition, it is important that you make use of already established materials/products/elements. Eventually, you will then have a well-tried, proven concept. This standard then can be used in the different situations.	LH
Adapting the structure	
Van Schagen states that although it is possible, it is not realistic that the current structures will be adapted in the future. He thinks it is more likely that a new structure will be built next to the current construction.	FS
It would be a good idea to already think of how we can adapt the objects to the changed market situation over time. It could be beneficial, referring to the new contract forms.	KL
Currently not asked by RWS	JB
It is possible to design a viaduct that can be more easily adapted to changing circumstances. However, developments go fast and, as also the standard concept will be developed further, so the question is if the new "Lego-blocks" will comply with the old blocks.	LH
Click-system	
In theory, this could be possible, but in practice Folkert van Schagen does not think this will be realistic. The current norms will not provide sufficient freedom to implement a click-system. Moreover, currently mainly concrete is applied, the structure is not demountable. Considering a railway underpass, this object is constructed next to the site, by an in-situ process. He points out the pre-fabricated parts are not used, as they are not easy to transport to the side. Moreover, when prefabrication is possible, it is more expensive that when constructed in-situ.	FS
Johan Bolhuis thinks it is possible but is of the opinion that this is too expensive. Maybe that eventually, considering the total life cycle, applying a click-system can be cheaper than our current practices. However, the initial costs, to start working this way, are very high. The client (RWS) should specify this. Otherwise, the construction industry will not see a need to develop a click-system.	JB
We can always make the connections between the elements in a way that the components can be easily connected. Appling bolts and nuts (bouten en moeren) is possible as well. A supplier of aluminium edge profiles (randelementen) has developed a system that could be easily constructed. The different element (edge profiles) could just be hanged on a framework that was connected to beams of the deck. The different elements did not need to be firmed to this framework; they could just be hanged up, and no additional bolts and nuts were needed. This is an innovation that could be very useful and will have benefits considering the maintenance and ability to make the construction demountable.	LH
Innovation	
Avinash Gangaram-Panday points out that there is not sufficient time for the initiative to be developed further. Currently, the further development is established when limited work is procured. Then there is time to continue with the researches. There will need to be a budget for an initiative to be further developed (time and money).	AGP
Innovation is a substantial part of the project, the risks for the contractor apply an innovation are too high. "You then cannot take the gamble, the projects are too large, and the contract conditions are too strict." If we want to stimulate innovation, it is essential to have a dialogue about what the impact/consequences will be for certain requirements listed and decisions made. (the oil and gas industry apply a procedure/contract that makes it possible to innovate)	AH
If you want to design a new concept, it has to come from the current situation and the future circumstances. Just developing an innovation without analysing the current situation and the future situation will not be successful.	AH
Current contract forms do not give sufficient freedom for innovation, as the risks for the construction firm are too high.	JB

TABLE OF CONTENT: APPLICATION OF THE DEVELOPED METHOD

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- C10-2B: Outcome - Table Coupling-Indexes - Direct relations – Session

C.11 Combined results and conclusion

- C11-1: Combined results – Session structural engineers with average parametric indexes
- C11-2: Combined results - Individual outcomes structural engineers with session
- C11-3: Combined results - Individual outcome structural engineers
- C11-4: Conclusion – Method applied – With not clear
- C11-5: Conclusion – Method applied – Without not clear

C1-1: General Variety Index - Template

General Variety Index (GVI)

Give numbers: 1, 3, 6, 9

Weight factor - Chance of occurence/likely to happen: 1,2,3

By:

Prefabricated concrete viaduct (NL)

			Foundation		Substructure				Superstructure							Bearings, expansion joints and approach slab				Non- structural components						
									Core	*Extension*																
		Chance of occurence/ likely to happen	Foundation pad (sloof for intermediate wall/column(s))	Foundation piles	Intermediate wall/colomn(s)	Abutment or bank seat (including foundation pad)	Capping beam	Wing walls	Deck: prefabricated beams (box-beams)	Edge beam: prefabricated	Pavement: Asphalt	Edge element (finishing)	Parapets (pedestrians + traffic)	Upstand (schamkant)	Safety guards (Geleiderail)	Bearings	Expansion joints(abutment/bank seat and deck + beams at the location of the intermediate pier)	Connection between approach slab and abutment/bankseat	Approach slab	Traffic signs	Lighting	Cables	Water drainage	Camera's and sensors	Sum: GVI	Sum, with weight factor: GVI*factor
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22		
A	**Location-specific constraints**																									
A1	Length of the span																								0	0
A2	Space available (build within urban area or outside urban area)																								0	0
A3	Crossing with other infrastructure																								0	0
A4	Underlying road underneath the deck (traffic interruption)																								0	0
A5	Soil-conditions																								0	0
A6	Depth of the load bearing layer																								0	0
A7	Design speed/velocity traffic under the viaduct																								0	0
A8	Design speed/velocity on the viaduct.																								0	0
A9	Clearance (profile of free space, height construction)																								0	0
A10	Angle of crossing																								0	0
A11	Talud/slope																								0	0
A13																									0	0
B	**Changes in demand and wishes of the client**																									
B1	Width and amount of roads																								0	0
B2	Functions of these roads (pedestrian, bicycles, cars, trucks)																								0	0
B3	Esthetic appearance: Edge beams, edge element and colum																								0	0
B5	Sustainability: Client wants more sustainable objects																								0	0
B6	Demand faster building times																								0	0
B7	Viaduct should be adaptable: possibility to expend																								0	0
B8	Building demountable																								0	0
B9	Less impact/effect on the surrounding area																								0	0
B10	Increasing wishes of clients for less trafic interruption.																								0	0
B11																									0	0
C	**Changes in regulations**																									
C1	Increasing regulations - general design of construction																								0	0
C2	Decreasing regulation - general design of construction																								0	0
C3	Increasing regulations - sustainability																								0	0
C4	Decreasing regulation - sustainability																								0	0
C5	Increasing regulations - safety (during construction)																								0	0
C6	Increasing regulations - safety (utilization phase)																								0	0
C7	Increasing regulations - safety (inspection+maintenance)																								0	0
C8	Design speed/velocity of the road changes (goverment)																								0	0
C9																									0	0
D	**Possible trends**																									

D1	Road-use decreases: Less traffic																								0	0
D2	Vehicles become less heavy or become heavier																								0	0
D3	Vehicles become bigger/smaller in width and height																								0	0
D5	Changing weather circumstances (more heavy rainfall)																								0	0
D6	Scarcity of materials																								0	0
D7	Appliance of new innovative materials (example: composite)																								0	0
D8	Development of new type of construction																								0	0
D9	3D-printing																								0	0
D10	Independent driving cars																								0	0
D11																									0	0
E	Facilitation of new/extra functions																									
E1	Generate electric energy out of the "vibrations																								0	0
E2	Add smart and/or interactive guidance (like lights that respond)																								0	0
E3																									0	0
	Sum		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		

F	Other influences that also have to be incorporated in the table																									
F1	Buiding with limited vibration (Trillingsvrij bouwen)																								0	0
F2	Durability - levensduur																								0	0
F3	Maintenance (door DBFM(O) contract)																								0	0
F4	EMVI-citeria (invloed EMVI-criteria algemeen)																								0	0
	Sum (additional influences)																									
	Sum table + Sum additional influences																									

C1-2: Table Coupling-Index - Template - Direct constructive relations

Coupling - index: Direct constructive relations

Give numbers of 1,3,6 or 9

Prefabricated concrete viaduct (NL)

			Foundation		Substructure				Superstructure							Bearings, expansion joints and approach slab				Non- structural components					
									Core		*Extension*														
		B	Foundation pad (pad for intermediate wall/column(s))	Foundation piles	Intermediate wall/column(s)	Abutment or bank seat (including foundation pad)	Capping beam	Wing walls	Deck: prefabricated beams (box-beams)	Edge beam: prefabricated	Pavement: Asphalt	Edge element (finishing)	Parapets (pedestrians + traffic)	Upstand (schampkant)	Safety guards	Bearings	Expansion joints(abutment/bank seat and deck + beams at the location of the intermediate pier)	Connection between approach slab and abutment/bankseat	Approach slab	Traffic signs	Lighting	Cables	Water drianage	Camara's and sensors	CI-S (supply)
A			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
Foundation																									
	Foundation pad	1																							0
	Foundation piles	2																							0
Substructure																									0
	Intermediate wall/column(s)	3																							0
	Abutment or bank seat	4																							0
	Capping beam	5																							0
	Wing walls	6																							0
Superstructure																									0
Core elements	Deck: prefabricated beams	7																							0
	Edge beam: prefabricated beams	8																							0
Extension	Pavement: Asphalt	9																							0
	Edge element (finishing)	10																							0
	Parapets (pedestrians+ traffic)	11																							0
	Upstand (schampkant)	12																							0
	Safety guards	13																							0
Bearings, expansion joints and transition slab																									
	Bearings	14																							0
	Expansion joints	15																							0
	Connection between	16																							0
	Approach slab	17																							0
Non- structural components:																									
	Traffic signs	18																							0
	Lighting	19																							0
	Cables	20																							0
	Water drainage	21																							0
	Camera's and sensors	22																							0
CI -R (recieve)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

C1-3: Table Coupling-Index - Template - Parametric constructive relations

Coupling - index: Parametric relations Give numbers 1,3,6 or 9 Prefabricated concrete viaduct (NL)			Foundation		Substructure				Superstructure							Bearings, expansion joints and approach slab				Non- structural components					CI-S (supply)
									Core		*Extension*														
			Foundation pad (pad for intermediate wall/column(s))	Foundation piles	Intermediate wall/colomn(s)	Abutment or bank seat (including foundation pad)	Capping beam	Wing walls	Deck: prefabricated beams (box-beams)	Edge beam: prefabricated	Pavement: Asphalt	Edge element (finishing)	Parapets (pedestrians + traffic)	Upstand (schampkant)	Safety guards	Bearings	Expansion joints(abutment/bank seat and deck + beams at the location of the intermediate pier)	Connection between approach slab and abutment/bankseat	Approach slab	Traffic signs	Lighting	Cables	Water drianage	Camara's and sensors	
A		B	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
Foundation																									
	Foundation pad	1																							0
	Foundation piles	2																							0
Substructure																									0
	Intermediate wall/colomn	3																							0
	Abutment or bank seat	4																							0
	Capping beam	5																							0
	Wing walls	6																							0
Superstructure																									0
Core elements	Deck: prefabricated beams	7																							0
	Edge beam: prefabricated beams	8																							0
Extension	Pavement: Asphalt	9																							0
	Edge element (finishing)	10																							0
	Parapets (pedestrians+ traffic)	11																							0
	Upstand (schampkant)	12																							0
	Safety guards	13																							0
Bearings, expansion joints and transition slab																									
	Bearings	14																							0
	Expension joints	15																							0
	Connection between	16																							0
	Approach slab	17																							0
Non- structural components:																									
	Traffic signs	18																							0
	Lighting	19																							0
	Cables	20																							0
	Water drainage	21																							0
	Camera's and sensors	22																							0
CI -R (recieve)			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

C2-1: Results filled in tables - Structural engineer individually - Gerard Waayer

Results - Gerard Waayer		GVI	CI-R - Direct	CI-R Parametric	CI-S - Direct	CI-S - Parametric
		1	2	3	4	5
Foundation pad	1	97	4	21	2	32
Foundation piles	2	76	2	29	2	35
Intermediate wall/column(s)	3	67	7	24	6	32
Abutment or bank seat	4	127	50	55	38	31
Capping beam	5	104	30	31	30	28
Wing walls	6	61	3	36	4	22
Deck: prefabricated beams	7	142	36	63	37	46
Edge beam: prefabricated beams	8	104	51	78	52	52
Pavement: Asphalt	9	94	17	49	24	24
Edge element (finishing)	10	57	10	18	9	30
Parapets (pedestrians+ traffic)	11	31	6	27	3	21
Upstand (schampkant)	12	33	6	23	11	45
Safety guards	13	34	6	16	0	24
Bearings	14	88	24	21	36	36
Expansion joints	15	64	27	18	27	36
Connection between	16	58	9	15	15	18
Approach slab	17	39	15	18	9	30
Traffic signs	18	0	0	0	0	0
Lighting	19	0	0	0	0	0
Cables	20	0	1	0	0	0
Water drainage	21	0	1	0	0	0
Camera's and sensors	22	0	0	0	0	0

C2-2: Results filled in tables - Structural engineer individually - Avinash Gangaram Panday

Results - Avinash Gangaram Pandey		GVI	CI-R - direct	CI-R parametric	CI-S - direct	CI-S - parametric
		1	2	3	4	5
Foundation pad	1	29	7	14	2	2
Foundation piles	2	45	2	8	12	12
Intermediate wall/column(s)	3	31	4	6	7	13
Abutment or bank seat	4	33	14	27	10	19
Capping beam	5	30	9	20	8	16
Wing walls	6	0	4	4	1	1
Deck: prefabricated beams	7	40	5	11	9	22
Edge beam: prefabricated beams	8	38	8	18	22	18
Pavement: Asphalt	9	19	3	3	4	2
Edge element (finishing)	10	4	6	7	4	8
Parapets (pedestrians+ traffic)	11	0	9	0	3	3
Upstand (schampkant)	12	2	5	1	16	0
Safety guards	13	10	10	0	1	0
Bearings	14	43	12	18	4	14
Expansion joints	15	63	8	10	4	13
Connection between	16	30	5	6	4	7
Approach slab	17	0	4	6	4	9
Traffic signs	18	0	0	0	0	0
Lighting	19	0	0	0	0	0
Cables	20	0	0	0	0	0
Water drainage	21	0	0	0	0	0
Camera's and sensors	22	0	0	0	0	0

Results - Maarten de Moel		GVI	CI-R - direct	CI-R parametric	CI-S - direct	CI-S - parametric
		1	2	3	4	5
Foundation pad	1	147	12	21	13	22
Foundation piles	2	171	25	30	15	15
Intermediate wall/column(s)	3	137	6	18	6	15
Abutment or bank seat	4	152	32	32	36	32
Capping beam	5	131	21	27	11	22
Wing walls	6	50	8	2	4	15
Deck: prefabricated beams	7	176	16	22	31	43
Edge beam: prefabricated beams	8	182	25	28	24	41
Pavement: Asphalt	9	86	1	2	21	21
Edge element (finishing)	10	21	7	13	10	5
Parapets (pedestrians+ traffic)	11	27	0	2	7	2
Upstand (schampkant)	12	23	24	10	12	4
Safety guards	13	39	0	1	3	3
Bearings	14	31	15	19	18	9
Expansion joints	15	35	15	10	7	5
Connection between	16	24	7	5	2	3
Approach slab	17	12	2	2	4	2
Traffic signs	18	33	1	0	1	0
Lighting	19	33	3	3	1	0
Cables	20	20	5	5	3	0
Water drainage	21	13	6	7	3	0
Camera's and sensors	22	24	1	0	0	0

C2-3: Results filled in tables - Structural engineer individually - Maarten de Moel

C2-4: Results filled in tables - Structural eningeer individually - Maurice Hol

Results - Maurice Hol		GVI	CI-R - direct	CI-R parametric	CI-S - direct	CI-S - parametric
		1	2	3	4	5
Foundation pad	1	89	9	10	11	22
Foundation piles	2	83	13	6	7	47
Intermediate wall/column(s)	3	99	15	21	14	19
Abutment or bank seat	4	113	50	9	35	40
Capping beam	5	108	35	5	24	30
Wing walls	6	87	19	4	7	3
Deck: prefabricated beams	7	110	32	46	43	18
Edge beam: prefabricated beams	8	107	54	45	44	25
Pavement: Asphalt	9	43	14	41	22	0
Edge element (finishing)	10	48	19	19	18	6
Parapets (pedestrians+ traffic)	11	54	3	17	15	0
Upstand (schampkant)	12	82	67	20	30	46
Safety guards	13	90	2	11	14	0
Bearings	14	55	24	14	18	29
Expansion joints	15	87	37	0	52	15
Connection between	16	31	4	1	4	3
Approach slab	17	68	5	12	11	6
Traffic signs	18	0	2	5	14	0
Lighting	19	0	2	5	14	0
Cables	20	4	37	8	22	0
Water drainage	21	36	14	8	28	0
Camera's and sensors	22	0	2	3	12	0

C2-5: Results filled in tables - Structural engineer individually - Tristan Wolvekamp

Results - Tristan Wolvekamp		GVI	CI-R - direct	CI-R parametric	CI-S - direct	CI-S - parametric
		1	2	3	4	5
Foundation pad	1	129	16	16	18	16
Foundation piles	2	153	17	43	18	18
Intermediate wall/column(s)	3	177	18	16	16	16
Abutment or bank seat	4	162	55	57	89	65
Capping beam	5	126	23	23	18	25
Wing walls	6	81	16	4	16	11
Deck: prefabricated beams	7	190	43	43	56	69
Edge beam: prefabricated beams	8	205	53	66	65	57
Pavement: Asphalt	9	123	57	57	36	49
Edge element (finishing)	10	93	31	24	47	40
Parapets (pedestrians+ traffic)	11	82	10	17	30	37
Upstand (schampkant)	12	123	91	87	76	74
Safety guards	13	109	24	24	6	10
Bearings	14	117	36	38	14	14
Expansion joints	15	108	35	33	51	58
Connection between	16	42	9	5	9	9
Approach slab	17	42	9	3	18	18
Traffic signs	18	25	5	5	3	3
Lighting	19	51	17	15	3	7
Cables	20	15	19	17	7	7
Water drainage	21	102	25	25	18	18
Camera's and sensors	22	25	8	6	3	7

C2-6: *Summary of results - Structural eningeer individually*

GVI - General		GVI - GW	GVI - APG	GVI - MM	GVI - TW	GVI - MH	
		1	2	3	4	5	
Foundation pad	1	97	29	147	129	89	
Foundation piles	2	76	45	171	153	83	
Intermediate wall/colomn(s)	3	67	31	137	177	99	
Abutment or bank seat	4	127	33	152	162	113	
Capping beam	5	104	30	131	126	108	
Wing walls	6	61	0	50	81	87	
Deck (prefabricated beams)	7	142	40	176	190	110	
Edge beam: prefabricated beams	8	104	38	182	205	107	
Pavement: Asphalt	9	94	19	86	123	43	
Edge element (finishing)	10	57	4	21	93	48	
Parapets (pedestrians+ traffic)	11	31	0	27	82	54	
Upstand (schampkant)	12	33	2	23	123	82	
Safety guards	13	34	10	39	109	90	
Bearings	14	88	43	31	117	55	
Expension joints	15	64	63	35	108	87	
Connection between	16	58	30	24	42	31	
Approach slab	17	39	0	12	42	68	
Traffic signs	18	0	0	33	25	0	
Lighting	19	0	0	33	51	0	
Cables	20	0	0	20	15	4	
Water drainage	21	0	0	13	102	36	
Camera's and sensors	22	0	0	24	25	0	

C3-1: Results GVI-general - Structural engineer individually - Ranked

GVI - General	component number	GVI - GW
Abutment or bank seat	4	127
Capping beam	5	104
Edge beam: prefabricated beams	8	104
Foundation pad	1	97
Pavement: Asphalt	9	94
Bearings	14	88
Foundation piles	2	76
Intermediate wall/colomn(s)	3	67
Expension joints	15	64
Wing walls	6	61
Connection between	16	58
Edge element (finishing)	10	57
Approach slab	17	39
Safety guards	13	34
Upstand (schampkant)	12	33
Parapets (pedestrians+ traffic)	11	31
Traffic signs	18	0
Lighting	19	0
Cables	20	0
Water drainage	21	0
Camera's and sensors	22	0

GVI - General	component number	GVI - MM
Edge beam: prefabricated beams	8	182
Foundation piles	2	171
Abutment or bank seat	4	152
Foundation pad	1	147
Intermediate wall/colomn(s)	3	137
Capping beam	5	131
Pavement: Asphalt	9	86
Wing walls	6	50
Safety guards	13	39
Expension joints	15	35
Traffic signs	18	33
Lighting	19	33
Bearings	14	31
Parapets (pedestrians+ traffic)	11	27
Connection between	16	24
Camera's and sensors	22	24
Upstand (schampkant)	12	23
Edge element (finishing)	10	21
Cables	20	20
Water drainage	21	13
Approach slab	17	12

GVI - General	component number	GVI - MH
Abutment or bank seat	4	113
Capping beam	5	108
Edge beam: prefabricated beams	8	107
Intermediate wall/colomn(s)	3	99
Safety guards	13	90
Foundation pad	1	89
Wing walls	6	87
Expension joints	15	87
Foundation piles	2	83
Upstand (schampkant)	12	82
Approach slab	17	68
Bearings	14	55
Parapets (pedestrians+ traffic)	11	54
Edge element (finishing)	10	48
Pavement: Asphalt	9	43
Water drainage	21	36
Connection between	16	31
Cables	20	4
Traffic signs	18	0
Lighting	19	0
Camera's and sensors	22	0

GVI - General	component number	GVI - APG
Expension joints	15	63
Foundation piles	2	45
Bearings	14	43
Edge beam: prefabricated beams	8	38
Abutment or bank seat	4	33
Intermediate wall/colomn(s)	3	31
Capping beam	5	30
Connection between	16	30
Foundation pad	1	29
Pavement: Asphalt	9	19
Safety guards	13	10
Edge element (finishing)	10	4
Upstand (schampkant)	12	2
Wing walls	6	0
Parapets (pedestrians+ traffic)	11	0
Approach slab	17	0
Traffic signs	18	0
Lighting	19	0
Cables	20	0
Water drainage	21	0
Camera's and sensors	22	0

GVI - General	component number	GVI - TW
Edge beam: prefabricated beams	8	205
Intermediate wall/colomn(s)	3	177
Abutment or bank seat	4	162
Foundation piles	2	153
Foundation pad	1	129
Capping beam	5	126
Pavement: Asphalt	9	123
Upstand (schampkant)	12	123
Bearings	14	117
Safety guards	13	109
Expension joints	15	108
Water drainage	21	102
Edge element (finishing)	10	93
Parapets (pedestrians+ traffic)	11	82
Wing walls	6	81
Lighting	19	51
Connection between	16	42
Approach slab	17	42
Traffic signs	18	25
Camera's and sensors	22	25
Cables	20	15

GVI - General	component number	Average GVI
Edge beam: prefabricated beams	8	127,2
Abutment or bank seat	4	117,4
Foundation piles	2	105,6
Intermediate wall/colomn(s)	3	102,2
Capping beam	5	99,8
Foundation pad	1	98,2
Pavement: Asphalt	9	73
Expension joints	15	71,4
Bearings	14	66,8
Safety guards	13	56,4
Wing walls	6	55,8
Upstand (schampkant)	12	52,6
Edge element (finishing)	10	44,6
Parapets (pedestrians+ traffic)	11	38,8
Connection between	16	37
Approach slab	17	32,2
Water drainage	21	30,2
Lighting	19	16,8
Traffic signs	18	11,6
Camera's and sensors	22	9,8
Cables	20	7,8

C3-2: Overview results GVI-general - Structural engineer individually

GVI - General - Analysis highest values (1-5)	component number	GVI - GW	GVI - APG	GVI - MM	GVI - TW	GVI - MH	Sum
		1	2	3	4	5	
Foundation pad	1	5	10	5	6	7	33
Foundation piles	2	8	2	3	5	10	28
Intermediate wall/colomn(s)	3	9	7	6	3	5	30
Abutment or bank seat	4	2	6	4	4	1	16
Capping beam	5	3	8	7	7	3	25
Wing walls	6	11	15	9	15	8	50
Deck: prefabricated beams	7	1	4	2	2	2	9
Edge beam: prefabricated beams	8	4	5	1	1	4	11
Pavement: Asphalt	9	6	11	8	8	16	49
Edge element (finishing)	10	13	13	16	13	15	70
Parapets (pedestrians+ traffic)	11	17	16	13	14	14	74
Upstand (schampkant)	12	16	14	15	9	11	65
Safety guards	13	15	12	10	11	6	54
Bearings	14	7	3	12	10	13	45
Expension joints	15	10	1	11	12	9	43
Connection between	16	12	9	14	16	17	68
Approach slab	17	14	17	17	17	12	77

GVI - General - Analysis lowest values (1-5)	component number	GVI - GW	GVI - APG	GVI - MM	GVI - TW	GVI - MH	Sum
		1	2	3	4	5	
Foundation pad	1	13	8	13	12	11	57
Foundation piles	2	10	16	15	13	8	62
Intermediate wall/colomn(s)	3	9	11	12	15	13	60
Abutment or bank seat	4	16	12	14	14	17	56
Capping beam	5	15	10	11	11	15	47
Wing walls	6	7	3	9	3	10	22
Deck: prefabricated beams	7	17	14	16	16	16	63
Edge beam: prefabricated beams	8	14	13	17	17	14	61
Pavement: Asphalt	9	12	7	10	10	2	41
Edge element (finishing)	10	5	5	2	5	3	20
Parapets (pedestrians+ traffic)	11	1	2	5	4	4	16
Upstand (schampkant)	12	2	4	3	9	7	25
Safety guards	13	3	6	8	7	12	36
Bearings	14	11	15	6	8	5	45
Expension joints	15	8	17	7	6	9	47
Connection between	16	6	9	4	2	1	22
Approach slab	17	4	1	1	1	6	13

C3-3: Overview results GVI-general - Structural engineer individually - Ranked

Highest value	GVI - General - Ranked highest values (1-5)	component number	GVI - GW	GVI - APG	GVI - MM	GVI - TW	GVI - MH		Sum
			1	2	3	4	5		
1	Deck: prefabricated beams	7	1	4	2	2	2		9
2	Edge beam: prefabricated beams	8	4	5	1	1	4		11
3	Abutment or bank seat	4	2	6	4	4	1		16
4	Capping beam	5	3	8	7	7	3		25
5	Foundation piles	2	8	2	3	5	10		28
6	Intermediate wall/colomn(s)	3	9	7	6	3	5		30
7	Foundation pad	1	5	10	5	6	7		33
8	Expension joints	15	10	1	11	12	9		43
9	Bearings	14	7	3	12	10	13		45
10	Pavement: Asphalt	9	6	11	8	8	16		49
11	Wing walls	6	11	15	9	15	8		50
12	Safety guards	13	15	12	10	11	6		54
13	Upstand (schampkant)	12	16	14	15	9	11		65
14	Connection between	16	12	9	14	16	17		68
15	Edge element (finishing)	10	13	13	16	13	15		70
16	Parapets (pedestrians+ traffic)	11	17	16	13	14	14		74
17	Approach slab	17	14	17	17	17	12		77

Lowest value	GVI - General - Ranked lowest values (1-5)	component number	GVI - GW	GVI - APG	GVI - MM	GVI - TW	GVI - MH		Sum
			1	2	3	4	5		
1	Approach slab	17	4	1	1	1	6		13
2	Parapets (pedestrians+ traffic)	11	1	2	5	4	4		16
3	Edge element (finishing)	10	5	5	2	5	3		20
4	Wing walls	6	7	3	9	3	10		22
5	Connection between	16	6	9	4	2	1		22
6	Upstand (schampkant)	12	2	4	3	9	7		25
7	Safety guards	13	3	6	8	7	12		36
8	Pavement: Asphalt	9	12	7	10	10	2		41
9	Bearings	14	11	15	6	8	5		45
10	Capping beam	5	15	10	11	11	15		47
11	Expension joints	15	8	17	7	6	9		47
12	Abutment or bank seat	4	16	12	14	14	17		56
13	Foundation pad	1	13	8	13	12	11		57
14	Intermediate wall/colomn(s)	3	9	11	12	15	13		60
15	Edge beam: prefabricated beams	8	14	13	17	17	14		61
16	Foundation piles	2	10	16	15	13	8		62
17	Deck: prefabricated beams	7	17	14	16	16	16		63

C4-1: Results GVI*factor - Structural engineer individually - Ranked

GVI * factor - General		GVI * factor - GW	Highest value	Lowest value
Deck: prefabricated beams	7	280	1	17
Abutment or bank seat	4	251	2	16
Edge beam: prefabricated bea	8	238	3	15
Capping beam	5	215	4	14
Intermediate wall/colomn(s)	3	210	5	13
Foundation pad	1	198	6	12
Bearings	14	165	7	11
Pavement: Asphalt	9	158	8	10
Foundation piles	2	152	9	9
Expension joints	15	128	10	8
Connection between	16	110	11	7
Wing walls	6	102	12	6
Edge element (finishing)	10	81	13	5
Approach slab	17	80	14	4
Safety guards	13	53	15	3
Upstand (schampkant)	12	47	16	2
Parapets (pedestrians+ traffic	11	41	17	1
Traffic signs	18	0		
Lighting	19	0		
Cables	20	0		
Water drainage	21	0		
Camera's and sensors	22	0		

GVI * factor - General		GVI * factor - MM	Highest value	Lowest value
Edge beam: prefabricated beams	8	441	1	17
Deck: prefabricated beams	7	429	2	16
Foundation piles	2	424	3	15
Abutment or bank seat	4	372	4	14
Foundation pad	1	336	5	13
Intermediate wall/colomn(s)	3	334	6	12
Capping beam	5	317	7	11
Pavement: Asphalt	9	168	8	10
Wing walls	6	138	9	9
Expension joints	15	93	10	8
Bearings	14	81	11	7
Connection between	16	63	12	6
Upstand (schampkant)	12	48	13	5
Safety guards	13	45	14	4
Traffic signs	18	30		
Lighting	19	30		
Edge element (finishing)	10	27	15	3
Approach slab	17	27	16	2
Water drainage	21	27		
Parapets (pedestrians+ traffic)	11	21	17	1
Cables	20	20		
Camera's and sensors	22	18		

GVI * factor - General		GVI * factor - MH	Highest value	Lowest value
Abutment or bank seat	4	253	1	17
Capping beam	5	229	2	16
Deck: prefabricated beams	7	229	3	15
Expension joints	15	216	4	14
Foundation piles	2	209	5	13
Edge beam: prefabricated beam	8	208	6	12
Intermediate wall/colomn(s)	3	201	7	11
Foundation pad	1	200	8	10
Safety guards	13	186	9	9
Wing walls	6	183	10	8
Approach slab	17	175	11	7
Upstand (schampkant)	12	156	12	6
Bearings	14	127	13	5
Pavement: Asphalt	9	98	14	4
Parapets (pedestrians+ traffic)	11	93	15	3
Water drainage	21	87		
Edge element (finishing)	10	75	16	2
Connection between	16	56	17	1
Cables	20	12		
Traffic signs	18	0		
Lighting	19	0		
Camera's and sensors	22	0		

GVI * factor - General		GVI * factor - APG	Highest value	Lowest value
Expension joints	15	135	1	17
Bearings	14	95	2	16
Deck: prefabricated beams	7	84	3	15
Foundation piles	2	83	4	14
Edge beam: prefabricated bea	8	81	5	13
Abutment or bank seat	4	68	6	12
Intermediate wall/colomn(s)	3	66	7	11
Connection between	16	66	8	10
Capping beam	5	65	9	9
Foundation pad	1	61	10	8
Pavement: Asphalt	9	37	11	7
Safety guards	13	24	12	6
Edge element (finishing)	10	11	13	5
Upstand (schampkant)	12	2	14	4
Wing walls	6	0	15	3
Parapets (pedestrians+ traffic	11	0	16	2
Approach slab	17	0	17	1
Traffic signs	18	0		
Lighting	19	0		
Cables	20	0		
Water drainage	21	0		
Camera's and sensors	22	0		

GVI * factor - General		GVI * factor - TW	Highest value	Lowest value
Edge beam: prefabricated beams	8	472	1	17
Deck: prefabricated beams	7	436	2	16
Intermediate wall/colomn(s)	3	411	3	15
Abutment or bank seat	4	363	4	14
Foundation piles	2	348	5	13
Foundation pad	1	282	6	12
Capping beam	5	273	7	11
Bearings	14	267	8	10
Pavement: Asphalt	9	261	9	9
Water drainage	21	261		
Expension joints	15	240	10	8
Upstand (schampkant)	12	228	11	7
Edge element (finishing)	10	189	12	6
Safety guards	13	182	13	5
Parapets (pedestrians+ traffic)	11	143	14	4
Wing walls	6	135	15	3
Lighting	19	108		
Connection between	16	69	16	2
Approach slab	17	69	17	1
Cables	20	39		
Camera's and sensors	22	30		
Traffic signs	18	27		

GVI * factor - General		Average GVI * facto	Highest value	Lowest value
Deck: prefabricated beams	7	291,6	1	17
Edge beam: prefabricated beam	8	288	2	16
Abutment or bank seat	4	261,4	3	15
Intermediate wall/colomn(s)	3	244,4	4	14
Foundation piles	2	243,2	5	13
Capping beam	5	219,8	6	12
Foundation pad	1	215,4	7	11
Expension joints	15	162,4	8	10
Bearings	14	147	9	9
Pavement: Asphalt	9	144,4	10	8
Wing walls	6	111,6	11	7
Safety guards	13	98	12	6
Upstand (schampkant)	12	96,2	13	5
Edge element (finishing)	10	76,6	14	4
Water drainage	21	75		
Connection between	16	72,8	15	3
Approach slab	17	70,2	16	2
Parapets (pedestrians+ traffic)	11	59,6	17	1
Lighting	19	27,6		
Cables	20	14,2		
Traffic signs	18	11,4		
Camera's and sensors	22	9,6		

C4-2A: Overview results GVI*factor - Structural engineer individually

Highest values	GVI* factor - Analysis highest values (1-5)	component number	GVI* factor - GW	GVI*factor - APG	GVI*factor - MM	GVI*factor - TW	GVI*factor - MH		Sum	GVI*factor - Average
			1	2	3	4	5			
7	Foundation pad	1	6	10	5	6	8		35	7
4	Foundation piles	2	9	4	3	5	5		26	5
6	Intermediate wall/colomn(s)	3	5	7	6	3	7		28	4
3	Abutment or bank seat	4	2	6	4	4	1		16	3
5	Capping beam	5	4	9	7	7	2		27	6
11	Wing walls	6	12	15	9	15	10		51	11
1	Deck: prefabricated beams	7	1	3	2	2	3		8	1
2	Edge beam: prefabricated beams	8	3	5	1	1	6		10	2
10	Pavement: Asphalt	9	8	11	8	9	14		50	10
15	Edge element (finishing)	10	13	13	15	12	16		69	14
17	Parapets (pedestrians+ traffic)	11	17	16	17	14	15		79	17
14	Upstand (schampkant)	12	16	14	13	11	12		66	13
12	Safety guards	13	15	12	14	13	9		63	12
9	Bearings	14	7	2	11	8	13		41	9
8	Expension joints	15	10	1	10	10	4		35	8
13	Connection between	16	11	8	12	16	17		64	15
16	Approach slab	17	14	17	16	17	11		75	16

Lowest values	GVI* factor - Analysis lowest values (1-5)	component number	GVI* factor - GW	GVI*factor - APG	GVI*factor - MM	GVI*factor - TW	GVI*factor - MH		Sum	GVI*factor - Average
			1	2	3	4	5			
11	Foundation pad	1	12	8	13	12	10		55	11
16	Foundation piles	2	9	14	15	13	13		64	13
14	Intermediate wall/colomn(s)	3	13	11	12	15	11		62	14
13	Abutment or bank seat	4	16	12	14	14	17		56	15
9	Capping beam	5	14	9	11	11	16		45	12
3	Wing walls	6	6	3	9	3	8		21	7
17	Deck: prefabricated beams	7	17	15	16	16	15		64	17
15	Edge beam: prefabricated beams	8	15	13	17	17	12		62	16
8	Pavement: Asphalt	9	10	7	10	9	4		40	8
4	Edge element (finishing)	10	5	5	3	6	2		21	4
1	Parapets (pedestrians+ traffic)	11	1	2	1	4	3		11	1
5	Upstand (schampkant)	12	2	4	5	7	6		24	5
7	Safety guards	13	3	6	4	5	9		27	6
10	Bearings	14	11	16	7	10	5		49	9
12	Expension joints	15	8	17	8	8	14		55	10
6	Connection between	16	7	10	6	2	1		26	3
2	Approach slab	17	4	1	2	1	7		15	2

C4-2B: Overviewresults GVI*factor - Structural engineerindividually

GVI* factor	component number	GVI*factor - Highest	GVI*factor - Lowest	GVI*factor - Low,Medium,high
Foundation pad	1	7	11	Medium
Foundation piles	2	5	13	High
Intermediate wall/colomn(s)	3	4	14	High
Abutment or bank seat	4	3	15	High
Capping beam	5	6	12	Medium
Wing walls	6	11	7	Medium
Deck: prefabricated beams	7	1	17	High
Edge beam: prefabricated beams	8	2	16	High
Pavement: Asphalt	9	10	8	Medium
Edge element (finishing)	10	14	4	Low
Parapets (pedestrians+ traffic)	11	17	1	Low
Upstand (schampkant)	12	13	5	Low
Safety guards	13	12	6	Medium
Bearings	14	9	9	Medium
Expension joints	15	8	10	Medium
Connection between	16	15	3	Low
Approach slab	17	16	2	Low

C5-1: Difference between GVI-general and GVI*factor

GVI	component number	GVI - Ranked: high	GVI Ranked: lowest	GVI: Low,Medium,High
Foundation pad	1	7	13	Medium
Foundation piles	2	5	16	High
Intermediate wall/colomn(s)	3	6	14	Medium
Abutment or bank seat	4	3	12	High
Capping beam	5	4	10	High
Wing walls	6	11	4	Low
Deck: prefabricated beams	7	1	17	High
Edge beam: prefabricated beams	8	2	15	High
Pavement: Asphalt	9	10	8	Medium
Edge element (finishing)	10	15	3	Low
Parapets (pedestrians+ traffic)	11	16	2	Low
Upstand (schampkant)	12	13	6	Medium
Safety guards	13	12	7	Medium
Bearings	14	9	9	Medium
Expension joints	15	8	11	Medium
Connection between	16	14	5	Low
Approach slab	17	17	1	Low

GVI* factor	component number	GVI*factor - Highest	GVI*factor - Lowest	GVI*factor - Low,Medium,High
Foundation pad	1	7	11	Medium
Foundation piles	2	5	13	High
Intermediate wall/colomn(s)	3	4	14	High
Abutment or bank seat	4	3	15	High
Capping beam	5	6	12	Medium
Wing walls	6	11	7	Medium
Deck: prefabricated beams	7	1	17	High
Edge beam: prefabricated beams	8	2	16	High
Pavement: Asphalt	9	10	8	Medium
Edge element (finishing)	10	14	4	Low
Parapets (pedestrians+ traffic)	11	17	1	Low
Upstand (schampkant)	12	13	5	Low
Safety guards	13	12	6	Medium
Bearings	14	9	9	Medium
Expension joints	15	8	10	Medium
Connection between	16	15	3	Low
Approach slab	17	16	2	Low

Difference GVI and GVI*factor	component number	High - Medium - Low: GVI	GVI*factor - Low,Medium,high		Different
Foundation pad	1	Medium	Medium		
Foundation piles	2	High	High		
Intermediate wall/colomn(s)	3	Medium	High		X
Abutment or bank seat	4	High	High		
Capping beam	5	High	Medium		X
Wing walls	6	Low	Medium		X
Deck: prefabricated beams	7	High	High		
Edge beam: prefabricated beams	8	High	High		
Pavement: Asphalt	9	Medium	Medium		
Edge element (finishing)	10	Low	Low		
Parapets (pedestrians+ traffic)	11	Low	Low		
Upstand (schampkant)	12	Medium	Low		X
Safety guards	13	Medium	Medium		
Bearings	14	Medium	Medium		
Expension joints	15	Medium	Medium		
Connection between	16	Low	Low		
Approach slab	17	Low	Low		

C6-1: Direct constructive relations - Highest values CI-R and CI-S

Direct constructive - CI-R - highest values (1-5)	component number	CI-R GW	CI-R - APG	CI-R - MM	CI-R - TW	CI-R - MH	Sum
		1	2	3	4	5	
Foundation pad	1	15	8	9	13	13	58
Foundation piles	2	17	17	2	12	12	60
Intermediate wall/colomn(s)	3	11	13	13	11	10	58
Abutment or bank seat	4	2	1	1	3	3	7
Capping beam	5	4	4	5	10	5	23
Wing walls	6	16	14	10	14	8	54
Deck: prefabricated beams	7	3	10	6	5	6	24
Edge beam: prefabricated beams	8	1	6	3	4	2	14
Pavement: Asphalt	9	7	16	18	2	11	54
Edge element (finishing)	10	9	9	11	8	9	46
Parapets (pedestrians+ traffic)	11	12	5	11	15	16	59
Upstand (schampkant)	12	13	11	4	1	1	30
Safety guards	13	14	3	7	9	17	50
Bearings	14	6	2	7	6	7	28
Expension joints	15	5	7	8	7	4	31
Connection between	16	10	12	8	16	15	61
Approach slab	17	8	15	14	17	14	68

Direct constructive - CI-S- highest values	component number	CI-S - GW	CI-S - APG	CI-S - MM	CI-S - TW	CI-S - MH	Sum
		1	2	3	4	5	
Foundation pad	1	15	15	7	9	13	46
Foundation piles	2	16	3	6	10	6	35
Intermediate wall/colomn(s)	3	12	7	13	13	11	45
Abutment or bank seat	4	2	4	1	1	4	8
Capping beam	5	5	6	9	11	7	31
Wing walls	6	13	16	14	14	16	57
Deck: prefabricated beams	7	3	5	2	4	3	14
Edge beam: prefabricated beams	8	1	1	3	3	2	8
Pavement: Asphalt	9	7	8	4	7	8	26
Edge element (finishing)	10	10	9	10	6	8	35
Parapets (pedestrians+ traffic)	11	14	14	8	8	10	44
Upstand (schampkant)	12	9	2	8	2	5	21
Safety guards	13	17	17	16	17	12	67
Bearings	14	4	10	5	16	11	35
Expension joints	15	6	11	12	5	1	34
Connection between	16	8	12	17	16	17	53
Approach slab	17	11	13	15	12	14	51

C6-2: Direct constructive relations - Highest values CI-R and CI-S - Ranked

Highest values ranked	Direct constructive - CI-R - Ranked highest values (1-5)	component number	CI-R GW	CI-R - APG	CI-R - MM	CI-R - TW	CI-R - MH		Sum
			1	2	3	4	5		
1	Abutment or bank seat	4	2	1	1	3	3		7
2	Edge beam: prefabricated beams	8	1	6	3	4	2		14
3	Capping beam	5	4	4	5	10	5		23
4	Deck: prefabricated beams	7	3	10	6	5	6		24
5	Bearings	14	6	2	7	6	7		28
6	Upstand (schampkant)	12	13	11	4	1	1		30
7	Expension joints	15	5	7	8	7	4		31
8	Edge element (finishing)	10	9	9	11	8	9		46
9	Safety guards	13	14	3	7	9	17		50
10	Wing walls	6	16	14	10	14	8		54
11	Pavement: Asphalt	9	7	16	18	2	11		54
12	Foundation pad	1	15	8	9	13	13		58
13	Intermediate wall/colomn(s)	3	11	13	13	11	10		58
14	Parapets (pedestrians+ traffic)	11	12	5	11	15	16		59
15	Foundation piles	2	17	17	2	12	12		60
16	Connection between	16	10	12	8	16	15		61
17	Approach slab	17	8	15	14	17	14		68

	Direct constructive - CI-S- Ranked highest values	component number	CI-S - GW	CI-S - APG	CI-S - MM	CI-S - TW	CI-S - MH		Sum
			1	2	3	4	5		
	Abutment or bank seat	4	2	4	1	1	4		8
	Edge beam: prefabricated beams	8	1	1	3	3	2		8
	Deck: prefabricated beams	7	3	5	2	4	3		14
	Upstand (schampkant)	12	9	2	8	2	5		21
	Pavement: Asphalt	9	7	8	4	7	8		26
	Capping beam	5	5	6	9	11	7		31
	Expension joints	15	6	11	12	5	1		34
	Foundation piles	2	16	3	6	10	6		35
	Edge element (finishing)	10	10	9	10	6	8		35
	Bearings	14	4	10	5	16	11		35
	Parapets (pedestrians+ traffic)	11	14	14	8	8	10		44
	Intermediate wall/colomn(s)	3	12	7	13	13	11		45
	Foundation pad	1	15	15	7	9	13		46
	Approach slab	17	11	13	15	12	14		51
	Connection between	16	8	12	17	16	17		53
	Wing walls	6	13	16	14	14	16		57
	Safety guards	13	17	17	16	17	12		67

C6-3: Direct constructive relations - Lowest values CI-R and CI-S

	Direct constructive - CI-S - lowest values (1-5)	component number	CI-R - GW	CI-R - APG	CI-R - MM	CI-R - TW	CI-R - MH		Sum
			1	2	3	4	5		
	Foundation pad	1	3	3	11	7	5		24
	Foundation piles	2	2	15	12	8	3		37
	Intermediate wall/colomn(s)	3	6	11	5	5	7		27
	Abutment or bank seat	4	16	14	17	17	14		64
	Capping beam	5	13	12	9	7	12		41
	Wing walls	6	5	2	4	4	2		17
	Deck: prefabricated beams	7	15	13	16	14	15		73
	Edge beam: prefabricated beams	8	17	17	15	15	16		80
	Pavement: Asphalt	9	11	10	14	11	11		57
	Edge element (finishing)	10	8	9	8	12	10		47
	Parapets (pedestrians+ traffic)	11	4	4	7	10	8		33
	Upstand (schampkant)	12	9	16	10	16	13		64
	Safety guards	13	1	1	2	1	6		5
	Bearings	12	14	8	13	3	9		38
	Expension joints	15	12	7	6	6	17		31
	Connection between	16	10	6	1	2	1		20
	Approach slab	17	7	5	3	6	4		25

	Direct constructive - CI-R - lowest values (1-5)	component number	CI-R - GW	CI-R - APG	CI-R - MM	CI-R - TW	CI-R - MH		Sum
			1	2	3	4	5		
	Foundation pad	1	3	8	9	5	5		25
	Foundation piles	2	1	1	16	6	6		30
	Intermediate wall/colomn(s)	3	7	5	5	7	8		32
	Abutment or bank seat	4	16	17	17	15	15		80
	Capping beam	5	14	14	13	8	13		62
	Wing walls	6	2	4	8	4	10		18
	Deck: prefabricated beams	7	15	10	12	13	12		50
	Edge beam: prefabricated beams	8	17	12	15	14	16		58
	Pavement: Asphalt	9	11	2	3	16	7		32
	Edge element (finishing)	10	9	9	7	16	9		41
	Parapets (pedestrians+ traffic)	11	6	13	2	3	2		24
	Upstand (schampkant)	12	5	7	14	17	17		60
	Safety guards	13	4	15	1	9	1		30
	Bearings	12	12	16	11	12	11		62
	Expension joints	15	13	11	10	11	14		59
	Connection between	16	8	6	6	2	3		22
	Approach slab	17	10	3	4	1	4		18

C6-4 Direct constructive relations - Lowest values CI-R and CI-S - Ranked

Highest values ranked	Direct constructive - CI-S - Ranked lowest values (1-5)	component number	CI-R - GW	CI-R - APG	CI-R - MM	CI-R - TW	CI-R - MH		Sum
			1	2	3	4	5		
1	Safety guards	13	1	1	2	1	6		5
2	Wing walls	6	5	2	4	4	2		17
3	Connection between	16	10	6	1	2	1		20
4	Foundation pad	1	3	3	11	7	5		24
5	Approach slab	17	7	5	3	6	4		25
6	Intermediate wall/colomn(s)	3	6	11	5	5	7		27
7	Expension joints	15	12	7	6	6	17		31
8	Parapets (pedestrians+ traffic)	11	4	4	7	10	8		33
9	Foundation piles	2	2	15	12	8	3		37
10	Bearings	12	14	8	13	3	9		38
11	Capping beam	5	13	12	9	7	12		41
12	Edge element (finishing)	10	8	9	8	12	10		47
13	Pavement: Asphalt	9	11	10	14	11	11		57
14	Abutment or bank seat	4	16	14	17	17	14		64
15	Upstand (schampkant)	12	9	16	10	16	13		64
16	Deck: prefabricated beams	7	15	13	16	14	15		73
17	Edge beam: prefabricated beams	8	17	17	15	15	16		80

Highest values ranked	Direct constructive - CI-R - Ranked lowest values (1-5)	component number	CI-R - GW	CI-R - APG	CI-R - MM	CI-R - TW	CI-R - MH		Sum
			1	2	3	4	5		
1	Wing walls	6	2	4	8	4	10		18
2	Approach slab	17	10	3	4	1	4		18
3	Connection between	16	8	6	6	2	3		22
4	Parapets (pedestrians+ traffic)	11	6	13	2	3	2		24
5	Foundation pad	1	3	8	9	5	5		25
6	Foundation piles	2	1	1	16	6	6		30
7	Safety guards	13	4	15	1	9	1		30
8	Intermediate wall/colomn(s)	3	7	5	5	7	8		32
9	Pavement: Asphalt	9	11	2	3	16	7		32
10	Edge element (finishing)	10	9	9	7	16	9		41
11	Deck: prefabricated beams	7	15	10	12	13	12		50
12	Edge beam: prefabricated beams	8	17	12	15	14	16		58
13	Expension joints	15	13	11	10	11	14		59
14	Upstand (schampkant)	12	5	7	14	17	17		60
15	Capping beam	5	14	14	13	8	13		62
16	Bearings	12	12	16	11	12	11		62
17	Abutment or bank seat	4	16	17	17	15	15		80

C7-1: Results Parametric relations -CI-R - Structural engineer individually - Ranked

Parametric relations - CI-R		CI-R - GW
Parametric		7
Edge beam: prefabricated beams	8	78
Deck: prefabricated beams	7	63
Abutment or bank seat	4	55
Pavement: Asphalt	9	49
Wing walls	6	36
Capping beam	5	31
Foundation piles	2	29
Parapets (pedestrians+ traffic)	11	27
Intermediate wall/colomn(s)	3	24
Upstand (schampkant)	12	23
Foundation pad	1	21
Bearings	14	21
Edge element (finishing)	10	18
Expension joints	15	18
Approach slab	17	18
Safety guards	13	16
Connection between	16	15
Traffic signs	18	0
Lighting	19	0
Cables	20	0
Water drainage	21	0
Camera's and sensors	22	0

Parametric relations - CI-R		CI-R - MM
Parametric		9
Abutment or bank seat	4	32
Foundation piles	2	30
Edge beam: prefabricated beams	8	28
Capping beam	5	27
Deck: prefabricated beams	7	22
Foundation pad	1	21
Bearings	14	19
Intermediate wall/colomn(s)	3	18
Edge element (finishing)	10	13
Upstand (schampkant)	12	10
Expension joints	15	10
Water drainage	21	7
Connection between	16	5
Cables	20	5
Lighting	19	3
Wing walls	6	2
Pavement: Asphalt	9	2
Parapets (pedestrians+ traffic)	11	2
Approach slab	17	2
Safety guards	13	1
Traffic signs	18	0
Camera's and sensors	22	0

Parametric relations - CI-R		CI-R - MH
Parametric		11
Deck: prefabricated beams	7	46
Edge beam: prefabricated beams	8	45
Pavement: Asphalt	9	41
Intermediate wall/colomn(s)	3	21
Upstand (schampkant)	12	20
Edge element (finishing)	10	19
Parapets (pedestrians+ traffic)	11	17
Bearings	14	14
Approach slab	17	12
Safety guards	13	11
Foundation pad	1	10
Abutment or bank seat	4	9
Cables	20	8
Water drainage	21	8
Foundation piles	2	6
Capping beam	5	5
Traffic signs	18	5
Lighting	19	5
Wing walls	6	4
Camera's and sensors	22	3
Connection between	16	1
Expension joints	15	0

Parametric relations - CI-R		CI-R - APG
Parametric		8
Abutment or bank seat	4	27
Capping beam	5	20
Edge beam: prefabricated beams	8	18
Bearings	14	18
Foundation pad	1	14
Deck: prefabricated beams	7	11
Expension joints	15	10
Foundation piles	2	8
Edge element (finishing)	10	7
Intermediate wall/colomn(s)	3	6
Connection between	16	6
Approach slab	17	6
Wing walls	6	4
Pavement: Asphalt	9	3
Upstand (schampkant)	12	1
Parapets (pedestrians+ traffic)	11	0
Safety guards	13	0
Traffic signs	18	0
Lighting	19	0
Cables	20	0
Water drainage	21	0
Camera's and sensors	22	0

Parametric relations - CI-R		CI-R - TW
Parametric		10
Upstand (schampkant)	12	87
Edge beam: prefabricated beams	8	66
Abutment or bank seat	4	57
Pavement: Asphalt	9	57
Foundation piles	2	43
Deck: prefabricated beams	7	43
Bearings	14	38
Expension joints	15	33
Water drainage	21	25
Edge element (finishing)	10	24
Safety guards	13	24
Capping beam	5	23
Parapets (pedestrians+ traffic)	11	17
Cables	20	17
Foundation pad	1	16
Intermediate wall/colomn(s)	3	16
Lighting	19	15
Camera's and sensors	22	6
Connection between	16	5
Traffic signs	18	5
Wing walls	6	4
Approach slab	17	3

Parametric relations - CI-R		Average CI-R
Parametric		12
Foundation pad	1	33,4
Foundation piles	2	29,6
Intermediate wall/colomn(s)	3	28,2
Abutment or bank seat	4	21
Capping beam	5	19,4
Deck: prefabricated beams	7	16,4
Wing walls	6	18
Edge beam: prefabricated beams	8	15,2
Pavement: Asphalt	9	15,2
Bearings	14	13,8
Edge element (finishing)	10	11,4
Safety guards	13	12,4
Upstand (schampkant)	12	13,4
Parapets (pedestrians+ traffic)	11	14,4
Approach slab	17	9,6
Expension joints	15	6,8
Cables	20	9,8
Traffic signs	18	7,4
Camera's and sensors	22	5,8
Water drainage	21	7,8
Connection between	16	7
Lighting	19	7,4

C7-2: Results Parametric relations- CI-S - Structural engineer individually - Ranked

Parametric relations - CI-S		CI-S - GW
Parametric		1
Edge beam: prefabricated beams	8	52
Deck: prefabricated beams	7	46
Upstand (schampkant)	12	45
Bearings	14	36
Expension joints	15	36
Foundation piles	2	35
Foundation pad	1	32
Intermediate wall/colomn(s)	3	32
Abutment or bank seat	4	31
Edge element (finishing)	10	30
Approach slab	17	30
Capping beam	5	28
Pavement: Asphalt	9	24
Safety guards	13	24
Wing walls	6	22
Parapets (pedestrians+ traffic)	11	21
Connection between	16	18
Traffic signs	18	0
Lighting	19	0
Cables	20	0
Water drainage	21	0
Camera's and sensors	22	0

Parametric relations - CI-S		CI-S - MM
Parametric		3
Deck: prefabricated beams	7	43
Edge beam: prefabricated beams	8	41
Abutment or bank seat	4	32
Foundation pad	1	22
Capping beam	5	22
Pavement: Asphalt	9	21
Foundation piles	2	15
Intermediate wall/colomn(s)	3	15
Wing walls	6	15
Bearings	14	9
Edge element (finishing)	10	5
Expension joints	15	5
Upstand (schampkant)	12	4
Safety guards	13	3
Connection between	16	3
Parapets (pedestrians+ traffic)	11	2
Approach slab	17	2
Traffic signs	18	0
Lighting	19	0
Cables	20	0
Water drainage	21	0
Camera's and sensors	22	0

Parametric relations - CI-S		CI-S - MH
Parametric		5
Foundation piles	2	47
Upstand (schampkant)	12	46
Abutment or bank seat	4	40
Capping beam	5	30
Bearings	14	29
Edge beam: prefabricated beams	8	25
Foundation pad	1	22
Intermediate wall/colomn(s)	3	19
Deck: prefabricated beams	7	18
Expension joints	15	15
Edge element (finishing)	10	6
Approach slab	17	6
Wing walls	6	3
Connection between	16	3
Pavement: Asphalt	9	0
Parapets (pedestrians+ traffic)	11	0
Safety guards	13	0
Traffic signs	18	0
Lighting	19	0
Cables	20	0
Water drainage	21	0
Camera's and sensors	22	0

Parametric relations - CI-S		CI-S - APG
Parametric		2
Deck: prefabricated beams	7	22
Abutment or bank seat	4	19
Edge beam: prefabricated beams	8	18
Capping beam	5	16
Bearings	14	14
Intermediate wall/colomn(s)	3	13
Expension joints	15	13
Foundation piles	2	12
Approach slab	17	9
Edge element (finishing)	10	8
Connection between	16	7
Parapets (pedestrians+ traffic)	11	3
Foundation pad	1	2
Pavement: Asphalt	9	2
Wing walls	6	1
Upstand (schampkant)	12	0
Safety guards	13	0
Traffic signs	18	0
Lighting	19	0
Cables	20	0
Water drainage	21	0
Camera's and sensors	22	0

Parametric relations - CI-S		CI-S - TW
Parametric		4
Upstand (schampkant)	12	74
Deck: prefabricated beams	7	69
Abutment or bank seat	4	65
Expension joints	15	58
Edge beam: prefabricated beams	8	57
Pavement: Asphalt	9	49
Edge element (finishing)	10	40
Parapets (pedestrians+ traffic)	11	37
Capping beam	5	25
Foundation piles	2	18
Approach slab	17	18
Water drainage	21	18
Foundation pad	1	16
Intermediate wall/colomn(s)	3	16
Bearings	14	14
Wing walls	6	11
Safety guards	13	10
Connection between	16	9
Lighting	19	7
Cables	20	7
Camera's and sensors	22	7
Traffic signs	18	3

Parametric relations - CI-S		Average CI-S
Parametric		6
Deck: prefabricated beams	7	39,6
Edge beam: prefabricated beams	8	38,6
Abutment or bank seat	4	37,4
Upstand (schampkant)	12	33,8
Foundation piles	2	25,4
Expension joints	15	25,4
Capping beam	5	24,2
Bearings	14	20,4
Pavement: Asphalt	9	19,2
Intermediate wall/colomn(s)	3	19
Foundation pad	1	18,8
Edge element (finishing)	10	17,8
Approach slab	17	13
Parapets (pedestrians+ traffic)	11	12,6
Wing walls	6	10,4
Connection between	16	8
Safety guards	13	7,4
Water drainage	21	3,6
Lighting	19	1,4
Cables	20	1,4
Camera's and sensors	22	1,4
Traffic signs	18	0,6

C7-3: Parametric relations - Highest values CI-R and CI-S

	Parametric relations - CI-R - highest value (1-5)	component number	CI-R - GW	CI-R - APG	CI-R - MM	CI-R - TW	CI-R - MH		Sum
			1	2	3	4	5		
	Foundation pad	1	11	5	6	15	11		48
	Foundation piles	2	7	8	2	5	15		37
	Intermediate wall/colomn(s)	3	9	10	8	16	4		47
	Abutment or bank seat	4	3	1	1	3	12		20
	Capping beam	5	6	2	4	12	16		40
	Wing walls	6	5	13	16	21	19		74
	Deck: prefabricated beams	7	2	6	5	6	1		20
	Edge beam: prefabricated beams	8	1	3	3	2	2		11
	Pavement: Asphalt	9	4	14	17	4	3		42
	Edge element (finishing)	10	8	9	9	9	6		41
	Parapets (pedestrians+ traffic)	11	13	16	15	12	7		63
	Upstand (schampkant)	12	10	15	10	1	5		41
	Safety guards	13	16	17	17	10	10		70
	Bearings	14	12	4	7	7	8		38
	Expension joints	15	14	7	15	7	17		60
	Connection between	16	17	11	12	15	16		71
	Approach slab	17	15	12	16	17	9		69

	Parametric relations - CI-S - highest value (1-5)	component number	CI-S - GW	CI-S - APG	CI-S - MM	CI-S - TW	CI-S - MH		Sum
			1	2	3	4	5		
	Foundation pad	1	7	13	4	13	7		44
	Foundation piles	2	6	8	7	10	1		32
	Intermediate wall/colomn(s)	3	8	6	8	13	8		43
	Abutment or bank seat	4	9	2	3	3	3		20
	Capping beam	5	12	4	5	9	4		34
	Wing walls	6	15	15	9	15	13		67
	Deck: prefabricated beams	7	2	1	1	2	9		15
	Edge beam: prefabricated beams	8	1	3	2	5	6		17
	Pavement: Asphalt	9	13	14	6	6	15		54
	Edge element (finishing)	10	10	10	11	7	11		49
	Parapets (pedestrians+ traffic)	11	16	12	16	8	16		68
	Upstand (schampkant)	12	3	16	13	1	2		35
	Safety guards	13	14	17	14	16	17		78
	Bearings	14	4	5	10	15	5		39
	Expension joints	15	5	7	12	4	10		38
	Connection between	16	17	11	15	17	14		74
	Approach slab	17	11	9	17	11	12		60

C7-4: Parametric relations - Highest values CI-R and CI-S - Ranked

Highest values ranked	Parametric relations - CI-R - ranked highest value (1-5)	component number	CI-R - GW	CI-R - APG	CI-R - MM	CI-R - TW	CI-R - MH		Sum
			1	2	3	4	5		
1	Edge beam: prefabricated beams	8	1	3	3	2	2		11
2	Abutment or bank seat	4	3	1	1	3	12		20
3	Deck: prefabricated beams	7	2	6	5	6	1		20
4	Foundation piles	2	7	8	2	5	15		37
5	Bearings	14	12	4	7	7	8		38
6	Capping beam	5	6	2	4	12	16		40
7	Edge element (finishing)	10	8	9	9	9	6		41
8	Upstand (schampkant)	12	10	15	10	1	5		41
9	Pavement: Asphalt	9	4	14	17	4	3		42
10	Intermediate wall/colomn(s)	3	9	10	8	16	4		47
11	Foundation pad	1	11	5	6	15	11		48
12	Expension joints	15	14	7	15	7	17		60
13	Parapets (pedestrians+ traffic)	11	13	16	15	12	7		63
14	Approach slab	17	15	12	16	17	9		69
15	Safety guards	13	16	17	17	10	10		70
16	Connection between	16	17	11	12	15	16		71
17	Wing walls	6	5	13	16	21	19		74

Highest values ranked	Parametric relations - CI-S - ranked highest value (1-5)	component number	CI-S - GW	CI-S - APG	CI-S - MM	CI-S - TW	CI-S - MH		Sum
			1	2	3	4	5		
1	Deck: prefabricated beams	7	2	1	1	2	9		15
2	Edge beam: prefabricated beams	8	1	3	2	5	6		17
3	Abutment or bank seat	4	9	2	3	3	3		20
4	Foundation piles	2	6	8	7	10	1		32
5	Capping beam	5	12	4	5	9	4		34
6	Upstand (schampkant)	12	3	16	13	1	2		35
7	Expension joints	15	5	7	12	4	10		38
8	Bearings	14	4	5	10	15	5		39
9	Intermediate wall/colomn(s)	3	8	6	8	13	8		43
10	Foundation pad	1	7	13	4	13	7		44
11	Edge element (finishing)	10	10	10	11	7	11		49
12	Pavement: Asphalt	9	13	14	6	6	15		54
13	Approach slab	17	11	9	17	11	12		60
14	Wing walls	6	15	15	9	15	13		67
15	Parapets (pedestrians+ traffic)	11	16	12	16	8	16		68
16	Connection between	16	17	11	15	17	14		74
17	Safety guards	13	14	17	14	16	17		78

C7-5: Parametric relations - Lowest values CI-R and CI-S

Parametric relations - CI-R - lowest value (1-5)	component number	CI-R - GW	CI-R - APG	CI-R - MM	CI-R - TW	CI-R - MH	Sum
		1	2	3	4	5	
Foundation pad	1	7	13	12	5	7	44
Foundation piles	2	11	10	16	13	5	55
Intermediate wall/colomn(s)	3	9	8	10	4	14	45
Abutment or bank seat	4	15	17	17	15	6	70
Capping beam	5	12	16	14	7	4	53
Wing walls	6	13	5	5	2	3	28
Deck: prefabricated beams	7	16	12	13	12	17	70
Edge beam: prefabricated beams	8	17	15	15	16	16	79
Pavement: Asphalt	9	14	4	4	14	15	51
Edge element (finishing)	10	5	9	9	9	12	44
Parapets (pedestrians+ traffic)	11	10	2	3	6	11	32
Upstand (schampkant)	12	8	3	8	17	13	49
Safety guards	13	2	1	1	8	8	20
Bearings	12	6	3	8	11	10	38
Expension joints	15	4	11	7	10	1	33
Connection between	16	1	7	6	3	2	19
Approach slab	17	3	6	2	1	9	21

Parametric relations - CI-S - lowest value (1-5)	component number	CI-S - GW	CI-S - APG	CI-S - MM	CI-S - TW	CI-S - MH	Sum
		1	2	3	4	5	
Foundation pad	1	11	5	14	6	11	47
Foundation piles	2	12	10	11	8	17	58
Intermediate wall/colomn(s)	3	10	12	10	5	10	47
Abutment or bank seat	4	9	16	15	15	15	70
Capping beam	5	6	14	13	9	14	56
Wing walls	6	3	3	9	3	5	23
Deck: prefabricated beams	7	16	17	17	16	9	75
Edge beam: prefabricated beams	8	17	15	16	13	12	73
Pavement: Asphalt	9	5	4	12	12	3	36
Edge element (finishing)	10	8	8	7	11	7	41
Parapets (pedestrians+ traffic)	11	2	6	2	10	2	22
Upstand (schampkant)	12	15	2	5	17	16	55
Safety guards	13	4	1	4	2	1	12
Bearings	12	14	13	8	4	13	52
Expension joints	15	13	11	6	14	8	52
Connection between	16	1	7	3	1	4	16
Approach slab	17	7	9	1	7	6	30

C7-6: Parametric relations - Lowest values CI-R and CI-S - Ranked

Highest values ranked	Parametric relations - CI-R - ranked lowest value (1-5)	component number	CI-R - GW	CI-R - APG	CI-R - MM	CI-R - TW	CI-R - MH		Sum
			1	2	3	4	5		
1	Connection between	16	1	7	6	3	2		19
2	Safety guards	13	2	1	1	8	8		20
3	Approach slab	17	3	6	2	1	9		21
4	Wing walls	6	13	5	5	2	3		28
5	Parapets (pedestrians+ traffic)	11	10	2	3	6	11		32
6	Expension joints	15	4	11	7	10	1		33
7	Bearings	12	6	3	8	11	10		38
8	Foundation pad	1	7	13	12	5	7		44
9	Edge element (finishing)	10	5	9	9	9	12		44
10	Intermediate wall/colomn(s)	3	9	8	10	4	14		45
11	Upstand (schampkant)	12	8	3	8	17	13		49
12	Pavement: Asphalt	9	14	4	4	14	15		51
13	Capping beam	5	12	16	14	7	4		53
14	Foundation piles	2	11	10	16	13	5		55
15	Abutment or bank seat	4	15	17	17	15	6		70
16	Deck: prefabricated beams	7	16	12	13	12	17		70
17	Edge beam: prefabricated beams	8	17	15	15	16	16		79

	Parametric relations - CI-S - ranked lowest value (1-5)	component number	CI-S - GW	CI-S - APG	CI-S - MM	CI-S - TW	CI-S - MH		Sum
			1	2	3	4	5		
1	Safety guards	13	4	1	4	2	1		12
2	Connection between	16	1	7	3	1	4		16
3	Parapets (pedestrians+ traffic)	11	2	6	2	10	2		22
4	Wing walls	6	3	3	9	3	5		23
5	Approach slab	17	9	9	1	7	6		32
6	Pavement: Asphalt	9	5	4	12	12	3		36
7	Edge element (finishing)	10	8	8	7	11	7		41
8	Foundation pad	1	11	5	14	6	11		47
9	Intermediate wall/colomn(s)	3	10	12	10	5	10		47
10	Expension joints	15	13	11	6	14	8		52
11	Bearings	12	14	13	8	4	13		52
12	Upstand (schampkant)	12	15	2	5	17	16		55
13	Capping beam	5	6	14	13	9	14		56
14	Foundation piles	2	12	10	11	8	17		58
15	Abutment or bank seat	4	9	16	15	15	15		70
16	Edge beam: prefabricated beams	8	17	15	16	13	12		73
17	Deck: prefabricated beams	7	16	17	17	16	9		75

C8-1: Overview results - Structural engineer - Gerard Waayer

Overview		GVI			CI-R						CI-S					
Gerard Waayer	Component number	GVI - Ranked: high	GVI Ranked: lowest	High - Medium - Low: GVI	CI-R - parametric - ranked lowest value	CI-R - parametric - ranked highest value	Low - Medium - High	CI-R - direct - ranked lowest value	CI-R - direct - ranked highest value	Low - Medium - High	CI-S - parametric - ranked lowest value	CI-S - parametric -ranked highest value	Low - Medium - High	CI-S - direct - ranked lowest value	CI-S - direct - ranked highest value	Low - Medium - High
Foundation pad	1	7	13	Medium	7	11	Medium	3	15	Low	11	7	Medium	3	15	Low
Foundation piles	2	5	16	High	11	7	Medium	1	17	Low	12	6	Medium	2	16	Low
Intermediate wall/colomn(s)	3	6	14	Medium	9	9	Medium	7	11	Medium	10	8	Medium	6	12	Medium
Abutment or bank seat	4	3	12	High	15	3	High	16	2	High	9	9	Medium	16	2	High
Capping beam	5	4	10	High	12	6	Medium	14	4	High	6	12	Medium	13	5	High
Wing walls	6	11	4	Low	13	5	High	2	16	Low	3	15	Low	5	13	Low
Deck: prefabricated beams	7	1	17	High	16	2	High	15	3	High	16	2	High	15	3	High
Edge beam: prefabricated beams	8	2	15	High	17	1	High	17	1	High	17	1	High	17	1	High
Pavement: Asphalt	9	10	8	Medium	14	4	High	11	7	Medium	5	13	Low	11	7	Medium
Edge element (finishing)	10	15	3	Low	5	8	Low	9	9	Medium	8	10	Medium	8	10	Medium
Parapets (pedestrians+ traffic)	11	16	2	Low	10	13	Medium	6	12	Medium	2	16	Low	4	14	Low
Upstand (schampkant)	12	13	6	Medium	8	10	Medium	5	13	Low	15	3	High	9	9	Low
Safety guards	13	12	7	Medium	2	16	Low	4	14	Low	4	14	Low	1	17	Low
Bearings	14	9	9	Medium	6	12	Medium	12	6	Medium	14	4	High	14	4	High
Expension joints	15	8	11	Medium	4	14	Low	13	5	High	13	5	High	12	6	Medium
Connection between	16	14	5	Low	1	17	Low	8	10	Medium	1	17	Medium	10	8	Medium
Approach slab	17	17	1	Low	3	15	Low	10	8	Medium	7	11	Medium	7	11	Medium

C8-2: Overview results - Structural engineer - Avinash Gangaram-Pandey

Overview Avinash Gangaram-Pandey	GVI				CI-R						CI-S					
	Component number	GVI - Ranked: high	GVI Ranked: lowest	High - Medium - Low: GVI	CI-R - parametric - ranked lowest value	CI-R - parametric - ranked highest valu	Low - Medium - High	CI-R - direct - ranked lowest value	CI-R - direct - ranked highest value	Low - Medium - High	CI-S - parametric - ranked lowest value	CI-S - parametric -ranked highest value	Low - Medium - High	CI-S - direct - ranked lowest value	CI-S - direct - ranked highest value	Low - Medium - High
Foundation pad	1	7	13	Medium	7	5	High	8	8	Medium	5	13	Low	3	15	Low
Foundation piles	2	5	16	High	1	8	Low	1	17	Low	10	8	Medium	15	3	High
Intermediate wall/colomn(s)	3	6	14	Medium	6	10	Medium	5	13	Low	12	6	Medium	11	7	Medium
Abutment or bank seat	4	3	12	High	5	1	High and low	17	1	High	16	2	High	14	4	High
Capping beam	5	4	10	High	2	2	High and low	14	4	High	14	4	High	12	6	Medium
Wing walls	6	11	4	Low	11	13	Medium	4	14	Low	3	15	Low	2	16	Low
Deck: prefabricated beams	7	1	17	High	3	6	Medium	10	10	Medium	17	1	High	13	5	High
Edge beam: prefabricated beams	8	2	15	High	13	3	High	12	6	Medium	15	3	High	17	1	High
Pavement: Asphalt	9	10	8	Medium	9	14	Medium	2	16	Low	4	14	Low	10	8	Medium
Edge element (finishing)	10	15	3	Low	8	9	Medium	9	9	Medium	8	10	Medium	9	9	Medium
Parapets (pedestrians+ traffic)	11	16	2	Low	3	16	Low	13	5	High	6	12	Medium	4	14	Low
Upstand (schampkant)	12	13	6	Medium	4	15	Low	7	11	Medium	2	16	Low	16	2	High
Safety guards	13	12	7	Medium	16	17	Medium	15	3	High	1	17	Low	1	17	Low
Bearings	14	9	9	Medium	10	4	High	16	2	High	13	5	High	8	10	Medium
Expension joints	15	8	11	Medium	17	7	Medium	11	7	Medium	11	7	Medium	7	11	Medium
Connection between	16	14	5	Low	12	11	Medium	6	12	Medium	7	11	Medium	6	12	Medium
Approach slab	17	17	1	Low	15	12	Medium	3	15	Low	9	9	Medium	5	13	Low

		GVI			CI-R						CI-S					
Overview / Maarten de Moel	Component number	GVI - Ranked: high	GVI Ranked: lowest	High - Medium - Low: GVI	CI-R - parametric - ranked lowest value	CI-R - parametric - ranked highest value	Low - Medium - High	CI-R - direct - ranked lowest value	CI-R - direct - ranked highest value	Low - Medium - High	CI-S - parametric - ranked lowest value	CI-S - parametric -ranked highest value	Low - Medium - High	CI-S - direct - ranked lowest value	CI-S - direct - ranked highest value	Low - Medium - High
Foundation pad	1	7	13	Medium	12	6	Medium	9	9	Medium	14	4	High	11	7	Medium
Foundation piles	2	5	16	High	16	2	High	16	2	High	11	7	Medium	12	6	Medium
Intermediate wall/colomn(s)	3	6	14	Medium	10	8	Medium	5	13	Low	10	8	Medium	5	13	Low
Abutment or bank seat	4	3	12	High	17	1	High	17	1	High	15	3	High	17	1	High
Capping beam	5	4	10	High	14	4	High	13	5	Medium	13	5	High	9	9	Medium
Wing walls	6	11	4	Low	5	16	Low	8	10	Medium	9	9	Medium	4	14	Low
Deck: prefabricated beams	7	1	17	High	13	5	High	12	6	Medium	17	1	High	16	2	High
Edge beam: prefabricated beams	8	2	15	High	15	3	High	15	3	High	16	2	High	15	3	High
Pavement: Asphalt	9	10	8	Medium	4	17	Low	3	18	Low	12	6	Medium	14	4	High
Edge element (finishing)	10	15	3	Low	9	9	Medium	7	11	Medium	7	11	Medium	8	10	Medium
Parapets (pedestrians+ traffic)	11	16	2	Low	3	15	Low	2	11	Low	2	16	Low	7	8	Medium
Upstand (schampkant)	12	13	6	Medium	8	10	Medium	14	4	High	5	13	Low	10	8	Medium
Safety guards	13	12	7	Medium	1	17	Low	1	7	Low	4	14	Low	2	16	Low
Bearings	14	9	9	Medium	8	7	Medium	11	7	Medium	8	10	Medium	13	5	High
Expension joints	15	8	11	Medium	7	15	Medium	10	8	Medium	6	12	Medium	6	12	Medium
Connection between	16	14	5	Low	6	12	Medium	6	8	Medium	3	15	Low	1	17	Low
Approach slab	17	17	1	Low	2	16	Low	4	14	Low	1	17	Low	3	15	Low

C8-4: Overview results - Structural engineer-Maurice Hol

		GVI				CI-R						CI-S				
Overview Maurice Hol	Component number	GVI - Ranked: high	GVI Ranked: lowest	High - Medium - Low: GVI	CI-R - parametric - ranked lowest value	CI-R - parametric - ranked highest value	Low - Medium - High	CI-R - direct - ranked lowest value	CI-R - direct - ranked highest value	Low - Medium - High	CI-S - parametric - ranked lowest value	CI-S - parametric -ranked highest value	Low - Medium - High	CI-S - direct - ranked lowest value	CI-S - direct - ranked highest value	Low - Medium - High
Foundation pad	1	7	13	Medium	7	11	Medium	5	13	Low	11	7	Medium	5	13	Low
Foundation piles	2	5	16	High	5	15	Low	6	12	Medium	17	1	High	3	6	Low
Intermediate wall/colomn(s)	3	6	14	Medium	14	4	High	8	10	Medium	10	8	Medium	7	11	Medium
Abutment or bank seat	4	3	12	High	6	12	Medium	15	3	High	15	3	High	14	4	High
Capping beam	5	4	10	High	4	16	Low	13	5	High	14	4	High	12	7	Medium
Wing walls	6	11	4	Low	3	19	Low	10	8	Medium	5	13	Low	2	16	Low
Deck: prefabricated beams	7	1	17	High	17	1	High	12	6	Medium	9	9	Medium	15	3	High
Edge beam: prefabricated beams	8	2	15	High	16	2	High	16	2	High	12	6	Medium	16	2	High
Pavement: Asphalt	9	10	8	Medium	15	3	High	7	11	Medium	3	15	Low	11	8	Medium
Edge element (finishing)	10	15	3	Low	12	6	Medium	9	9	Medium	7	11	Medium	10	8	Medium
Parapets (pedestrians+ traffic)	11	16	2	Low	11	7	Medium	2	16	Low	2	16	Low	8	10	Medium
Upstand (schampkant)	12	13	6	Medium	13	5	High	17	1	High	16	2	High	13	5	High
Safety guards	13	12	7	Medium	8	10	Medium	1	17	Low	1	17	Low	6	12	Medium
Bearings	14	9	9	Medium	10	8	Medium	11	7	Medium	13	5	High	9	11	Medium
Expension joints	15	8	11	Medium	1	17	Low	14	4	High	8	10	Medium	17	1	High
Connection between	16	14	5	Low	2	16	Low	3	15	Low	4	14	Low	1	17	Low
Approach slab	17	17	1	Low	9	9	Medium	4	14	Low	6	12	Medium	4	14	Low

C8-5: Overview results - Structural engineer - Tristan Wolvekamp

		GVI				CI-R						CI-S				
Overview Tristan Wolvekamp	Component number	GVI - Ranked: high	GVI Ranked: lowest	High - Medium - Low: GVI	CI-R - parametric - ranked lowest value	CI-R - parametric - ranked highest value	Low - Medium - High	CI-R - direct - ranked lowest value	CI-R - direct - ranked highest value	Low - Medium - High	CI-S - parametric - ranked lowest value	CI-S - parametric -ranked highest value	Low - Medium - High	CI-S - direct - ranked lowest value	CI-S - direct - ranked highest value	Low - Medium - High
Foundation pad	1	7	13	Medium	5	15	Low	5	13	Low	6	13	Medium	7	9	Medium
Foundation piles	2	5	16	High	13	5	High	6	12	Medium	8	10	Medium	8	10	Medium
Intermediate wall/colomn(s)	3	6	14	Medium	4	16	Low	7	11	Medium	5	13	Low	5	13	Low
Abutment or bank seat	4	3	12	High	15	3	High	15	3	High	15	3	High	17	1	High
Capping beam	5	4	10	High	7	12	Medium	8	10	Medium	9	9	Medium	7	11	Medium
Wing walls	6	11	4	Low	2	21	Low	4	14	Low	3	15	Low	4	14	Low
Deck: prefabricated beams	7	1	17	High	12	6	Medium	13	5	High	16	2	High	14	4	High
Edge beam: prefabricated beams	8	2	15	High	16	2	High	14	4	High	13	5	High	15	3	High
Pavement: Asphalt	9	10	8	Medium	14	4	High	16	2	High	12	6	Medium	11	7	Medium
Edge element (finishing)	10	15	3	Low	9	9	Medium	16	8	Medium	11	7	Medium	12	6	Medium
Parapets (pedestrians+ traffic)	11	16	2	Low	6	12	Medium	3	15	Low	10	8	Medium	10	8	Medium
Upstand (schampkant)	12	13	6	Medium	17	1	High	17	1	High	17	1	High	16	2	Medium
Safety guards	13	12	7	Medium	8	10	Medium	9	9	Medium	2	16	Low	1	17	Low
Bearings	14	9	9	Medium	11	7	Medium	12	6	Medium	4	15	Low	3	16	Low
Expension joints	15	8	11	Medium	10	7	Medium	11	7	Medium	14	4	High	6	5	High
Connection between	16	14	5	Low	3	15	Low	2	16	Low	1	17	Low	2	16	Low
Approach slab	17	17	1	Low	1	17	Low	1	17	Low	7	11	Medium	6	12	Medium

C9-1: Overview and interpretation results - Structural engineer-Gerard Waayer

Overview Gerard Waayer	Component number	High - Medium - Low: GVI	Low - Medium - High CI-R Direct	Low - Medium - High CI-S Direct	Low - Medium - High CI-R Parametric	Low - Medium - High CI-S Parametric	Interesting to standardize or modularize
Foundation pad	1	Medium	Low	Low	Medium	Medium	Standardize parametrical
Foundation piles	2	High	Low	Low	Medium	Medium	Modularize
Intermediate wall/colomn(s)	3	Medium	Medium	Medium	Medium	Medium	Not clear (modularize or standardize parametrical)
Abutment or bank seat	4	High	High	High	High	Medium	Modularize
Capping beam	5	High	High	High	Medium	Medium	Modularize
Wing walls	6	Low	Low	Low	High	Low	Standardize
Deck: prefabricated beams	7	High	High	High	High	High	Modularize
Edge beam: prefabricated beams	8	High	High	High	High	High	Modularize
Pavement: Asphalt	9	Medium	Medium	Medium	High	Low	Not clear (modularize or standardize parametrical)
Edge element (finishing)	10	Low	Medium	Medium	Low	Medium	Standardize
Parapets (pedestrians+ traffic)	11	Low	Medium	Low	Medium	Low	Standardize
Upstand (schampkant)	12	Medium	Low	Low	Medium	High	Standardize parametrical
Safety guards	13	Medium	Low	Low	Low	Low	Standardize
Bearings	14	Medium	Medium	High	Medium	High	Modularize
Expension joints	15	Medium	High	Medium	Low	High	Modularize
Connection between	16	Low	Medium	Medium	Low	Medium	Standardize
Approach slab	17	Low	Medium	Medium	Low	Medium	Standardize

C9-2: Overviewand interpretation results - Structural engineer - Avinash Gangaram-Pandey

Overview Avinash Gangaram-Pandey	Component number	High - Medium - Low: GVI	Low - Medium - High CI-R direct	Low - Medium - High CI-S Direct	Low - Medium - High CI-R Parametric	Low - Medium - High CI-S Parametric	General outcome
Foundation pad	1	Medium	Medium	Low	High	Low	Not clear: standardize parametrical
Foundation piles	2	High	Low	High	Low	Medium	Modularize
Intermediate wall/colomn(s)	3	Medium	Low	Medium	Medium	Medium	Not clear: standardize parametrical
Abutment or bank seat	4	High	High	High	High and low	High	Modularize
Capping beam	5	High	High	Medium	High and low	High	Modularize
Wing walls	6	Low	Low	Low	Medium	Low	Standardize
Deck: prefabricated beams	7	High	Medium	High	Medium	High	Modularize
Edge beam: prefabricated beams	8	High	Medium	High	High	High	Modularize
Pavement: Asphalt	9	Medium	Low	Medium	Medium	Low	Not clear: standardize parametrical
Edge element (finishing)	10	Low	Medium	Medium	Medium	Medium	Standardize parametrical
Parapets (pedestrians+ traffic)	11	Low	High	Low	Low	Medium	Modularize
Upstand (schampkant)	12	Medium	Medium	High	Low	Low	Modularize
Safety guards	13	Medium	High	Low	Medium	Low	Modularize
Bearings	14	Medium	High	Medium	High	High	Modularize
Expension joints	15	Medium	Medium	Medium	Medium	Medium	Not clear (modularize of standardize parametrical)
Connection between	16	Low	Medium	Medium	Medium	Medium	Standardize parametrical
Approach slab	17	Low	Low	Low	Medium	Medium	Standardize

C9-3: Overviewand interpretation results - Structural engineer - Maarten de Moel

Overview Maarten de Moel	Component number	High - Medium - Low: GVI	Low - Medium - High CI-R direct	Low - Medium - High CI-S Direct	Low - Medium - High CI-R Parametric	Low - Medium - High CI-S Parametric	General outcome
Foundation pad	1	Medium	Medium	Medium	Medium	High	Not clear: modularize or standardize parametrical
Foundation piles	2	High	High	Medium	High	Medium	Modularize
Intermediate wall/colomn(s)	3	Medium	Low	Low	Medium	Medium	Standardize parametrical
Abutment or bank seat	4	High	High	High	High	High	Modularize
Capping beam	5	High	Medium	Medium	High	High	Modularize
Wing walls	6	Low	Medium	Low	Low	Medium	Standardize
Deck: prefabricated beams	7	High	Medium	High	High	High	Modularize
Edge beam: prefabricated beams	8	High	High	High	High	High	Modularize
Pavement: Asphalt	9	Medium	Low	High	Low	Medium	Modularize
Edge element (finishing)	10	Low	Medium	Medium	Medium	Medium	Not clear: standardize parametrical
Parapets (pedestrians+ traffic)	11	Low	Low	Medium	Low	Low	Standardize
Upstand (schampkant)	12	Medium	High	Medium	Medium	Low	Modularize
Safety guards	13	Medium	Low	Low	Low	Low	Standardize parametrical
Bearings	14	Medium	Medium	High	Medium	Medium	Modularize
Expension joints	15	Medium	Medium	Medium	Medium	Medium	Not clear: modularize or standardize parametrical
Connection between	16	Low	Medium	Low	Medium	Low	Standardize
Approach slab	17	Low	Low	Low	Low	Low	Standardize

C9-4: Overviewand interpretation results - Structural engineer -Maurice Hol

Overview Maurice Hol	Component number	High - Medium - Low: GVI	Low - Medium - High CI-R direct	Low - Medium - High CI-S Direct	Low - Medium - High CI-R Parametric	Low - Medium - High CI-S Parametric	General outcome
Foundation pad	1	Medium	Low	Low	Medium	Medium	Standardize parametrical
Foundation piles	2	High	Medium	Low	Low	High	Modularize
Intermediate wall/colomn(s)	3	Medium	Medium	Medium	High	Medium	Not clear: modularize or standardize parametrical
Abutment or bank seat	4	High	High	High	Medium	High	Modularize
Capping beam	5	High	High	Medium	Low	High	Modularize
Wing walls	6	Low	Medium	Low	Low	Low	Standardize
Deck: prefabricated beams	7	High	Medium	High	High	Medium	Modularize
Edge beam: prefabricated beams	8	High	High	High	High	Medium	Modularize
Pavement: Asphalt	9	Medium	Medium	Medium	High	Low	Not clear: modularize or standardize parametrical
Edge element (finishing)	10	Low	Medium	Medium	Medium	Medium	Not clear: standardize parametrical
Parapets (pedestrians+ traffic)	11	Low	Low	Medium	Medium	Low	Standardize
Upstand (schampkant)	12	Medium	High	High	High	High	Modularize
Safety guards	13	Medium	Low	Medium	Medium	Low	Not clear: standardize parametrical
Bearings	14	Medium	Medium	Medium	Medium	High	Not clear: standardize parametrical
Expension joints	15	Medium	High	High	Low	Medium	Modularize
Connection between	16	Low	Low	Low	Low	Low	Standardize
Approach slab	17	Low	Low	Low	Medium	Medium	Standardize

C9-5: Overview and interpretation results - Structural engineer - Tristan Wolvekamp

Overview Tristan Wolvekamp	Component number	High - Medium - Low: GVI	Low - Medium - High CI-R Direct	Low - Medium - High CI-S Direct	Low - Medium - High CI-R Parametric	Low - Medium - High CI-S Parametric	General outcome
Foundation pad	1	Medium	Low	Medium	Low	Medium	Not clear: standardize
Foundation piles	2	High	Medium	Medium	High	Medium	Modularize
Intermediate wall/colomn	3	Medium	Medium	Low	Low	Low	Not clear: standardize
Abutment or bank seat	4	High	High	High	High	High	Modularize
Capping beam	5	High	Medium	Medium	Medium	Medium	Modularize
Wing walls	6	Low	Low	Low	Low	Low	Standardize
Deck: prefabricated beams	7	High	High	High	Medium	High	Modularize
Edge beam: prefabricated	8	High	High	High	High	High	Modularize
Pavement: Asphalt	9	Medium	High	Medium	High	Medium	Modularize
Edge element (finishing)	10	Low	Medium	Medium	Medium	Medium	Standardize parametrical
Parapets (pedestrians+ tra	11	Low	Low	Medium	Medium	Medium	Standardize parametrical
Upstand (schampkant)	12	Medium	High	Medium	High	High	Modularize
Safety guards	13	Medium	Medium	Low	Medium	Low	Not clear: standardize parametrical
Bearings	14	Medium	Medium	Low	Medium	Low	Not clear: standardize parametrical
Expension joints	15	Medium	Medium	High	Medium	High	Modularize
Connection between	16	Low	Low	Low	Low	Low	Standardize
Approach slab	17	Low	Low	Medium	Low	Medium	Standardize parametrical

C10-1: Table Coupling-Indexes - Direct relations - Session

Coupling - index: Direct constructive relations

Give numbers 1, 3, 6, 9

By: All constructeurs together
05-sep-16

Prefabricated concrete viaduct (NL)

		Foundation		Substructure				Superstructure							Bearings, expansion joints and approach slab				Non- structural components					
								Core elements		*Extension*														
	B	Foundation pad (pad for intermediate wall/column(s))	Foundation piles	Intermediate wall/column(s)	Abutment or bank seat (including foundation pad)	Capping beam	Wing walls	Deck: prefabricated beams (box-beams)	Edge beam: prefabricated	Pavement: Asphalt	Edge element (finishing)	Parapets (pedestrians + traffic)	Upstand (schampkant)	Safety guards	Bearings	Expansion joints(abutment/bank seat and deck + beams at the location of the intermediate pier)	Connection between approach slab and abutment/bankseat	Approach slab	Traffic signs	Lighting	Cables	Water drianage	Camara's and sensors	CI-S (supply)
A		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
Foundation																								
Foundation pad	1		3	3																	1	1		8
Foundation piles	2	6			6																			12
Substructure																								
Intermediate wall/colomn(s)	3	6				6															1	1		14
Abutment or bank seat	4		3				3	6	6		3		1		6	6	1	3			1	1		40
Capping beam	5			6				6	6		1				6					1	1	1		28
Wing walls	6				1						1		1					1			1	1		6
Superstructure																								
Deck: prefabricated beams	7				6	6			6	1			1		9	6								35
Edge beam: prefabricated beams	8				6	6	1	3		1	6		3		9	6								41
Pavement: Asphalt	9							1	1				3			9	1					1		16
Edge element (finishing)	10				1	1	3		6			1	6			1					3	3		25
Parapets (pedestrians+ traffic)	11						1				1		6								1	1		10
Upstand (schampkant)	12				1		3	1	6		1	1		1		6				1	1	1		23
Safety guards	13												3											3
Bearings, expansion joints and transition slab																								
Bearings	14				6	6		3	3															18
Expension joints	15				3			3	3	1			1	1							1	1		14
Connection between	16				1													1						2
Approach slab	17				3					1							1							5
Non- structural components:																								
Traffic signs	18										6		3								1			10
Lighting	19				1	1															1			3
Cables	20												3											3
Water drainage	21				3		3						3			1								10
Camera's and sensors	22																							0
CI -R (recieve)		12	6	9	38	26	14	23	37	4	19	2	34	2	30	35	3	5	0	2	13	12	0	

C10-2A: Outcome - Table Coupling-Indexes - Direct relations - Session

Session structural engineers - GVI, CI-R Direct and CI-S Direct	component number	Highest values 1-5 GVI	Lowest values 1-5 GVI	Low-Medium-High GVI	CI-R Direct	Highest values 1-5 CI-R Direct	Lowest values 1-5 CI-R Direct	Low - Medium - High CI-R Direct	CI-S Direct	Highest values 1-5 CI-S Direct	Lowest values 1-5 CI-S Direct	Low - Medium - High CI-S Direct
Foundation pad	1	7	13	Medium	12	10	8	Medium	8	13	5	Low
Foundation piles	2	5	16	High	6	12	6	Medium	12	11	7	Medium
Intermediate wall/colomn(s)	3	6	14	Medium	9	11	7	Medium	14	9	9	Medium
Abutment or bank seat	4	3	12	High	38	1	17	High	40	2	16	High
Capping beam	5	4	10	High	26	6	12	Medium	28	4	14	High
Wing walls	6	11	4	Low	14	9	9	Medium	6	14	4	Low
Deck: prefabricated beams	7	1	17	High	23	7	11	Medium	35	3	15	High
Edge beam: prefabricated beams	8	2	15	High	37	2	16	High	41	1	17	High
Pavement: Asphalt	9	10	8	Medium	4	14	4	Low	16	8	10	Medium
Edge element (finishing)	10	15	3	Low	19	8	10	Medium	25	5	13	High
Parapets (pedestrians+ traffic)	11	16	2	Low	2	16	1	Low	10	12	6	Medium
Upstand (schampkant)	12	13	6	Medium	34	4	14	High	23	6	12	Medium
Safety guards	13	12	7	Medium	2	17	2	Low	3	16	2	Low
Bearings	14	9	9	Medium	30	5	13	High	18	7	11	Medium
Expension joints	15	8	11	Medium	35	3	15	High	14	10	8	Medium
Connection between	16	14	5	Low	3	15	3	Low	2	17	1	Low
Approach slab	17	17	1	Low	5	13	5	Low	5	15	3	Low

Session structural engineers - GVI, CI-R Direct and CI-S Direct	component number	Low-Medium-High GVI	Low - Medium - High CI-R Direct	Low - Medium - High CI-S Direct
Foundation pad	1	Medium	Medium	Low
Foundation piles	2	High	Medium	Medium
Intermediate wall/colomn(s)	3	Medium	Medium	Medium
Abutment or bank seat	4	High	High	High
Capping beam	5	High	Medium	High
Wing walls	6	Low	Medium	Low
Deck: prefabricated beams	7	High	Medium	High
Edge beam: prefabricated beams	8	High	High	High
Pavement: Asphalt	9	Medium	Low	Medium
Edge element (finishing)	10	Low	Medium	High
Parapets (pedestrians+ traffic)	11	Low	Low	Medium
Upstand (schampkant)	12	Medium	High	Medium
Safety guards	13	Medium	Low	Low
Bearings	14	Medium	High	Medium
Expension joints	15	Medium	High	Medium
Connection between	16	Low	Low	Low
Approach slab	17	Low	Low	Low

C10-2B: Outcome - Table Coupling-Indexes - Direct relations - Session

C11-1: Combined results - Sessionstructural engineers with average parametric indexes

Session structural engineers								
Session structural engineers	component number	GVI (average ranked 1-5)	CI-R direct	CI-S direct	CI-R parametric (average individual)	CI-S parametric (average individual)	Interesting to (GVI and CI-R and CI-S direct)	Conclusion (GBI, CI-R and CI-S direct and parametrical)
Foundation pad	1	Medium	Low	Low	Medium	Medium	Not clear	Standardise parametrical
Foundation piles	2	High	Low	Low	High	High	Modularize	Modularize
Intermediate wall/colomn(s)	3	Medium	Low	Low	Medium	Medium	Not clear	Standardise parametrical
Abutment or bank seat	4	High	High	High	High	High	Modularize	Modularize
Capping beam	5	High	High	High	High	High	Modularize	Modularize
Wing walls	6	Low	Low	Low	Low	Low	Standardise	Standardise
Deck: prefabricated beams	7	High	High	High	High	High	Modularize	Modularize
Edge beam: prefabricated beams	8	High	High	High	High	High	Modularize	Modularize
Pavement: Asphalt	9	Medium	Low	High	High and low	Low	Not clear	Not clear
Edge element (finishing)	10	Low	Medium	Medium	Medium	Medium	Not clear	Standardise parametrical
Parapets (pedestrians+ traffic)	11	Low	Low	Low	Low	Low	Standardise	Standardise
Upstand (schampkant)	12	Medium	High	High	High	High	Modularize	Modularize
Safety guards	13	Medium	Medium	Low	Medium	Low	Not clear	Not clear
Bearings	14	Medium	Low	Medium	Low	High and Low	Not clear	Not clear
Expension joints	15	Medium	High	High	Low	High	Modularize	Modularize
Connection between	16	Low	Low	Low	Low	Low	Standardise	Standardise
Approach slab	17	Low	Low	Low	Low	Low	Standardise	Standardise

C11-2: Combined results - Individual outcomes structural engineers with session

Suitable approach		Structural engineers individual + session											
Component	Component number	General outcome - GW	General outcome - AGP	General outcome - MM	General outcome - MH	General outcome - TW	Outcome session	Modularize	Standardise parametrical	Standardise	Not clear	Conclusion (with not-clear)	Conclusion (without not-clear)
Foundation pad	1	Standardise parametrical	Not clear	Not clear	Standardise parametrical	Not clear	Standardise parametrical		3		3	Not clear	Standardise parametrical
Foundation piles	2	Modularize	Modularize	Modularize	Modularize	Modularize	Modularize	6				Modularize	Modularize
Intermediate wall/column(s)	3	Not clear	Not clear	Standardise parametrical	Not clear	Not clear	Standardise parametrical		2		4	Not clear	Standardise parametrical
Abutment or bank seat	4	Modularize	Modularize	Modularize	Modularize	Modularize	Modularize	6				Modularize	Modularize
Capping beam	5	Modularize	Modularize	Modularize	Modularize	Modularize	Modularize	6				Modularize	Modularize
Wing walls	6	Standardise	Standardise	Standardise	Standardise	Standardise	Standardise			6		Standardise	Standardise
Deck: prefabricated beams	7	Modularize	Modularize	Modularize	Modularize	Modularize	Modularize	6				Modularize	Modularize
Edge beam: prefabricated beams	8	Modularize	Modularize	Modularize	Modularize	Modularize	Modularize	6				Modularize	Modularize
Pavement: Asphalt	9	Not clear	Not clear	Modularize	Not clear	Modularize	Not clear	2			4	Not clear	Modularize
Edge element (finishing)	10	Standardise	Standardise parametrical	Not clear	Not clear	Standardise parametrical	Standardise		2	2	2	Not clear	Not clear
Parapets (pedestrians+ traffic)	11	Standardise	Modularize	Standardise	Standardise	Standardise parametrical	Standardise	1	1	4		Standardise	Standardise
Upstand (schampkant)	12	Standardise parametrical	Modularize	Modularize	Modularize	Modularize	Modularize	5	1			Modularize	Modularize
Safety guards	13	Standardise	Modularize	Standardise parametrical	Not clear	Not clear	Not clear	1	1	1	3	Not clear	Not clear
Bearings	14	Modularize	Modularize	Modularize	Not clear	Not clear	Not clear	3			3	Not clear	Modularize
Expansion joints	15	Modularize	Not clear	Not clear	Modularize	Modularize	Modularize	4			2	Modularize	Modularize
Connection between	16	Standardise	Standardise parametrical	Standardise	Standardise	Standardise	Standardise		1	5		Standardise	Standardise
Approach slab	17	Standardise	Standardise	Standardise	Standardise	Standardise parametrical	Standardise		1	5		Standardise.	Standardise.

C11-3: Combined results - Individual outcomes structural engineers

Suitable approach		Structural engineers - individual										
Component	Component number	General outcome - GW	General outcome - AGP	General outcome - MM	General outcome - MH	General outcome - TW	Modularize	Standardise parametrical	Standardise	Not clear	Conclusion (with not-clear)	Conclusion (without not-clear)
Foundation pad	1	Standardise parametrical	Not clear	Not clear	Standardise parametrical	Not clear		2		3	Not clear	Standardise parametrical
Foundation piles	2	Modularize	Modularize	Modularize	Modularize	Modularize	5				Modularize	Modularize
Intermediate wall/column(s)	3	Not clear	Not clear	Standardise parametrical	Not clear	Not clear		1		4	Not clear	Standardise parametrical
Abutment or bank seat	4	Modularize	Modularize	Modularize	Modularize	Modularize	5				Modularize	Modularize
Capping beam	5	Modularize	Modularize	Modularize	Modularize	Modularize	5				Modularize	Modularize
Wing walls	6	Standardise	Standardise	Standardise	Standardise	Standardise		5			Standardise	Standardise
Deck: prefabricated beams	7	Modularize	Modularize	Modularize	Modularize	Modularize	5				Modularize	Modularize
Edge beam: prefabricated beams	8	Modularize	Modularize	Modularize	Modularize	Modularize	5				Modularize	Modularize
Pavement: Asphalt	9	Not clear	Not clear	Modularize	Not clear	Modularize	2			3	Not clear	Modularize
Edge element (finishing)	10	Standardise	Standardise parametrical	Not clear	Not clear	Standardise parametrical		2	1	2	Not clear	Standardise parametrical
Parapets (pedestrians+ traffic)	11	Standardise	Modularize	Standardise	Standardise	Standardise parametrical	1	1	3		Standardise	Standardise
Upstand (schampkant)	12	Standardise parametrical	Modularize	Modularize	Modularize	Modularize	4	1			Modularize	Modularize
Safety guards	13	Standardise	Modularize	Standardise parametrical	Not clear	Not clear	1	1	1	2	Not clear	Not clear
Bearings	14	Modularize	Modularize	Modularize	Not clear	Not clear	3			2	Modularize	Modularize
Expansion joints	15	Modularize	Not clear	Not clear	Modularize	Modularize	3			2	Modularize	Modularize
Connection between	16	Standardise	Standardise parametrical	Standardise	Standardise	Standardise		1	4		Standardise	Standardise
Approach slab	17	Standardise	Standardise	Standardise	Standardise	Standardise parametrical		1	4		Standardise.	Standardise.

C11-4: Conclusion - Method applied - With not clear

Suitable approach		Outcome (with not-clear)		
Component	Component number	Conclusion (individual, with not-clear)	Conclusion (session)	Result (with not-clear)
Foundation pad	1	Not clear	Standardise parametrical	Need to be analysed further
Foundation piles	2	Modularize	Modularize	Modularize
Intermediate wall/column(s)	3	Not clear	Standardise parametrical	Need to be analysed further
Abutment or bank seat	4	Modularize	Modularize	Modularize
Capping beam	5	Modularize	Modularize	Modularize
Wing walls	6	Standardise	Standardise	Standardise
Deck: prefabricated beams	7	Modularize	Modularize	Modularize
Edge beam: prefabricated beams	8	Modularize	Modularize	Modularize
Pavement: Asphalt	9	Not clear	Not clear	Need to be analysed further
Edge element (finishing)	10	Not clear	Standardise	Need to be analysed further
Parapets (pedestrians+ traffic)	11	Standardise	Standardise	Standardise
Upstand (schampkant)	12	Modularize	Modularize	Modularize
Safety guards	13	Not clear	Not clear	Need to be analysed further
Bearings	14	Modularize	Not clear	Need to be analysed further
Expansion joints	15	Modularize	Modularize	Modularize
Connection between	16	Standardise	Standardise	Standardise
Approach slab	17	Standardise.	Standardise	Standardise

C11-5: Conclusion-Method applied - Without not clear

Suitable approach		Outcome (without not-clear)		
Component	Component number	Conclusion (individual - without not-clear)	Conclusion (session)	Result (without not-clear)
Foundation pad	1	Standardise parametrical	Standardise parametrical	Standardize parametrical
Foundation piles	2	Modularize	Modularize	Modularize
Intermediate wall/column(s)	3	Standardise parametrical	Standardise parametrical	Standardize parametrical
Abutment or bank seat	4	Modularize	Modularize	Modularize
Capping beam	5	Modularize	Modularize	Modularize
Wing walls	6	Standardise	Standardise	Standardize
Deck: prefabricated beams	7	Modularize	Modularize	Modularize
Edge beam: prefabricated beams	8	Modularize	Modularize	Modularize
Pavement: Asphalt	9	Modularize	Not clear	Need to be analysed further
Edge element (finishing)	10	Standardise parametrical	Standardise	Need to be analysed further
Parapets (pedestrians+ traffic)	11	Standardise	Standardise	Standardize
Upstand (schampkant)	12	Modularize	Modularize	Modularize
Safety guards	13	Not clear	Not clear	Need to be analysed further
Bearings	14	Modularize	Not clear	Need to be analysed further
Expansion joints	15	Modularize	Modularize	Modularize
Connection between	16	Standardise	Standardise	Standardize
Approach slab	17	Standardise.	Standardise	Standardize