Ing. L. M. Klarenbeek

The circularity principle in the design process of the public client

The project 'Stuwen van de Maas' for future generations

TU Delft

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Thesis

By

Ing. L. M. Klarenbeek

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Thesis committee:	Prof. Dr. Ir. H.M. Jonkers	TU Delft (Chairman)
	Dr. Ir. E. J. Houwing	TU Delft
	Ir. S. Hellebrand	Rijkswaterstaat

Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

Preface

Before you lies the thesis report on the implementation of circularity in the design process of the public client. This report is the result of the performed thesis research in partial fulfillment of the master degree Construction management & Engineering at the Delft University of Technology. The research was conducted at Rijkswaterstaat to contribute in their ambition to transfer towards a circular construction industry.

An integral character of the construction industry together with a sustainable sector that does not put environmental pressure on our beautiful planet are my ambitions when thinking about my own desired contribution for a sector I am so passionate about. Therefore I want to thank Erik-Jan Houwing for listening to this ambition and contacting Simone Hellebrand. Together we formulated a research question that precisely paired with my own ambitions. I am very grateful for that opportunity because even during the more challenging periods of this thesis I could stay motivated due to the passion I have for this topic.

I want to thank Erik-Jan Howing, Henk Jonkers and Simone Hellebrand for their excellent guidance and the always-present possibilities to catch -up, brainstorm, discuss my encountered problems and giving me insight and guidance in times I got stuck in my own thought pattern. I also would like to thank Marcel Hertogh for the guidance during the first months of this research. Additionally, I would like to thank the employees of Rijkswaterstaat for giving me insight in the current practice during my research interviews and the members of the design team Grave who took the time to review my results and from whom I learned a lot about the almost endless possibilities and followed challenges that accompany the responsibility of the Dutch public client.

Finally, I would like to thank my friends and family for their inexhaustible and unconditional support throughout this period, for listening to me and motivate me when needed and for always making time for a cup of coffee or ice-cream break.

Ing. L. M. Klarenbeek
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Samenvatting

Het klimaat verandert en industrieën over de hele wereld moeten hervormen om een leefbare aarde voor toekomstige generaties te garanderen. Binnen de bouwsector vraagt dit om een andere benadering van de levenscyclus van civieltechnische bouwwerken, aangezien de bouwsector en haar gebouwde omgeving 's werelds grootste verbruiker van grondstoffen is en verantwoordelijk voor 25-40% van de CO2-uitstoot. Een steeds meer besproken aanpak om de transitie naar een duurzamer systeem te maken is de verschuiving van de huidige lineaire levensduur van assets naar een circulair georiënteerd systeem. Dit laatste betekent het behoud de waarde van gebruikte materialen in plaats van deze weg te gooien. Op deze manier wordt de gebruikscyclus van materialen gesloten en neemt de vraag naar schaarse grondstoffen af. Deze circulaire manier van bouwen houdt in dat de end-of-life-fase van de assets en de circulaire oplossingen voor deze end-of-life-fase worden geïntegreerd in het ontwerp. Het hergebruik van assets en componenten, flexibiliteit en aanpasbaarheid in de functie, modulaire assets en een materiaaldatabase zijn allemaal mogelijke manieren om bouwwerken na hun levensduur op een circulaire manier te hergebruiken. De verschuiving naar een circulaire economie biedt mogelijkheden om het gebruik van primaire grondstoffen te verminderen en de CO2-voetafdruk te verkleinen. Dit bevordert een duurzamere werkwijze in de bouwsector, maar vraagt om grote veranderingen in de huidige aanpak.

Opdrachtgevers spelen een belangrijke rol in de transitie naar een circulaire bouwsector door hun verantwoordelijkheid in het formuleren van de scope, projectambities en eisen in de startfase van een project. Rijkswaterstaat, de grootste publieke opdrachtgever van Nederland, heeft de ambitie om alle projecten klimaatneutraal en circulair aan te besteden, samen met het versterken van de duurzame leefomgeving in 2030 en een volledig circulair te werken in 2050. Om het gebruik van circulaire principes in de initiatie fase te bevorderen worden circulaire pilots en programma's ontwikkeld. Desalniettemin wordt circulariteit nu vaak gezien als een bijkomend kenmerk in plaats van een integraal ontwerpprincipe. Dit resulteert in een late overweging van het aspect en daarmee een laag circulariteitsniveau. Om de circulariteit van projecten te versterken is er behoefte aan een helder integraal ontwerpproces waarin circulariteit een plek heeft. Daarnaast is er een toename in kennis over circulariteit en de mogelijkheden voor het ontwerp nodig onder alle teamleden van een project. Het doel van dit onderzoek is om de principes van circulariteit te verenigen met het ontwerpproces van waterbouwkundige projecten en ervoor te zorgen dat circulariteit gemeengoed en een manier van denken wordt. Dit is vormgegeven met een stroomschema voor het implementeren van circulariteit in het ontwerpproces op basis van de literatuur met als doel een projectteam begeleiden bij het meenemen van circulariteit tijdens het integrale ontwerpproces van een asset. Vervolgens wordt het huidige ontwerpproces en werkwijze van publieke opdrachtgever met betrekking tot het implementeren van circulariteit onderzocht in een empirisch kwantitatief onderzoek. Deze bevindingen worden gespiegeld tegen het eerdergenoemde stroomschema en geven de aandachtspunten weer voor de publieke opdrachtgever bij het implementeren van circulariteit in het ontwerpproces. Het stroomschema wordt geverifieerd met de casestudy Stuw Grave aangaande de vervanging en renovatie van een historische stuw in de Maas in de provincie Noord-Brabant. Deze casestudy toonde aan dat het stroomschema waardevol is voor de implementatie van circulariteit en de belangrijke aspecten omvat waarmee rekening moet worden gehouden. Echter is het stroomschema nog geen toepasbaar gebruiksvriendelijk schema voor ontwerpteams vanwege de grote hoeveelheid informatie, lay-out en Engelse taal. Hiervoor is een werkbare versie met handleiding gerealiseerd.

De implementatie van circulariteit in de bouwsector gaat gepaard met diverse belemmeringen. De meest substantiële zijn het noodzakelijke integrale karakter van het ontwerpproces en het aspect vroegtijdig in het proces op te nemen. Een integrale ontwerpmethode komt de circulariteit ten goede, omdat tal van aspecten en alle levenscyclusfasen van een asset de mate van circulariteit kunnen beïnvloeden. Het integrale karakter helpt ook bij het vroegtijdig overwegen van circulariteit, waar nu vaak te laat in het ontwerpproces aan wordt gedacht. Momenteel zijn de circulaire richtlijnen voor de publieke opdrachtgever gericht op hun rol als inkooppartij en niet op hun aandeel in het ontwerp en de keuzes voorafgaand aan de aanbesteding. De ontwerpstappen voor circulaire assets maken daarom geen onderdeel uit van de procedure van de opdrachtgever, hoewel deze procedure wel invloed heeft op de mogelijkheden voor circulariteit. De publieke opdrachtgever dient daarom voorafgaand aan de aanbesteding, in de gebiedsagenda en planuitwerkingsfase, rekening te houden met circulariteit, aangezien in deze fasen beslissingen worden genomen die de mogelijkheden voor circulariteit beïnvloeden. Dit heeft ook invloed op de samenwerking met de marktpartij en vraagt om een duidelijke en uniforme ambitie en aanpak. Daarnaast zijn draagvlak, kennis en een organisatie brede aanpak van circulariteit van belang bij het implementeren in het ontwerpproces. Dit vermindert de huidige risicomijdende cultuur rond circulair ontwerp en ondersteunt de genomen beslissingen ten gunste van circulariteit. Een van de meest praktische maatregelen om de positie van circulariteit in een project te versterken, is de implementatie van het aspect in de eisen voor in de interne projectopdracht van de opdrachtgever en in de aanbesteding richting de markt om zo het overwegen van circulariteit een verplicht karakter te geven.

Abstract

The climate is changing and industries world-wide need to transform to assure a liveable earth for future generations. Within the construction sector, this requires a different approach and perspective on the life-cycle of civil engineering assets since the construction industry and its build environment is the world's largest consumer of raw materials and responsible for 25-40% of the CO2 emissions. To make the transit to a more sustainable system, an increasingly discussed approach is a shift from the current linear lifecycles to a circular orientated economy. This latter means the preservation of used materials rather than dispose. In this way, the lifecycle loop of the materials is closed and the energy demand and the scarcity of raw resources is reduced. This more circular way of constructing entails the integration of the assets' end-of-life phase and its' circular solutions into the design. The reuse of assets, flexibility and adaptability in its' function, modular based structures and a material database are all possible ways in dealing with assets after their lifetime in a circular manner. The shift towards a circular economy provides the possibilities for reducing the use of primary materials, protection of material resources and reduce the carbon footprint. This enhances a more sustainable practise of the construction industry though asks for major changes in its current operation.

Clients play a substantial part in the transition towards a circular construction industry due to their responsibility in the formulation of the scope, project ambitions and requirements in the initiation phase of a project. Rijkswaterstaat, the biggest public client in the Netherlands, has the ambition to tender all the projects climate neutral and circular together with enhancing the sustainable living environment by 2030 and be fully circular by 2050. Circular pilot projects and programs are developed to promote the use of circular principles in the initiation phase, although circularity is currently often seen as an additional feature instead of an integral design principle. This results in a late consideration of the aspect and therefore a low level of circularity. To enhance circularity in projects there is a need for a clear and integral design process that includes circularity and an increase in knowledge among all team members of a project on circularity and the possibilities for the design. The aim of this research is to unite the circularity principles with the design process of hydraulic infrastructure projects and enable circularity to become common practice and a way of thinking. This is accomplished with a framework for implementing circularity in the design process based on state-of-the-art literature and results in a flowchart that aims to guide a project team to consider circularity and its opportunities during the integral design process of an asset. The flowchart visualizes the important development steps needed for the implementation of circularity, together with a circular way of approaching de design of an asset that includes the circular design principles. Thereafter, the public clients' current design process and practice on implementing circularity is researched in an empirical quantitative study. These findings are reflected against the approach based on literature and show the points of attention for the public client on implementing circularity in the design process. The flowchart is verified with a case study on the project Weir Grave concerning the reconditioning of a historical weir in the river Meuse in the province of North-Brabant. This case study showed that the flowchart is valuable for the implementation of circularity and includes the significant aspects to consider. Although, the flowchart is not yet an applicable chart for design teams due to the high amount of information, layout and English language. A workable version with instructions is realized to improve this.

Various barriers accompany the implementation of circularity in the construction sector with the most substantial being the necessary integral character of the industry and design process along with the timing of including the aspect in this process. An integral design method benefits circularity because numerous aspects and lifecycle phases of an asset influence the level of circularity. The integral character also assist the required early consideration of circularity, which is now often considered too late in the design process. Currently, the circular guidelines for the public client are focused on their role as an acquisition party and not on their part in the design. Therefore the design steps for circular assets are not part of the clients' procedure, although this procedure does influence the possibilities for circularity. Therefore, the public client needs to take circularity into account prior to the tender procedure, in the initiation- and design phase, as relevant decision that influence the possibilities for circularity are made in these phases. This also influences the collaboration with the market party and requires a clear and uniform ambition towards them. Additionally, support, knowledge and an organization wide approach on circularity are of significance when implementing circularity in the design process. This reduces the current risk avoidance culture on circular design and supports the decisions made. One of the most practical measures to enhance circularity in a project is the implementation of the aspect as a requirement from the start in the clients' internal project assignment and in the tender towards the market to create a responsibility for considering the aspect.

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1. Introduction

Nowadays society benefits from the evolution we undergone since the industrial revolution, however we also face the downsides of this development. Seas are rising, weather patterns are getting more extreme and raw materials are becoming scarce. The climate is changing (IPCC, 2020). Industries world-wide need to change to assure a liveable earth for future generations. Within the construction sector, this askes for a different approach and perspective on the life-cycle of civil engineering assets (UNEP, 2018). With the growth of the human population and the global economy, the demand for raw materials and resources also grows. Many material resources are likely to become scarcer and more costly. The demand for these raw materials also cause ecological impact, as the single use of materials leaves a remarkable carbon footprint (K. T. Adams et al., 2017; Ritzén & Ölundh, 2017). The construction industry and its build environment is the world's largest consumer of raw materials and responsible for 25-40% of the CO2 emissions (WEF, 2016). The sector is now arranged in a linear fashion, but with the change in climate and scarcity of raw materials the request for a more circular way of constructing grows (Romme & Endenburg, 2006). The general philosophy of circularity and a circular economy is focused on closing the gap from disposal to start of life. For the construction sector, this entails a restorative and regenerative system for the whole industry (Ellen MacArthur Foundation, 2015). The elimination of waste through sustaining the added value in used construction materials for as long as possible by reusing them in new assets. This enables a closed loop from end-of-life to new projects (Mahpour, 2018). The main benefits of a circular economy are reducing the use of scarce resources and reducing the environmental impact together with the increasing economic benefits (Ritzén & Ölundh, 2017).

Circular economy is a much discussed topic in literature. However, a universal framework is missing. Through a research conducted by Julian Kirchherr on the of 114 definitions of circular economy, the most common and cited definitions for the framework regarding circular economy where extracted. It shows that the 4R framework and the waste hierarchy are the most cited core principles regarding circular economy. The 4R method is the collection of various circular approaches and is a common way to describe the principle of circular economy. The 4R framework focuses on the following hierarchical approaches to realize the most circular assets: Reduce, reuse, recycle, recover (Kirchherr et al., 2017). This can be seen as the core and the most used R-framework in the literature on circular economy, although it can be more detailed and extended to a 9R framework, as shown in Figure 1. This framework adds six additional approach stages that hierarchically enhance the circularity of assets which are refuse, rethink, repair, refurbish, remanufacture and repurpose (Potting et al., 2016). The waste hierarchy integrated in the R-framework entails the hierarchal order in which the R-approaches are most desirable to realize circularity to a greater extent and is the order in which the circularity of objects and systems are ranked from most circular to least circular. Circularity in construction focuses on the complete life cycle of the asset and its containing materials. The strategy considers the increase of material productivity, the increase of eco-efficiency and as a last resort, more environmental alternatives that replace currently used and environmental harmful strategies (Behrens et al., 2007).

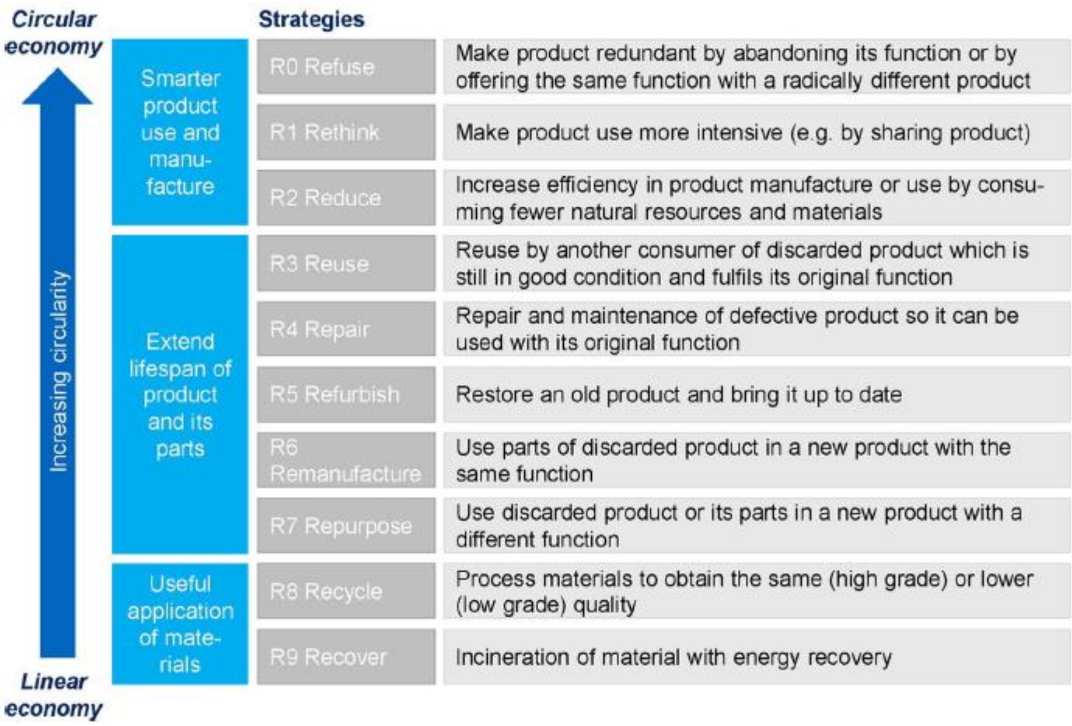

Figure 1: The 9R Framework (Potting et al., 2016)

The “Thematic Strategy on the sustainable use of natural resources” of the European Union focusses to facilitate and stimulate economic growth and at the same time reduce the environmental impact of material use in Europe (The Council of the European Union, 2009). Because of the impact of sustainable and circular ambitions in infrastructure projects, clients play a big role in making the switch from a linear to a circular construction industry (Versteeg Conlledo, 2019). Therefore circularity needs to be optimally included in the design of an asset and the process of the public client (Chahboun, 2019). The subject of this thesis is to research these fields and how the circular principles can be optimally incorporated in the design process of the public client.

There are multiple researches done on the barriers for the implementation of circularity in the construction sector. The unclear ownership of materials and responsibility for implementing circularity, the lack of integration of the sector and the insufficient level of knowledge and insight in the theme are the main arguments that currently withhold the implementation of circularity in de industry. To research circularity in the design process of the public client, the occurrence of the current barriers and at which point in the life-cycle of an asset these originate, need to be clear. In this research the barriers in the design process that need to be overcome to include circularity and implement it optimally are analysed and visualized. These conclusions are compared to the work method of the public client Rijkswaterstaat, their design process and circularity strategy, to visualize the gaps that withhold the implementation of circularity in their current process and identify additional barriers. For verification, the proposed circular development process is applied on the design process of the Weir near the town of Grave in the Netherlands that reaches its end of life phase soon and faces renovation or renewal. This research is focussed on the role of the public client to implement circularity in infrastructure projects as substantial gain on circularity can be realized at the start of the process (Versteeg Conlledo, 2019). This research is conducted with the cooperation of Rijkswaterstaat although the conclusions of this research are applicable for other public clients. An additional focus of this research is hydraulic infrastructure with the case study of the Weir Grave in the river Meuse.

This thesis describes a research that aims to optimally incorporate circular principles in the public clients' development process of assets. First, state-of-the-art literature is studied on the design process of infrastructure assets, the current practice on circularity in the infrastructure sector and the hurdles to overcome. These findings are captured in a flowchart that visualizes an approach on implementing circularity. This forms the base for the empirical quantitative research and shows the current research gap. In chapter 3, the methodology of this research is elaborated upon, together with the research objective and scope. Chapter 4 presents the research conducted on the implementation of circularity within the design process of the public client, in this case Rijkswaterstaat. Their development process and current practice on circular design is researched based on internal documentation followed by the preformed empirical research that is obtained by a qualitative data with semi-structured interviews. This gives more clarity in the design process of the public client and their current practice on circularity. These findings are compared to the findings retrieved from the literature study in chapter 5 and show the aspects that need attention for the implementation of circularity in the design process of the public client. As a final part of this study, in chapter 6, the suggested approach is verified with a case study on the Weir Grave. A weir that is located in the river Meuse in the Netherlands. Finally, the discussion of this study is presented in chapter 7, followed by the conclusion and recommendations for future study in chapter 8.

2. Literature study: Circular economy in the design process

The first part of the research is defined by a literary review to give insight in the current state of the design process and circularity in the infrastructure sector. First, the lifecycles and design process of an infrastructure asset is explained followed by the current circularity practise in the construction sector. This gives a overview of the moments in time that the barriers for implementing circularity occur in the life cycle of infrastructure assets and how these can be solved. This is the departure point for the empirical quantitative part of the research. The sources used for this literature study are articles, papers and reports on the topic retrieved from various academic databases.

2.1 The development of an infrastructure asset

To optimally implement circularity in the design process, there is a need to gain understanding of the design process itself first. In this way, the crucial decision points in time and perspectives can be found that play a role in the integration of circularity. In general, infrastructure projects are divided in phases of chronological order. The project starts with the initiation phase followed by the design-, realization-, exploitation- and final the reuse- or demolish phase. In different literature, these phases are distinguished in different ways. The different distinctions of phasing lies in the coverage of one phase. For example, the design phase of Voorendt (2017) covers the same steps as the orientation, feasibility, conceptual, preliminary and detail design stage described by De Ridder (2009), but are distinct in different phases. The different ways of phasing infrastructure projects can be seen in Table 1.

Table 1: Life-cycle phasing in infrastructure projects

	(Hertogh et al., 2018)	(De Ridder, 2009)	(Voorendt, 2017)	Systems Engineering	RWS MIRT
T=0	Initiation phase	Orientation stage	Design phase	Orientation	Area Agenda
		Feasibility stage			Exploration phase
	Preparation phase	Conceptual design stage		Concept phase	Plan development phase
				Development and contracting	
		Preliminary design stage			
		Detail design stage			
				Further development	Contract formulation and tender
	Realization phase	Construction stage	Realization phase	Realization phase	Realization phase
		Installation stage			

		Testing stage			
	Operation phase	Operation stage	Operation phase	Maintenance	Maintenance and Exploitation phase
T=t	Demolish or reuse phase	Demolition stage	Second life	[not defined]	[not defined]

To elaborate on the different life-cycle phases of infrastructure assets, the theory of Hertogh (2018) is used as a base since this phasing distinction is most similar to the MIRT process. The differences being the Initiation phase that the MIRT process divides in two, Area Agenda and Exploration phase, which can be explained by the variation in phase coverage as the substance of the phases are similar of both theories. Another difference is the additional End-of-Life phase of the theory of Hertogh, which is not defined in the MIRT process but of importance considering circularity. The other theories in phase distinctions are reflected against the theory of Hertogh. The MIRT process is further elaborated in 4.1 Research framework.

Initiation phase

The development of an asset starts with an initiative based on the need to adjust an existing situation. First, it is examined whether the project is feasible, useful and necessary. If it is indicated that there is a functional, spatial, organizational, technical and financial framework within which this is the case, the project is defined. A project objective is formulated followed by a list of requirements, possibly in a functional fashion (Hertogh et al., 2018). In this phase, an analysis is made of what needs to happen to achieve the desired end result. A list of goals is formulated together with the way to achieve these goals. The area study is an orientation and exploration of the characteristics of the surrounding landscape, its organization and use. The study aims to determine the current situation. The legislator, the owners and residents of the landscape are made acquainted with the choice of location, orientation, shape, dimensions and appearance of the intended spatial plans. They respond to the plans based on their own objectives and existing situation. An inventory of these responses provides an outline of the preconditions. Preconditions are the limitations that the designer encounters when he places his solution in the environment, therefore preconditions limit the number of possible solutions (De Ridder, 2009; Hertogh et al., 2018). The translation is made from ambitions and preconditions for sustainability into weighing criteria and the formulation of tangible goals. Requirements and criteria are factors that highly influence the design solution. These requirements are the base of the design alternatives and, together with the ambitions, set at the very beginning of the process when the situation is analyzed and mapped with the available knowledge. There is a distinction between the requirements and criteria. Requirements are characteristics that form the baseline for the design and all the concepts need to be in line with these requirements. Criteria are the aspects that give added value to the design and are not as mandatory as requirements (Voorendt, 2015, 2017).

When considering the implementation of circularity this phase, it is of importance that the aspect is taken into account in the project objective, as this is the base for the formulation of the requirements (Voorendt, 2015). The minimal desired level of circularity can therefore be secured in the requirements and the additional level of circularity for the design alternatives can be captured in the criteria. Additionally, the assessment of the necessity of an new asset and therefore the option to prevent to intervene (Refuse) or to carry out possible adjustments that are sufficient to reach the project objective (Rethink) are actions that impact the level of circularity substantially. It is important to keep in mind that the earlier stages have a great influence on the circularity for the following life cycle stages and therefore circularity needs to be considered at the beginning of the design process (K. T. Adams et al., 2017; Versteeg Conlledo, 2019).

The proposed design method of Mark Voorendt (2017) does not distinct any other phase prior to the realization than the design phase. The exploration and analysis of the problem is all done in the design phase. The actual steps that Voorendt takes are similar, although the initiation and preparation/design phase are merged into one design phase. The initiation phase is the first design cycle in the project process. At the end of this cycle, the decision is made to continue to the next phase of the process or go back to the analysis to adjust the goals of the phase and walk through the cycle again (De Ridder, 2009; Hertogh et al., 2018).

Preparation phase

In the preparation phase, the design is elaborated and in different stages. The design stages go from broad to detailed and are usually a sketch design, preliminary design, definitive design and execution design. The type of contract determines which design level is carried out by the client and ad which point the contracted construction firm takes over. In a traditional contract, technical consultants are asked to carry out all stages of the design for the client. The client thereafter writes out a tender for the construction, which is realized by a contracted construction firm. Nowadays, the construction firm is often involved earlier in the design process or even carries out the design process himself when this is included in the contract (De Ridder, 2009; Hertogh et al., 2018).

The design process is characterized as a funnel form. This entails that the design process works from broad to detailed in cyclic steps (Boeijen & Daalhuizen, 2017; De Groot, 1994). There are multiple models to design, such as the empirical cycle, the Delft Design Method, etc. (Boeijen & Daalhuizen, 2017; Enno Zuidema Stedebouw et al., 2011; Hertogh et al., 2018; Voorendt, 2017). Design models capture the philosophies or strategies proposed and show how a design is or could be made. The models can be illustrated with a flow diagram, that shows the iterative character of the process with a feedback link (Erbuomwan et al., 1996). A detailed explanation of the different models of design can be found in the appendix A. In literature on these design models, it seems like there is an ample of variety, although they have in their base the same cyclic approach to solving the problem. These cyclic steps are an important aspect of the design process because it enables the translation from design objectives into specifications and are therefore essential for reaching a detailed and feasible design. The possibility for iterative steps is also important for a design process and enables reaching an optimal design as more information gained during the process can change the preferable outcome of previous decisions. There is a difference between iterative steps and cyclic steps in the design process, where cyclic steps the same steps but in a more detailed manner, an iterative step is a rerun with more knowledge (Voorendt, 2017). Based on the feasibility study and project definition, various solutions are being examined with an increasing detail level of the design. The result consists of a spatial and functional design and financial, technical and qualitative plans. The requirements and wishes of the client, authorities, possible users and other interested parties are incorporated as much as possible. At the end of each cycle, there is a trade-off of the variants based on the criteria. Then the decision is made to continue to the next phase of the process with the preferred alternative and elaborate further or go back to, adjust and walk through the cycle again (De Ridder, 2009; Hertogh et al., 2018). The guide for sustainable GWW describes the design process in six steps, showed in Figure 2. The steps can be used for the different phases, but can also be walked through cyclic and multiple times within each phase (Rijkswaterstaat & Witteveen+Bos, 2018). This design process is used as a starting point for this research because it is already known among the Dutch public clients.

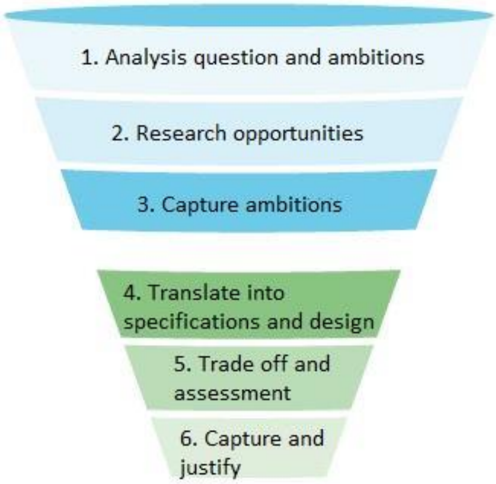

Figure 2: Six steps of sustainable GWW (Ministerie van Infrastructuur en Waterstaat, 2017)

The R-framework for circular principles can be applied in different detail levels of the design process, from reuse or repair of the whole asset to the reuse or repair of components and materials. There are also various design strategies to ensure a circular asset such as Design for Disassembly, Design for adaptability and flexibility and Design out Waste (K. T. Adams et al., 2017). In this phase, the requirements are translated into specifications. This entails that, in theory, when circularity is captured in the requirements, it finds its way into the design specifications. However, to achieve this requires sufficient knowledge and insight for the design team on the possibilities for circular design. Additionally, when circularity is captured in the criteria, it is included in the trade-off scheme for design alternatives and therefore a quantitative aspect to be considered. From a circular point of view, it is important to consider all following phases and their impact on circularity, including the end of life phase, during the design process to determine all aspects that have their influence on the circularity of an asset. This therefore requires a design method with an integral character that includes all significant aspects in the process (Mahpour, 2018).

Contract formulation and tender

The moment the project is tendered, the level of detail of the design is highly dependent of the type of contract. Figure 3 shows the domains for the two parties for different type of contracts. In a traditional contract, technical consultants are asked to carry out all stages of the design for the client and the contractor is barely or not at all involved. The client thereafter writes out a tender for the construction, which is realized by a contracted construction firm. In this case, the tender document is already a detailed design with specifications. The contractors interested prepare a budget based on these documents and the contractor with the lowest bid for quality wins the tender.

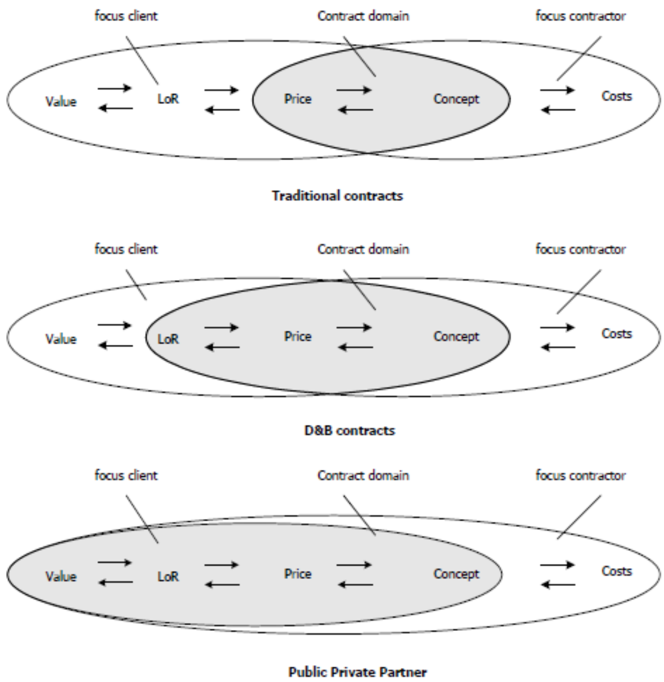

Figure 3: Domain of different type of contracts (De Ridder, 2009)

There are also contracts where the contractor is more involved in the design process or even does the whole detailed design itself, for example a Design-Build contract. These contracts can also contain the Finance, Maintain and/or Operate aspect. When the contractor is in addition to the construction also responsible for the design, the dynamics of the project change as the client is mainly present for the verification of the contractors work. This changes the responsibility for the design, maintenance and operation phase from the client to the contractor. However, ownership of the infrastructure and therefore exploitation and long-term maintenance are responsibilities for the asset owner, which is the public client. These projects are usually not tendered only on price but also on other features such as quality, construction time and nuisance during the construction. These contracts are then tendered on Economically Most Advantageous Tender, also known as EMAT or BPKV[1] in Dutch. These features can contain all aspects that are important to the client at which the contracted party can obtain a discount when sufficiently complying to these. Besides the project specific conditions, the contractors have to comply with minimum requirements such as work experience and financial health of the company (De Ridder, 2009; Hertogh et al., 2018).

In this phase, circularity can be captured in the contract formulation and specification. In this way, the contracted party is obligated to consider circularity in the continuation of the project. The aspect can be captured in the requirements of the project to create an obligation to fulfill. Circularity can also be part of the EMAT criteria to incentives the contracted party to consider circularity in their proposed solution when this criteria discount is sufficiently portentous (Van Oppen et al., 2018; Versteeg Conlledo, 2019).

Realization

The realization starts with the preparation for the execution by the contractor and the subcontractors. The supervision of contract and specifications compliance is carried out during the

[1] In Dutch: Beste Prijs Kwaliteit Verhouding

preparation, execution and delivery by the client. The realization ends with the delivery of the asset by the contractor to the client (Hertogh et al., 2018). The difference in life-cycle process described in literature are usually about the first part of the project, until the realization of the asset. From the realization phase, the process is similar for most theories.

When circularity is considered in an integral manner in the design phase of an asset, this shows in the realization phase. This could be, for example, because the asset is repaired or by repurposing or reusing materials or components. During construction, the minimization of waste and an optimal recycle strategy are measures to ensure a more circular realization phase (K. T. Adams et al., 2017).

Maintenance and Exploitation

The delivery of the asset, or parts of the asset, takes place after the construction work has been completed. The exploitation phase covers the longest period in the construction cycle. The completed structure is used, managed and maintained. All project data obtained in the previous phases is used, such as construction drawings and wiring plans. Small and large maintenance is carried out (Hertogh et al., 2018).

When considering circularity, sufficient and on time maintenance is important as it increases the lifespan of an asset and therefore its level of circularity. To consider minimal and accessible maintenance is therefore important when designing an asset. Additionally, the possibilities for reusing materials that are released during maintenance such as grass clippings or dredged soil also contribute to the level of circular maintenance (K. T. Adams et al., 2017).

End of life / reuse

If the asset does not longer comply with the technical or functional requirement, preparations are made for demolition and recycling or for the reuse of the structure. In the first case, building site is available again on which new development can take place. A construction cycle is then restarted and building materials from the old structure are preferably recycled. The most sustainable way of disposing a structure is reuse. In this case, it is possible to adapt the construction to meet the desired functionality, such as an increase in capacity. A new construction cycle for the renovation is then started. There is also the possibility to reuse the components of the structure when the asset is dismantled properly (Hertogh et al., 2018).

The end of life phase is of great importance for the circularity of an asset. The possibilities to reuse an asset or the components surface in this phase, but are dependent on the design of an asset. Modular builds with standardized components are easier to reuse than a unique asset with distinct specifications. Additionally, circularity can be enhanced when an asset is designed for adaptability and can therefore be given an second lifecycle at the end-of-life phase when the functional lifespan had expired. An aspect that is less dependent on the design but can still influence the level of circularity in the end-of-life phase is the demolishing strategy and the management of the waste streams. When materials are, for example, properly separated, they can be recycled more easy (K. T. Adams et al., 2017; Mahpour, 2018).

An integral design approach

As described in the previous paragraph, the whole lifecycle of an asset needs to be considered when designing an optimal circular asset. An more integrated construction sector and integral design approach offers an opportunity to deal with this complexity and for the implementation of circularity

(Mahpour, 2018). Figure 4 shows the costs of changes in the design against the timespan of the project. It shows that the costs of adjustment that need to be made increase over time. To minimize these changes in a later phase of the project, integral approach form the start of a project could be a solution (Schoonwinkel et al., 2016). It is therefore also valuable to integrate circularity at the beginning of the development, because cost can increase when considered later in the process and changes in the design are needed (Versteeg Conlledo, 2019).

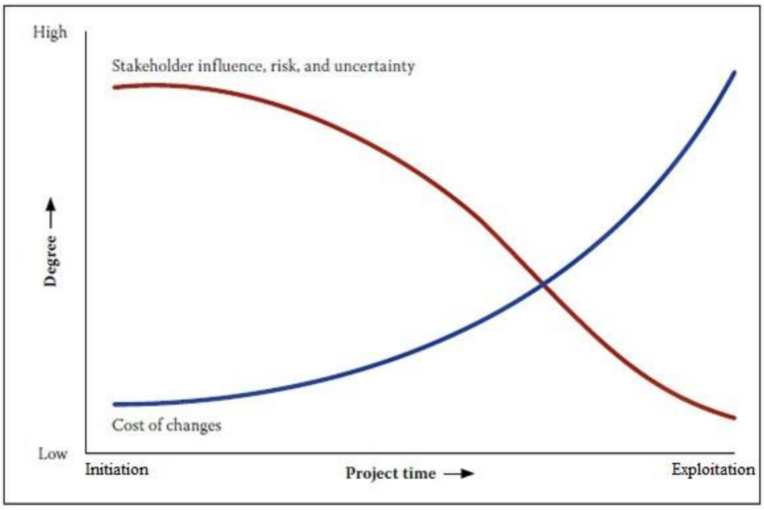

Figure 4: Impact of changes reflected on project time (Schoonwinkel et al., 2016)

Integral design considers the search for a viable solution for civil engineering issues, where all the aspects that can influence the design and can be influenced by the design are considered while designing the asset (Hertogh et al., 2018). It considers an holistic approach that sees the natural system and their properties as a whole and not as a collection of components. Researcher Mark Voorendt described integral design as *'the process of creating an optimal plan or convention for realizing an object or a system that is required to satisfy a need'* (Voorendt, 2017). In this description of the integral design, the objective of the process which is satisfying the need is explicitly mentioned. The goal of integral design is to create an solution that better fits the problem at fewer costs compared to a monodisciplinary variant. The method for designing products, assets or systems has a collaborative character and is done by using a multidisciplinary approach. Integrating system thinking, life cycle thinking and structural thinking is the base of the integral design. System thinking ensures that the bigger picture is kept in mind and the analysis of the situation is done properly and reduces the chance of drawing up solutions to quickly in the process. Life cycle thinking ensures that the whole lifecycle of an asset or system is considered and integrated in the design, including the financial part of these life cycle stages. Structural thinking aims at the integration of the different disciplines that are involved in designing the system or asset. An important aspect of this integration is the management of project information. Because people tend to think in their own design principle, it is not sufficient to only involve different disciplines in the design team. This can cause interface problems as the design consist of multiple monodisciplinary designs. The importance of an integrated design is an interdisciplinary approach where discipline boundaries are crossed. This is achieved by collaboration between the various disciplines during the formulation of the functional specifications, during the generation of concepts and at evaluation of these concepts during the first design cycles. In this way an understanding of principles between the various disciplines is created together with familiarity of the different languages and cultures. Later on in the process, as the design gets more detailed, specific parts of the design are executed by specialists, which is less of a problem as long as the bigger picture is kept in mind and the result fits and integrate with the overall design (Jyrkkä et al., n.d.; Voorendt, 2015, 2017).

The integral awareness of the design team can be raised by showing the impact that a design decision has on the performance of the various aspects, such as circularity, and therefore understand the interrelations that are present between the various elements of the project processes and the to be designed system (Faniran et al., 2001). It is important to enable the integral character of the design in the beginning of the process to map all important aspects and avoid changes later in the process, which are often more costly (Schoonwinkel et al., 2016). This starts with the formulation of the design objective. The objective should contain all the significant main aspects that has to be included in the design as the formulation of the requirements is based on this design objective. When these relevant aspects are not included in the design objective, the list of requirements will be incomplete and the formulated concepts are not verified on these aspects (Voorendt, 2015).

Within the Delft University of Technology a method is created for an integrated approach with multidisciplinairy teams. For this approach a framework of different lenses is formulated to enhance the visibility of these relevant design aspects and safeguard these aspects in an integral manner throughout the full design process. They formulated ten lenses, which are:

1. Functionality (FT): Fit for its purpose.
2. Intervention scales (IV): The role and fit in the area.
3. Performance (PF): Reliability, availability, maintainability and safety in all life cycle-phases.
4. Collaboration (CB): The alignment of all involved in the project
5. Complexity (CP): The number and variety of different aspects of the project
6. Permanence (PM): The long term or short term impact of the project
7. Perception (PC): The perception of the different stakeholders.
8. Spatial quality (SQ): The user experience and identify preservation or creation
9. Sustainability (SN): The impact on future generations with the carbon footprint and material use
10. Added value (AV): Create new social, economic and environmental benefits.

The lenses provide possible cross-connections cross disciplinary boundaries and connect the different disciplines. The use of these lenses in the first phases of the project process can improve the integral character of the final solution. During the formulation of the requirements, these lenses can be used to safeguard the integrality of the project and eventually the design. Lenses that could be a useful addition to the above described list are Adaptation & Reuse (Voorendt, 2017; Werkgroep Integrated Infrastructure Design (IDD), 2013). Especially when considering circularity and the impact of adaptation and reuse of assets on this aspect.

The realization of an integral design is beneficial because a higher value of the end product can be created since all relevant aspects are considered at the beginning of the project. This also means that there are likely to be fewer modifications later on in the design project due to aspects that were not considered, which saves time and financial resources. These advantages can be achieved when the awareness of the integral character of the project is present, the design phases are carried out in the right order and simultaneously with all disciplines and when after every design phase there is a reflection on the passed phase and return when needed. Furthermore, as stated before, it is important to include all relevant aspects in the design objective and assign requirements according to these aspects. Finally, the design team is multidisciplinary from the start of the project and the members work in a collaborative way as much as possible (Voorendt, 2017).

To conclude, for the implementation of circularity it is important to include the aspect in the ambitions, requirements and criteria in the first stages of the project. In the preparation phase, the project team can then give substance to these circularity requirements. To design an circular asset, it is important to include all aspects and lifecycle phases that can influence or are influenced by circularity. An integral design approach can contribute in this. To design a circular asset, the design team needs sufficient affinity and knowledge with circularity to optimally integrate the aspect in the design. Furthermore, the tender contract should include circularity to obligate or create an incentive for the contractor to include circularity in their project proposal. The circular design solutions show in the construction phase when, for example, repurposed materials or components are used. During the construction phase, the minimization of waste and optimal material streams can increase the level of circularity. The maintenance phase is of great importance for the circularity of an asset as it influences the lifespan substantially. Adequate maintenance is therefore of great importance when considering circularity. In the end of life phase of an asset, the measures designed in the preparation phase to enhance circularity surface. In this phase, the possibility to adjust the asset to the new situation or demolish it in reusable components are options considered in the design. It is therefore important to consider the end-of-life phase during the design of an asset.

2.2 Current state of Circular Economy in the construction sector

The construction industry and its build environment is the world’s largest consumer of raw materials (WEF, 2016). One of the main challenges for a sustainable economy in the upcoming decades, is to manage the use of natural resources in a way that reduces its current anthropogenic environmental pressures on our environment (Behrens et al., 2007). As can be read in the previous paragraph, the current life-cycle of an asset, is not a circular but a linear process, from initiation to end-of-life. In order to achieve a circular and sustainable construction sector and therefore reduce the environmental impact of the industry, there is a need to preserve the value of used materials rather than dispose them. In this way, a loop is established in the lifecycle of the materials which reduces the use of primary raw materials, protects material resources and reduces the carbon footprint (K. T. Adams et al., 2017; Ritzén & Ölundh, 2017). A circular construction industry entails the integration and consideration of the after lifetime phase of an asset in the design phase and askes for major changes in its practice (Romme & Endenburg, 2006). This paragraph elaborates on circular economy in the construction sector and the current barriers to overcome.

Currently, the circularity principle is applied on a rare and often only fragmental basis (Ritzén & Ölundh, 2017). In the Netherlands, multiple initiatives aim to enhance circularity in the Dutch construction sector, such as Platform CB’23 and CBE[2]. These platforms are a collaboration between market parties and governmental organizations with the objective to have a fully circular construction sector in 2050. (Platform CB’23, n.d.; Transitiebureau CBE, 2020). The public client plays a big role in many large construction projects in the Netherlands and therefore needs a clear and consistent objective on circularity over a longer period of time. To enhance circularity in the Dutch construction sector there is a need for circular tenders and a concrete timeline for the implementation of circularity (Rijksoverheid, 2018). The CBE tender plan describes eight steps for circular purchase and are based on the clients tender process of a project. The first of the eight steps

[2] Circulair Construction Economy. In Dutch: Circulaire Bouw Economie

starts with defining a clear ambition for the project. For this step sufficient time should be planned to reach a good ambition definition and to explore project-specific opportunities. Additionally, the responsibilities the client accumulates, for example the design, and the challenges which are placed with market parties are defined. The scheme based on the R-framework shown in Figure 5 is a guide to start defining this clear ambition. The first step is to prevent any intervention that is not necessary, which can be considered as the reduce step in the R framework. When this is not fully possible, the next step is to preserve the value of the existing asset, the reuse principle of the R-framework. Followed by the creation of value for the long term, a way to enable future reuse or recycling of the materials (Van Oppen et al., 2018).

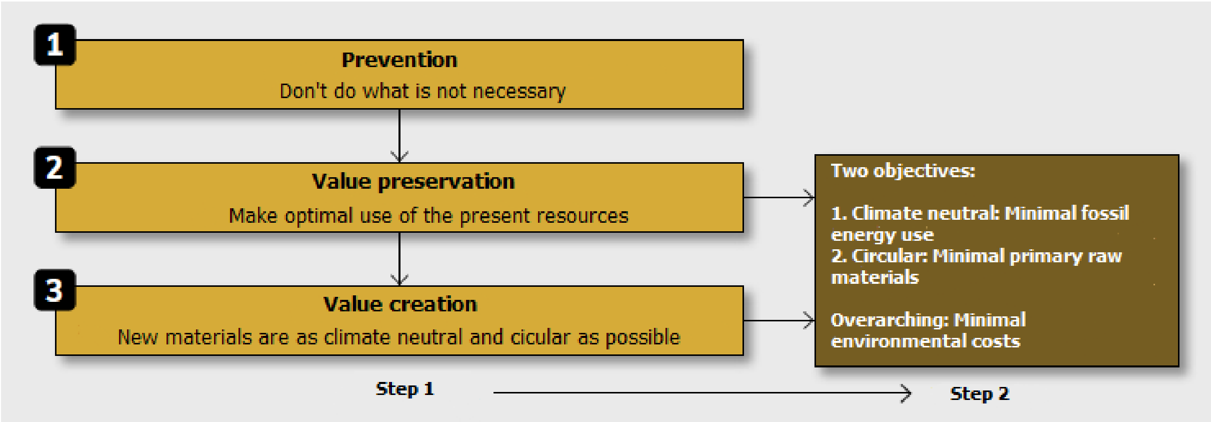

Figure 5: Steps for a circular asset (Van Oppen et al., 2018)

These steps also the base for the circular design principles which are supported by multiple parties in the Dutch construction sector (IPV Delft, 2019; Rijkswaterstaat, 2020; Rijkswaterstaat & Witteveen+Bos, 2018). These circular design principles are illustrated in Figure 6 and aim to assist in making design choices that enhance the circularity and are a more detailed approach on the steps for a circular asset. They do not necessarily have to be applied at the same time. For each project it should be considered where the biggest environmental benefits can be achieved and which principle fit the project best (Rijkswaterstaat, 2020). The circular design principles are included in the proposed flowchart presented in paragraph 2.3 Literature study conclusionto consider the opportunities for circularity in the design process.

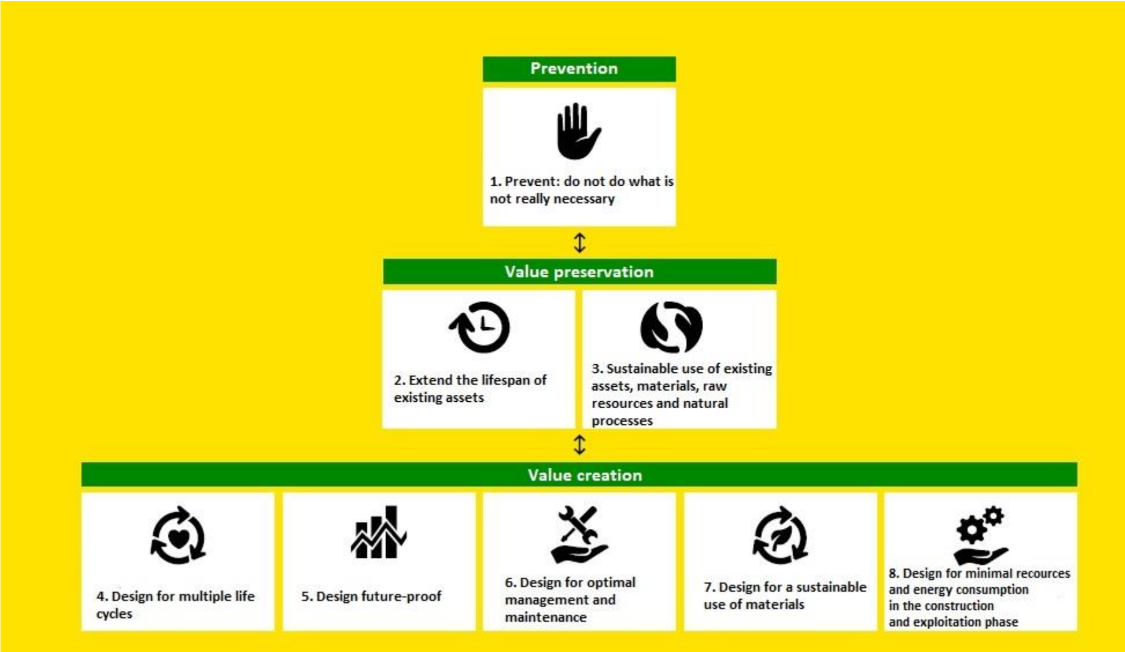

Figure 6: Eight design principles of Circularity (Rijkswaterstaat, 2019a, 2020)

The nine circular design principles are divided in three main circularity fundamentals: prevention, value preservation and value creation.

1: Prevention. The first main principle is prevention and intends to avoid building anything. This is relevant for both the construction and replacement of infrastructure. Prevention is possible by finding a solution that requires limited materials or more design and material efficient solution (Rijkswaterstaat, 2019a, 2020). The design team is asked to examine the intended functionality and resulting performance of the intended designed component and judge if it contribute sufficient to the functionality of the asset. The question should raise if there are solutions where certain components of the asset are no longer needed and at which moment additional components are needed. Additionally, the team can investigate whether common solutions can be interchanged by less material intensive alternatives (Rijkswaterstaat & Witteveen+Bos, 2018).

The second main principle is value preservation, which entails utilizing the value in existing infrastructure for a later life cycle. This is especially relevant with the modification, replacement or renovation of infrastructure. This can be achieved with two design principles (Rijkswaterstaat, 2019a, 2020).

2: Extend the lifespan of existing assets or components. This can be realized by expanding or adjusting the capacity, renovation instead of replacement or refurbishment or replace components instead of the entire asset. Additionally, the intensification of inspections and maintenance or the adjustment of performance requirements can be strategies to extend the lifespan of components or assets (Rijkswaterstaat & Witteveen+Bos, 2018).

3: Make sustainable use of existing assets, materials, raw resources and natural processes. In other words: use what is there. This means a development towards supply-driven design (Rijkswaterstaat, 2019a, 2020). This can entail the use of components that are available, the use of natural processes to achieve the project aims and the use of materials that are released during the project. What cannot be used within the project will be repurposed (Rijkswaterstaat & Witteveen+Bos, 2018).

The third main principle is value creation: creating as much value as possible for the long term with as little material as possible. This is especially important during the construction of new assets. There are five design principles for this.

4: Design for multiple life cycles. This entails the consideration of future life-cycles and possible feasible adjustments when designing the first life-cycle of the construction (Rijkswaterstaat, 2019a, 2020). Strategies that can be used to achieve this are design for deconstruction at object or component level or a design for recycling at material level. Also a modular design that enable the interchange of objects, components and materials like standardization can enable multiple lifecycles of components or objects. Design for movability and design for flexibility of functions are also ways to fulfil this principle (Rijkswaterstaat & Witteveen+Bos, 2018).

5: Design future-proof. This includes design for optimal lifespan by the adjustment of the lifespan requirements to the project-specific circumstances, the adjustment of the technical service lifespan to the expected functional service lifespan and distinguish in lifespan at system, object, component and material level (Rijkswaterstaat & Witteveen+Bos, 2018). Additionally this principle means designing an asset that is adaptable and reflects expected future evolution, such as space for future road widening or a higher water level. This includes natural ways to combat flooding and drought, such as water storage in surface water instead of quick drainage (Rijkswaterstaat, 2019a, 2020).

6: Design for optimal management and maintenance. The sixed principle includes the design for optimal raw materials and energy use in the maintenance or management phase and therefore the involvement of the operator in the design. Additionally it entails the examination of the current and future management strategies and the possibility of requesting components as a service rather than a structure (Rijkswaterstaat & Witteveen+Bos, 2018).

7: Design for sustainable use of materials. This involves the usage of materials with low CO2, avoiding the use of toxic substances and scarce materials and using renewable raw materials instead of primary ones (Rijkswaterstaat, 2019a, 2020). It also includes the design of low-material structures and the reuse of components and materials (Rijkswaterstaat & Witteveen+Bos, 2018).

8: Design for minimal raw resources and energy consumption during construction and exploitation phase. Materials can also have effects on energy consumption because they reduce the resistance, like the rolling resistance of asphalt. Unnecessary transport of soil can be eliminated by adapting the phasing of the project which can achieve a closed soil balance (Rijkswaterstaat, 2019a, 2020).

The tender plan of platform CBE differentiates circular construction into circular design and circular material use. Circular design focuses on the design of the asset and the possibilities for future use once the asset does not longer comply with the functional requirements. Circular material use concerns the choices in construction material for the asset and their environmental impact (Transitiebureau CBE, 2020). When a clear definition of circular economy for the project and for other concepts that are relevant such as circular material is determined, the goal for all parties involved is unambiguous. To make the ambition come to life for all parties involved and understand why the ambition has been set, as many internally involved parties as possible should be the owner of the ambition document. This ambition should be maintained as a common thread throughout the entire process. Additionally it forms the base for discussions with the market and for measuring and assessing circularity (Van Oppen et al., 2018).

The second step in the 8 step plan for circular purchase is gaining support within the organization to enable a clear and unambiguous representation towards the market on the circularity ambitions. To make the transfer from a linear to a circular way of thinking requires a long term vision. The public client needs to broadly support the application of circularity with propagating a clear ambition and a uniform inquiry for the market parties. The processes should then be established accordingly (Bouwend Nederland, 2020; Rijksoverheid, 2018). The third step is formulating an inquiry to tender to the market followed by the steps to collaborate with the market during the tender and contract period (Van Oppen et al., 2018). The guide for circular purchase focuses on the public client as an acquisition party. Therefore the guide does not describe the design steps for circular assets. This is seen frequently in the literature as often not the client but the market parties design the assets (Transitiebureau CBE, 2020).

The barriers faced when implementing circularity in the construction sector

As described in the previous paragraph, the guidelines on circularity for the public client are currently focused on the tender procedure and following phases, although implementing circularity only in purchase procedure causes decisions prior to this tender to barley or not include circularity which could have a great impact on the aspect. The public client therefore needs to take circularity into account prior to the tender procedure and in the initiation- and design phase of the project which asks for more capacity, knowledge and time to implement the aspect and acknowledge the influence of design decisions prior to the tender procedure on the circular possibilities (Bouwend Nederland, 2020). In the Netherlands, Rijkswaterstaat is the biggest client of infrastructure projects. The 'market, unless' principle has been the basis of the Dutch clients' purchasing policy since 2004 to make better use of the strength and knowledge of the market. Although, therefore Rijkswaterstaat has become distant and the tension between client and contractor has become central, instead of the social task. As the societal challenges are becoming more complicated and technological developments are accelerating, a different role and method of the public client is required. A role and working method where instead of 'the market, unless', 'together with the market' is central. Rijkswaterstaat wants to work with the market to realize their ambition by using, strengthening and expanding each other's craftsmanship (Rijkswaterstaat, 2018a). A different collaboration with the market, together with the sustainability ambitions of Rijkswaterstaat, requires a more integral design- and purchase approach where all aspects that influence and are influenced by the asset are recognized and considered. A dialogue between client and contractors has therefore a lot of added value at this stage of the transition towards a circular construction sector (Transitiebureau CBE, 2020).

Currently, the application of circular economy is in a starting phase and mainly focuses on minimizing construction waste and recycling. However, material is often recycled in a lower value product, which is undesirable. Reduce and reuse are applied to a minimal extend in the current projects (K. T. Adams et al., 2017; Mahpour, 2018). The study of researcher Amirreza Maphour from the Sharif University of Technology in Tehran, Iran (2018) presents and prioritizes the barriers in the application of a circular economy in construction and demolition waste management of the construction industry. An overview of these barriers that are faced when implementing circular economy in the construction sector can be seen in Table 2, sorted on priority.

Table 2: Barriers in the application of circularity in the construction industry (Mahpour, 2018)

Priority	Code	Barrier	Solution
1	B_{20}	Agency and ownership issues in C&D waste management.	All project stakeholders, individuals, and agencies should think about reducing, reusing, and upcycling C&D wastes.
2	B_{11}	Lack of integration of sustainable C&D waste management.	Disposal, landfilling, and incineration strategies in waste management hierarchy are not sustainable. Disposed of, landfilled, and incinerated C&D wastes should be reused or upcycled.
3	B_{16}	Uncertain aftermaths of moving toward circular economy in C&D waste management.	More research projects should be done to determine the aftermaths of this move.
4	B_3	Using finitely recyclable construction materials.	Using high-quality construction materials should be promoted. Recycling C&D wastes should be replaced with upcycling them.
5	B_9	Inadequate awareness, understanding, and insight into circular economy in C&D waste management.	Decision makers should be familiarized with the concept of circular economy and its benefits.
6	B_5	Preferring off-site C&D wastes sorting/C&D wastes landfilling over on-site sorting due to lack of incentives.	C&D projects' stakeholders should be incentivized to sort C&D wastes on-site.
7	B_{18}	Lack of funding to implement circular economy in C&D waste management.	Governments should allocate sufficient budget to implement circular economy in C&D waste management.
8	B_{10}	Inherent complexity of transforming to circular economy in C&D waste management.	The concept of circular economy should be studied more by researchers to reduce complexity of its implementation by developing guidelines.
9	B_{19}	Tendency to manage cost & time rather than C&D wastes.	C&D projects' stakeholders should be informed about bad consequents of neglecting C&D wastes
10	B_6	Inadequate policies and legal frameworks to manage C&D wastes as well as lack of supervision on C&D waste management.	Strict policies and legislations should be enacted to supervise C&D waste management according to goals of circular economy.

As shown, a major challenge is the responsibility of parties. Who is responsible for the waste streams and with whom lies the ownership are questions that need to be clear. Additionally, the segmentation of the sector and therefore the lack of integration between the different disciplines is the second major barrier. As the circularity of an asset is determined by its whole lifecycle, integration between all disciplines is key for enabling circularity. Other barriers that are in the top five of the research that consider the development process of infrastructure, is the incomplete knowledge and lack of deep understanding and the use of finitely recyclable materials. To gain a deeper understanding of these barriers and what they entail, they are elaborated in more detail in this paragraph. More insight in each barrier is given together with the moment in time of the process that they occur and possible solutions to overcome them.

Barrier 1: Unclear ownership and responsibility

The most significant barrier in implementing circularity is the unclear ownership of materials and responsibility on circular use. To obtain second hand materials that comply with the requirements is challenging because the industry is not organized as such. Finding materials before they arrive at the waste facility is difficult because there is no central documentation of demolished or to-be demolished structures, which causes a timing problem. The principle of a material passport can improve this. However, this concept is still in a developing phase (BAMB, 2017). Collecting materials at waste management companies is also not untroublesome because waste management companies are focused on their core business and are not familiar with product design, so do not see the potential for the development of products out of their materials. At this point, construction waste management professional are bound to dispose construction waste materials that they receive in the best possible manner. Therefore, recirculation of received materials need to be carried out by certified actors (Mahpour, 2018; Singh & Ordoñez, 2016).

This unclear responsibility of circular material use surfaces in the realization and end of life phase, although can be mostly effected in the initiation-, design and contracting phase. It also highly depends on the type of contract used as the various sequential stages can be contracted out both combined or in a separate fashion, as described in paragraph 2.1. It shows that in traditional contracts, the requirements domain lies with the client (De Ridder, 2009). Combining this with the conclusions that circularity should be considered at the beginning of the project (Versteeg Conlledo, 2019), one could say that the responsibility of circularity in this type of contracts lies with the client.

The client in this case lies down the ambitions and values of the project, such as circularity, that work through in the list of requirements. This does not mean that the contracted party should not consider circularity in any way. As Ana Versteeg Conlledo (2019) concluded, the entire supply chain of the project needs to embrace circularity and the ambition for a circular project in order to successfully realize such a project. With a more integral contract form, where the contracted party is more involved in the design of the asset, there is a shared responsibility for circularity. The client should be clear in its wishes and ambitions considering a circular asset in the initiation of the project and the contractor in his role is responsible to realize these ambitions in the design and realization phase.

The role and responsibility of the public client in the implementation of circularity also concerns their circularity ambition, which works in different ways. First, the transfer from a linear to a circular way of thinking requires a long term vision. The public client needs to broadly support the application of circularity with propagating a clear ambition and a uniform inquiry for the market parties (Bouwend Nederland, 2020). Additionally, the project specific ambition to work circular should be clear from the beginning of the project and there should be a dedicated project team with an open and transparent culture that shares the ambition to execute the project according the circular principles. This is not only the team of the client but also from the supplier and contractor (Versteeg Conlledo, 2019). Nowadays, the public client is seen as an acquisition party. Therefore the design steps for circular assets are not part of the clients policy. However, the public client needs to take circularity into account prior to the tender in the initiation- and preparation phase because relevant decision that influence the circularity are made in these phases. To enable this transfer, the public client should have sufficient capacity in knowledge of circularity and capacity in time to explore the possibilities. Because circularity is a relatively new aspect to include, a lot is learned while doing and therefore room to learn and experiment increases the knowledge on possibilities for a circular construction sector. The often risk averse perspective of the client is an important cause for the lack of sufficient circular assignments and room to innovate. The contract should however include circularity in a non-optional form while keeping some room to learn and innovate to increase and share knowledge and experience on circularity in the construction sector (Bouwend Nederland, 2020; Transitiebureau CBE, 2020).

This barrier also considers the realization phase of an asset. Applying circularity in the realization phase of an asset considers the use of circular materials and the minimization of waste (K. T. Adams et al., 2017). This responsibility lies with the constructing party. Although, the industry as is, is not organized for the use of circular materials and the availability of circular materials is limited due to the lack of ownership of the materials. (Mahpour, 2018; Singh & Ordoñez, 2016). In the exploitation and maintenance phase, the responsibility of circularity lies with the party that is executing this phase. Which means, in a DBFM contract it lies with the contractor and if the client carries out the maintenance, the responsibility lies with the client. A point of attention here is that the contracted party is usually responsible for maintenance for a certain number of years and not for the whole lifetime of an asset. This means that at a certain point in time, the responsibility of the maintenance and exploitation goes back to the client. The possibilities for circularity in this phase lies with minimizing waste and minimal and easy maintenance. Adaptability and flexibility of the asset is also reflected in this phase but has an important base during the design of the asset (K. T. Adams et al., 2017). The lack of ownership and responsibility of second hand materials also appears in the demolish and reuse phase of the structure. As stated before, the construction industry is not organized for the use of second hand materials. Repurpose or reuse an asset is the most circular way to manage the end-of-life phase of an asset, although often ambitious. Reuse of components of an asset is a more attainable option, but is often complicated due to the organization of the industry, the unfamiliarity with the manner and current construction legislation. A solution to this barrier is to organize the construction industry in favor of circularity. This means everyone that is involved in the project should think about how to reduce, reuse and upcycle construction waste (Mahpour, 2018). Additionally, the economic factor need to be addressed more explicitly and the urgency to reduce a structures carbon footprint needs to increase (Rakhshan et al., 2020). The platform for a material passport could be an approach that enhances the possibilities for reuse of components in the industry. The responsibility for this platform lies with the owners of the assets (BAMB, 2017).

Barrier 2: Segmentation of the construction sector

The fragmentation of the construction industry causes a barrier for the implementation of circularity, as it requires all dimensions and aspects to be considered in an integral manner if the aim is to realize a circular practice. This empathizes that the full complexity needs to be considered in order to achieve a high degree of circularity, which can only be accomplished with a collaboration that goes beyond department boundaries (Ritzén & Ölundh, 2017). This integration shortage is not a new phenomenon in the construction industry. With contracts that separate the design, construction and maintenance phase, it is a logical consequence that these disciplines are not integrated. However, this is a key issue in the implementation of circularity (K. T. Adams et al., 2017; Savanovic, 2009). The conclusion that collaboration is the key requirement for enabling a circular approach is broadly accepted in literature (K. T. Adams et al., 2017; Evbuomwan & Anumba, 1998; Ritzén & Ölundh, 2017).

Ambitions to develop circular and sustainable are most effective when determined initiation phase of a project as they have the most influence on the design because of the early consideration (Versteeg Conlledo, 2019). This entails that the ambition to work circular should be clear from the beginning of the project in the exploration phase and works throughout the following phases. Additionally, There should be a dedicated project team that shares the ambition to execute the project according the circular principles form the start of the project. This is not only the team of the client but also from the supplier and contractor. Besides this, there should be an open and transparent culture between the parties and they need to work together closely to make room for an innovative and creative solutions (Evbuomwan & Anumba, 1998; Ritzén & Ölundh, 2017; Versteeg Conlledo, 2019). Circularity of infrastructure assets covers the whole lifecycle of the asset. Therefore, an integral character of the design process helps to consider in a relative early stage all aspects that can influence the design and level of circularity (Mahpour, 2018). Enhancing the integration of all disciplines, lifecycle stages and ambitions in the development of the asset is therefore significantly important in the initiation and design phase to minimize changes in a later phase of the project and sufficiently include circularity (Schoonwinkel et al., 2016). Considering circularity late in the process may also have the consequence that circularity will be discharged due to high costs (Versteeg Conlledo, 2019)

Barrier 3: Knowledge on circular design and material use insufficiently integrated

The lack of knowledge covers multiple areas. First, the uncertainty in outcome of moving towards a circular construction industry because it is not yet a largely applied topic. To predict the impact of moving towards a circular economy, more research should be done. Circularity is becoming an increasingly popular topic for research, which therefore brings more clarity to these uncertainties (Ranta et al., 2018; Ritzén & Sandström, 2017). Another important factor is insufficiently integrated knowledge on circular economy throughout the industry. A lot of research has been conducted on the topic, but it is currently a specialists work field. This entails that knowledge on circularity is not widely spread and common practise. As shallow understanding might give a positive mindset towards circularity at first, resistance to the transition occurs as a deep understanding is essential for the transition to a new approach. Decision makers should be familiarized with the concept of circular economy and its benefits. The lack of understanding also causes the use of finitely recyclable construction materials, which is another barrier described by Mahpour (2018). This can cause an attitudinal barrier, such as risk aversion, because of the unawareness of opportunities that circularity can bring (Ritzén & Ölundh, 2017). In addition to that, lack of awareness and knowledge within companies about the effect that the design phase has on circularity is crucial to overcome when implementing because the design influences the degree of circularity largely (K. T. Adams et al., 2017; Mahpour, 2018). Together with the horizontal and vertical integration in the construction sector, knowledge of circular economy needs to be gained and spread and explorative work strategies would benefit both the adaption to disruptive changes and the implementation of radical innovations (Ritzén & Ölundh, 2017). A deep understanding of materials, their environmental impact and their possible level of circularity is crucial for decision making that enhances circularity (Mahpour, 2018).

Existing regulations can hold back innovations because regulations are lagging behind the state of technology. Facilitating room in order to be able to experiment in a circular manner is therefore a necessity (Rijksoverheid, 2018). Due to the relatively recent emerge of circularity, not everything is set and clear. Aspects of circularity are learned while doing and therefore room to learn and experiment increases the possibilities for a circular construction sector (Bouwend Nederland, 2020). This is an important cause for the lack of sufficient circular assignments. Large clients, like governments and corporations, should take the lead, but prove to be often hesitant. Not only because it is unclear what to ask for, but also legal, financial and organizational obstacles hinder the circular request. The price therefore still remains to be the determining factor, which hinders the required innovations (Transitiebureau CBE, 2020).

These described knowledge barriers work through all phases of the life-cycle of an asset. The knowledge goes from 'how do you design a circular asset?' to 'What is circular maintenance?'. From a circular realization phase to the possibilities to reuse components after demolishing. It is therefore important to raise the knowledge, awareness and possibilities on circularity throughout the entire supply chain, from client till waste management. (Evbuomwan & Anumba, 1998; Ritzén & Ölundh, 2017). In the initiation phase, the knowledge barrier lies of the most part with the client. They need to be aware of the possibilities when wanting to realize a circular asset. Although, especially when the client is not completely familiar with the concept and because an integral approach is desirable, information sharing between the supply chain and the parties that are involved throughout the entire life-cycle of the asset is crucial (Ritzén & Sandström, 2017). It is therefore important that all the parties in the supply chain of the asset are aware and understand circularity and its possibilities. In the design phase, this is the designing party, which depends on the contract chosen for the project. In an integrated contract it is important for both client and contractor to understand circular design. In these start phases, the most circular decisions can be made according to the 10R method. The realization phase is the circular focus is on the minimization of construction waste and reuse or recycle when possible, which is the domain of the contractor, but also finds its base in the design of the asset. The possibility for a circular exploitation and maintenance phase also lies in the design of the asset. It is therefore important to gain and exchange knowledge of the entire supply chain in the design phase of the project. Same goes for the demolish and reuse stage of the asset, although the construction waste management party can also find opportunities for reuse of materials when they were not initially designed as such. This asks for additional knowledge and awareness for the construction waste management party on circular economy and the reuse or recycle of materials.

2.3 Literature study conclusion

The barriers in the application of a circular economy in construction and demolition waste management of the construction industry can be categorized in three subjects:

- The unclear responsibility of circularity. This is highly dependent on type of contract that is chosen for the project and the agreements between the parties. This category includes the unclear ownership of materials and the needed clear and long term approach on circularity in the construction sector.
- The segmentation of the construction industry between the different disciplines and lifecycles. As the circularity of an asset is determined by its whole lifecycle, integration between all disciplines is key for enabling circularity. The aspect of integration is significantly important in the initiation and design phase of the project, because there the outline and the baseline of the asset is created.
- Knowledge of circular economy insufficiently integrated in the construction sector . Inadequate awareness, understanding and insight into circular economy in construction waste management causes circularity to be a difficult aspect to implement. Decision makers should be familiarized with the concept of circular economy and its benefits. A deep understanding of circularity is necessary to be able to implement it at full potential. This works through all phases of the life-cycle of an asset.

Table 3 summarizes the occurrence of the barriers for each phase. The table shows that all barriers occur in the initiation and preparation phase of the project an in the end of life phase. This research focuses on the implementation of circularity for the first phases to also contribute to lifting the barriers in the end-of-life phase.

Table 3: Barriers for implementation of CE[3] reflected against lifecycle phases

Barrier / Phase	Unclear responsibility for CE	Segmentation of the construction sector	Insufficient integrated knowledge on CE
Initiation	X	X	X
Design/preparation	X	X	X
Contract	X		X
Realization			X
Exploitation and maintenance			X
End-of-life	X	X	X

The implementation of circularity according to the literature study is captured in the flowchart that is shown in Appendix B. This flowchart shows the most significant aspects to consider when implementing circularity and the integration of circularity in an integral design process. The green blocks in the flowchart are aspects retrieved from literature and the blue blocks show aspects

[3] Circular Economy

retrieved from literature that is written in collaboration with the Dutch public client. The flowchart starts with the preliminary aspects to consider and commence when wanting to enforce circularity in the design process optimally. These preliminary aspects concern the organizational ambition and companywide and unfirm approach to support circular design and the knowledge and insight needed throughout the organization to enable circular design and reach the ambition.

The next part of the flowchart shown in Appendix B concerns the circular design process. The circular design principles are linked with the design approach to form a design cycle that considers circularity. This design approach finds its base in the six steps of sustainable GWW as described in paragraph 2.1 and further elaborated on in 4.1. This flowchart is based on the premises that there is sufficient capacity in time, budget and team members for the project and there is an integral design approach. The design cycle is walked through every phase and can be run multiple times to find the most optimal solution through iteration. The design cycle also works in a cyclic way with different detail levels, form system to component. In this way, circularity is considered for each decision made. A uniform organizational approach and design strategy would fit this scheme, where now the proposition is made for a design strategy based on desired lifespan an certainty of future developments. It is of importance to include all relevant aspects that effect or are effected by the design of the asset and consider their impact or opportunities on circularity. The collaboration with the market differs for each type of contract, although early engagement can offer more expertise and innovation. This however, should not result in premature scoping of the project which influences the integral character. A clear and uniform ambition toward the market enables a more efficient learning process and support. The contract should include circularity in a non-optional form while keeping some room to learn and innovate.

3. Methodology

This chapter describes the core of this research. The aim of the research and the problem statement are established as well as the sub-questions that lead to answering the main question.

3.1 Problem statement and research objective

Dutch public client has the ambition to move towards circular solutions within the Dutch infrastructure sector. The aim of this research is to unite the circularity ambitions of the public client with the design process of infrastructure projects that enable circularity to become common practice and a way of thinking. The result is a flowchart that aims to guide the project team of the client to timely consider circularity and its opportunities during the integral design process of an asset and transfer the linear way of approaching an asset to a circular way of thinking and designing while including the circular design principles. The role of the public client in the phases executed by the market, is also researched as well as the collaboration with market parties.

3.2 Research question

Main question

How can the design process of the public client be organized in order to optimally implement circularity in their hydraulic infrastructure projects?

The main question concerns finding a fit design approach for the public client that enables the circularity ambitions being implemented in infrastructure projects. This entails the current practice of the public clients design process and circularity and find the way in which their ambition is realized in this design process. These aspects are analysed and compared to state-of-the-art literature to find an approach to that integrates circularity in the initiation and pre-design process of the public client is developed.

Sub questions:

In order to give an answer to the main question, various sub-questions are formulated. The information conducted throughout these questions will lead to the answering of the main question.

What is the process of the public client for designing infrastructure assets?

To optimally implement circularity in the design process of the public client, there is a need to gain understanding of the design process of the public client. This sub-question shines a light on the current state of designing and which models are used in the design process to arrive to a design solution of an asset and the approach for the following life-cycle phases.

How does the public client implement circularity in infrastructure projects and what are the process-based implementation barriers faced?

To establish an adequate recommendation for public clients, their current workflow of circularity in the design process infrastructure projects is researched. This is done at Rijkswaterstaat as the biggest public client for infrastructure projects in the Netherlands. When researching their approach on designing circular infrastructure, this can be compared to the state-of-the-art literature.

How can a public client implement circularity in the initiation and design phase of an infrastructure project?
The design process of the public client and their take on circularity is compared to the approach in the state-of-the-art literature and additional obstacles found are taken into account. The result is a flowchart with the aim to guide a design team of the public client to timely consider circularity and its opportunities during the integral design process of an asset and create a circular way of thinking while including the circular design principles. With circularity being a government-wide program, the implementation of circularity for infrastructure project within Rijkswaterstaat, can also be applicable, with adjustments when necessary, for other public clients in the Netherlands such as provinces, municipalities and the regional water authorities.

Case study: Implementing circularity in the design process of Weir Grave
To examine the formulated approach and flowchart for implementing circularity in the design process of an asset, a case study is used. This concerns the weir Grave, an hydraulic infrastructure project in the South-East of the Netherlands. This weir is one of the seven weirs in the river Meuse that are reaching their end of life state between 2030 and 2040. The weir is used as a case study because of the aspiration for an approach on circularity for long lifespan infrastructure assets. The weir is considered on a complex level, including the bridge and ship lock.

3.3 Research approach

The first part of the research is defined by a literary review in chapter 2**.** This gives insight in the current state of the design process and circularity in the infrastructure sector and is the departure point for the empirical quantitative part of the research. According to the preformed literary study, various conclusions could be drawn that form the framework for the qualitative research. To answer the first two sub questions, the design process and the current practice on circularity of the public client is analysed trough documents of Rijkswaterstaat and by a qualitative approach with semi-structured interviews. In-depth interviews give insight on the current work flow and state of circularity in the design process of the public client, in this case Rijkswaterstaat, and are a verification for the conclusions of the literature study. The data processing is done by qualitative data processing, where the data is coded following the directed approach of content analysis. The purpose of coding is to gain insight on the occurrence of various incidents and the patterns that arise.

The results from the literature review and in-dept interviews are analysed and compared and an approach on circularity in the development infrastructure projects for the public client is formulated. The conclusions are visualized in a flowchart. This flowchart is applied on the case study weir Grave for validation and verification. Points for improvement and recommendations are evaluated and adjusted in the approach. Recommendations are made on when and at which level in the design process, decisions on circularity can be made to make it an integrated part of the design.

3.4 Scope

This research focusses on the role of the public client in implementing circularity in infrastructure projects because the most gain in sustainability can be realized at the start of the process (Versteeg Conlledo, 2019). As explained in paragraph 2.1, after the plan and the pre-design is drafted, the possibilities for a high level of circularity in a project decreases as more details of the project become set and decisions that influence the degree of circularity are already made without considering the aspect.

Additionally, this research is conducted with the cooperation of Rijkswaterstaat although the conclusions of this research are applicable for other public clients. Rijkswaterstaat is chosen as a focus as they are main client in the Netherlands regarding large infrastructure projects and have the goal to be fully circular in 2050. Therefore the research is focused is on the methods Rijkswaterstaat uses for their design process and their approach regarding sustainability and circularity.

Finally, this research focuses on hydraulic infrastructure with the Weir Grave in the river Meuse. The five weirs in the river Meuse are at the end of their live time between 2030 and 2040. Therefore they need to be replaced. The weir nearby Grave in the province of Noord-Brabant is the first on the agenda to be reconditioned. This civil engineering challenge has the possibilities to make, in an early project stage, choices to meet the public client's ambitions of being fully circular in 2050. Therefore the case study of this research is scoped to hydraulic infrastructure structures with the focus on the weir. An additional challenge in this replacement project is the relative long lifespan of hydraulic infrastructure compared to linear infrastructure such as roadway systems. A shorter lifespan result in components being replaced sooner which gives the opportunity for a fast transition towards a high degree of circularity. Hydraulic infrastructure, although containing several subcomponents with a shorter lifespan, have a relatively long lifetime and therefore there might be other needs and principles regarding circularity within these assets.

4. Circular economy in the design process of the public client

Rijkswaterstaat is the executive organization of the Ministry of Infrastructure and Water Management and the biggest public client in the Netherlands. They protect, together with other water managers such as water boards, provinces and municipalities the Netherlands against flooding. Additionally, they are responsible for the national infrastructure to enable transport on land and water (Rijkswaterstaat, n.d.). This chapter elaborates on the preformed empirical research concerning the implementation of circularity in the design process of the public client. First, the current design process and circularity strategy of Rijkswaterstaat, as described in the guidelines, is presented. This forms the starting point for the empirical research conducted among the employees of Rijkswaterstaat. This chapter shows the current state of the public client for meeting their circular ambitions and the challenges that come with it. The results of this chapter are reflected against the literature conclusion to identify the point of improvement for Rijkswaterstaat considering the implementation of circularity.

4.1 Research framework

The research framework is conducted out of the guidelines and internal documentation of Rijkswaterstaat on their design process and circularity strategy. It is of importance to point out that this paragraph is based on internal documentation and guidelines of the public client and does not show the level of implementation of these approaches. The level of implementation is researched in the next part of this chapter.

In 2007 the Dutch government organized nationwide infrastructure in a Multi-year program for Infrastructure, Area and Transport (MIRT[4]). The investment includes the various projects and programs in the spatial domain. The aim of this program is to integrate the decision-making on nationwide infrastructure and spatial planning in a more efficient way and to improve the collaboration and alignment between the national government and regional government. The MIRT projects of the Dutch national government also have its own distinction of life-cycle phases. Table 1 compares the phases of the previous described design process with the MIRT process. The phases that the Dutch public client specify are the area agenda[5], exploration phase, plan development phase, realization phase and maintenance phase (Enno Zuidema Stedebouw et al., 2011). The area agenda and partly the exploration phase lay with the ministry and region. Rijkswaterstaat takes full control from the plan development phase. The preferred alternative design is selected in the plan phase, although already prepared in the exploration phase. Because Rijkswaterstaat incorporates the knowledge and expertise of the market parties in the design of large infrastructure, a large part of the development phase is done by the selected market party. The preferred alternative is selected together with the client, the market and other actors involved whereafter the market develops this alternative further throughout the phase, continuously making decisions, while proceeding to more detailed design working from broad to detailed (Enno Zuidema Stedebouw et al., 2011; Eshuis et al., 2014).

[4] In Dutch: Meerjarenprogramma Infrastructuur, Ruimte en Transport. This program covers the projects that manage the functions of the Dutch road-, rail- and waterways.
[5] In Dutch: Gebiedsagenda

With the public role of Rijkswaterstaat in the Dutch society and the governmental program to make the Netherlands circular by 2050, the ministry of Infrastructure and Water management decided there is a need to change the way the Dutch construction sector functions and they want to reduce the impact of the sector on the environment (Ministerie van Infrastructuur en Waterstaat, 2017; Rijksoverheid, 2018). The sector is in total responsible for an estimated 50% of the raw material consumption, 40% of the total energy consumption and 30% of the total water consumption in the Netherlands. In addition, a large part of all waste in the Netherlands relates to construction and demolition waste and the sector is responsible for approximately 35% of CO_2 emissions. However, approximately 97% of the residential and commercial building construction demolition waste is reused, although with a significant part for lower value applications in the infrastructure sector. Therefore, the aim is that by 2030 all projects of Rijkswaterstaat are climate neutral and climate proof, designed circular and for multiple life cycles, developed collectively and contributes to the surroundings (Wegbeheerders ontmoeten Wegbeheerders, 2020). Additionally, there is the ambition for a fully circular construction industry with an energy decrease of 95% by 2050 (Rijksoverheid, 2018; Rijkswaterstaat, 2019a). The sustainability department of Rijkswaterstaat aims to integrate in all departments of the organization to make sustainability and circularity an integral part of all disciplines.

The ministry of Infrastructure and Water management kickstarted the implementation of circularity with the guide to sustainability for MIRT projects. The aim is to implement these subjects by utilizing the six steps in the approach for sustainable land, road and water engineering (GWW[6]). These steps are visualized in Figure 8 and shows the outline of the sustainable GWW approach. The steps are arranged in a phase but are also followed, on a more detailed level, within each phase (Ministerie van Infrastructuur en Waterstaat, 2017). It is remarkable that the arrangement in phases differ per studied document as the figure shows. In the guide for sustainable MIRT projects the exploration and the plan development phase start with an analysis of the demand and the ambitions, followed by investigating the opportunities and establishing project-specific ambitions with the required level of detail of the specific phase (Rijkswaterstaat, 2018b). The course for the use of the sustainability calculation program DuboCalc shows a different distinction in phases for MIRT projects where the first three steps are made in the exploration and plan phase and the final three steps are for the contract preparation phase (Rijkswaterstaat, 2019b).

[6] In Dutch: Grond-, Weg- en Waterbouw

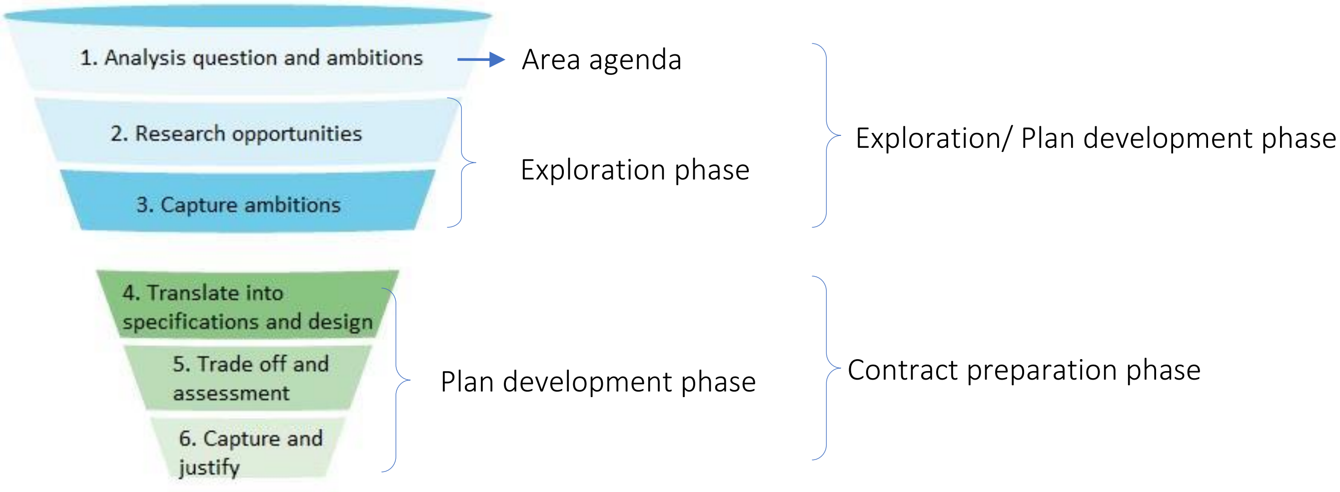

Figure 8: Six steps of sustainable GWW (Ministerie van Infrastructuur en Waterstaat, 2017; Rijkswaterstaat, 2019b)

The core of the public clients design process is funnelling by starting broadly and work towards a detailed, feasible project through transparent decision-making. At the end of a phase, directors involved decide which solutions need more detail in the next phase and which one do not go to the next phase. The funnel changes the abstract level at which sustainability is given substance: from urgency and ambitions in the initiation phase, trough spatial impact in the exploration phase to measures and a design in the plan phase (Rijkswaterstaat & Witteveen+Bos, 2018). This guide also connects to the circular design principles that are illustrated in Figure 6 and described in paragraph 2.2, although does not describe how these fit in the six steps of sustainable GWW (Rijkswaterstaat, 2020).

MIRT Area agenda:

The first step of the project process according to the workflow of the public client, the MIRT process, is the area agenda. It describes the long term aimed development direction of a region or part of the country and establishes a relationship with the national interest or national ambition. In this phase the foundation is laid for initial agreements in the MIRT administrative consultation, by recording sectoral ambitions in intersectoral drawings and discussing these with stakeholders. An inventory of requirements and wishes at area level is made and these are linked to government policy. The phase provides insight into the objectives, dilemmas and choices of the project and provides a direction for possible MIRT exploration. Additionally, it defines the area that needs to be further investigated and indicates how measures effect the problem and where there are opportunities. In this phase the stakeholders and their interests are identified and relevant parties are gathered, which contributes to the commitment. This leads to the formulation of the MIRT start decision (Enno Zuidema Stedebouw et al., 2011). In this phase the scope, ambitions, urgency, bottlenecks and possible development perspectives are investigated and set. The end result can take various forms, for example a report on research results, a vision in a specific area, an implementation program or the intention for a start decision for a MIRT project. In the completion of this phase, the decision is made which sustainability ambitions are incorporated in the project, who works together to achieve this ambition and what is the level of the ambition (Rijkswaterstaat & Witteveen+Bos, 2018).

The approach for sustainable GWW is less explicit for the initiation phase, because this phase is rather free in its form. It is important to properly include the ambitions and opportunities for sustainability in the Initiation phase, so that this topic also gets a good place in the future. The focus is on establishing the ambitions for the follow-up phase. The initiation phase starts with a dialogue with the regional partners and other stakeholders and survey the existing sustainability ambitions and partnerships. This phase also covers the formulation of the assignments with space for integrated or innovative solutions. The analysis supports which sustainability themes and ambitions are central in the project. These themes are given a place in the development perspectives and the assessment framework. In this way, sustainability becomes an integral part of the initiation phase and is not something "extra". The assessment framework and the development perspectives clearly substantiate why certain sustainability ambitions will or will not be further elaborated. It is therefore of importance to formulate strong indicators for the assessment framework. There are multiple ways to integrate sustainability in this phase, although the following points of attention apply to each project:

- the inventory of sustainability ambitions
- the broad analysis of the assignment and ambitions
- the trade-off assessment and development perspectives
- the administrative completion and advice on the follow-up

For circularity specifically, is the main focus on the on choices that guide the layout at area level and the choice for material use per mode of transport. The desirable circular transitions and spatial developments in the region are discussed, which give direction to the sustainability ambitions for the project. Together with the parties involved, concrete joint ambitions for circularity are formulated and anchored for the continuation of the project. For example, the use of secondary raw materials that are locally available (Ministerie van Infrastructuur en Waterstaat, 2017).

MIRT Exploration phase

The exploration phase in the MIRT process is where the design becomes more explicit. Various solutions are being developed in a large possible solution space, which leads to the preference decision for one of the alternatives. At the end of the exploration phase, there is a supported preferred alternative, with a perspective towards the realization. Besides the technical aspects, finance plan and the organizational model, the spatial requirements and ambitions are laid down. In this phase it is important to retrieve all relevant information, in order for the project statement to become clear and feasible. The spatial dilemmas and issues are identified which leads to a clear overview of the positions of parties and their interests, as well as of the qualities and opportunities in the area itself both physical, socio-economic and cultural. At the beginning of the exploration phase, there is still flexibility on the design. The bandwidth of possible solutions is deliberately made wide in the first stage. Later in the phase, the process gradually zooms further into the most promising preferred alternative. Spatial designing contributes to the smooth and structured management of this process. It depends on the type of contract if the contracted party joins in this phase or the next (Enno Zuidema Stedebouw et al., 2011).The literature splits this phase and incorporates its actions in the initiation- and preparation phase. However, the actions taken remain the same and the literature acknowledges the importance for including circularity in these actions. In the exploration phase, the translation is made from ambitions and preconditions for sustainability into alternatives and weighing criteria and the formulation of tangible goals for sustainability in the preferred alternative. This means that the choices in the exploration phase have a major impact on the sustainability and circularity of the final solution. The phase is embodied by the description of the utility and necessity of the project and the costs and benefits of the preferred solution. For MIRT projects this phase includes investigation of "non-infrastructural alternatives", which is in line with prevention as the first circular design principle (Rijkswaterstaat & Witteveen+Bos, 2018). The purpose of the exploration phase is to achieve smart, sustainable and climate-proof solution to a problem. In this phase the translation is made from the ambitions and preconditions for sustainability as included in the Start decision into concrete alternatives and assessment criteria and formulating concrete goals for sustainability in the preferred alternative (Ministerie van Infrastructuur en Waterstaat, 2017).

Among the team members, there should be sufficient affinity and experience with sustainability. The design alternatives need to be distinctive in terms of sustainability which can be reached by giving maximum substance to sustainability in one of the alternatives or by elaborating sustainability opportunities in several and different ways. It might be necessary to collect additional information about area features specifically for sustainability. This information can be used to arrive at integrated alternatives or important preconditions. Preventing climate effects with the design is generally cheaper is then the mitigating actions afterwards. The most sustainable solution for construction is sometimes less sustainable if you consider the entire life cycle, including exploitation, maintenance and replacement. It is essential to include sustainability criteria in the assessment framework: this makes the effects for sustainability explicit and provides insight into which alternative contributes the most to the various sustainability ambitions.

The circularity of the design can be established in the exploration phase by exploring how the alternatives can be designed with the least possible use of primary materials. Therefore the first step should be to explore if a new intervention in the area, perhaps with various measures such as life-extending maintenance, can be postponed or prevented. A preferred alternative with the minimal use of primary raw materials and as minimal transport of materials is the intention of circularity in the exploitation phase. A general picture of the possibilities of using secondary materials from the immediate surrounding in the future design is drawn up and the possibilities for repurposing the materials in the immediate surroundings that are released in the project are explored and mapped. This inventory can give direction to the design in the next phase of the project. The consequences of a circular design alternative for exploitation and maintenance should be clear.

Circular design can be in this phase compared by the level using primary raw materials. Alternatives can be distinguished by, for example a high-quality application of secondary materials from the local environment or the use of renewable materials as much as possible. It is recommended to examine this with the consultation with the market and region. The life cycle analysis (LCA) can be used in this phase. This is a method that helps to identify all significant environmental impacts during the different life phases of the asset. The analysis includes the environmental effects of, among others, the raw material extraction, production, the transport, construction, exploitation, maintenance and demolition. The DuboCalc instrument uses LCAs and can be used to provide insight in making sustainable design choices and to steer towards sustainable use of materials in the tender of the project (Ministerie van Infrastructuur en Waterstaat, 2017).

MIRT Plan elaboration phase:
In the MIRT process, this design phase is described as the plan development. In this phase, the alternative of the special design gets more explicit in dimensions and materials. This requires the translation of ambitions into performance to be delivered by the project through designing, elaboration and detailing. This also requires coordination with the relevant legislation and arranging the necessary permits. The phase works from sketch to final design of the preferred alternative and is directed towards implementation. Initially, the plan must be technical, financially and procedurally

feasible and meet the vision and ambitions of the project. To be able to award a contract to building parties, clear specification of the design is required together with a review of the design with legislation and permits. The specification can take the form of traditional specifications, but also of a program of requirements with an ambition document. Finally, the design must be realized within the intended budget and planning (Enno Zuidema Stedebouw et al., 2011).

During the plan phase the preferred alternative is elaborated into a detailed design with corresponding estimates. The project team searches for a spatial design with the highest possible environmental value and the lowest possible burden on the environment and surroundings during the construction, use, maintenance and replacement at the end of the service lifespan. In every design consideration the effect on material (re)use is included and becomes an integral part of the assessment framework. After the project decision, there is little room for spatial adjustments and it is therefore crucial to determine and document the space required by circular alternatives (Rijkswaterstaat & Witteveen+Bos, 2018). In the plan elaboration phase, the preferred alternative is made explicit as sustainable as possible within the preconditions provided in the exploration phase and other frameworks that apply. If sustainability has not received sufficient attention in earlier phases, the sustainability ambitions should be discussed with the ministry, other departments and other authorities. The ambitions for sustainability are visualized together with the parties involved in a structured way and translated into project-specific sustainability ambitions. The project specific sustainability ambitions should match the size of the project and the ambitions of the government and partners involved. This can be done by, for example, including very concrete goals as a lower limit and an ambition as a target value. It is of importance to continue to reflect the solutions to the assignment and the sustainability ambitions, as designing is a cyclical process. If innovations are needed to realize the sustainability ambitions, it is possible to test through a market consultation whether the innovations are feasible and what space and information the market needs for this. The maintenance and exploitation phases offer many opportunities to realize sustainability ambitions. Therefore, these opportunities should be explored in this phase and determine what they mean for the design. Additional sustainability ambitions can be added in this phase but the design solution should fit within the budget and other preconditions of the assignment to influence the decision.

In the plan elaboration phase, an accurate estimate of the costs of the design, including the measures and activities for sustainability is made. By determining Life Cycle Costs (LCC) the costs of the total lifespan are considered. Because sustainability is an integral part of the variants, the assessment framework, the cost estimates and the linkage opportunities, it is also an integral part of the project decision at the end of this phase. In the plan elaboration phase, the emphasis lies on the opportunities for circular material use. The design aims to make optimal use of existing materials from the local environment and for minimal use of primary raw materials. The next step is a design for multiple life cycles and optimal life. However, there is still little experience with this. The DuboCalc tool to calculate the MKI of a variant, cannot yet determine the sustainability of multiple lifecycles. The investigations needed as a result of the exploration phase, is also carried out. Additionally, agreements are made about the preparation and maintenance of a materials passport and a disassembly plan with the parties involved in these phases. For the following tender phase, it is of importance to indicate which sustainability measures were rejected in the plan elaboration because they did not seem feasible or too expensive. If these measures are in line with the decision, the market may be challenged to implement them anyway (Ministerie van Infrastructuur en Waterstaat, 2017).

MIRT Realization phase:

The MIRT process describes that after the plan elaboration phase, the design is sufficiently detailed to go to the realization phase, where the actual intervention takes place in the area and the project design is constructed. Spatial design in this phase concerns securing, adjusting, sharpening and providing feedback on the design. In this phase, the public client assists in making specific design choices and decisions for implementation. They also safeguard original quality and societal added value. The project environment is now clearly defined and there is less interaction with the surroundings (Enno Zuidema Stedebouw et al., 2011). The realization phase is not defined in the approach for sustainable GWW (Ministerie van Infrastructuur en Waterstaat, 2017).

MIRT Maintenance and Exploitation phase:

The final phase that the public client distinguish in the MIRT process is the maintenance and exploitation phase. In this phase, the asset is in function and needs to be maintained. The experiences of the whole process are fed back and that the necessary adjustments are made in the event of a problem. Contact between the administrator and the design is necessary for the transfer of knowledge, the exchange of experience and the implementation of adjustments (Enno Zuidema Stedebouw et al., 2011). The maintenance and exploitation phase is not defined in the approach for sustainable GWW (Ministerie van Infrastructuur en Waterstaat, 2017).

MIRT End of life / reuse phase:

The MIRT process of Rijkswaterstaat and the guide for sustainable GWW do not define the reuse/end of life phase (Enno Zuidema Stedebouw et al., 2011; Ministerie van Infrastructuur en Waterstaat, 2017).

To stimulate the use of circularity within the project of Rijkswaterstaat, the circularity department presented a video lecture. Here, the possibilities of circularity for projects are featured. As it seems, project managers withhold from implementing circularity within the projects as it is unfamiliar and it asks for a new way of approaching a project. Therefore, Rijkswaterstaat published multiple guides and tools to stimulate the use of circularity and the circularity department can support initiatives in projects (Wegbeheerders ontmoeten Wegbeheerders, 2020). Nowadays, the client mainly uses circularity in the form of recycling. Rijkswaterstaat is currently recycling a lot of resources that become available during renovation although, this is often downcycling such as repurpose in the foundation of roads (Rijkswaterstaat, 2019a). The initiative of a material passport of the current and future structures is thought of but does not yet have a tangible form (Wegbeheerders ontmoeten Wegbeheerders, 2020). To apply circularity in infrastructure, there needs to be a shift from thinking together to doing together. It is therefore also important that besides the realization of circular assets, the knowledge acquired about the design and implementation is shared within the industry. In this way, circular economy can be achieved, sooner rather than later (Chahboun, 2019).

The research framework is based on the researched documentation of Rijkswaterstaat and their processes. The integration level of these guidelines is not yet clear and is investigated in the following part of this research through an empirical qualitative study with semi-structured interviews. Although, some interesting findings already surface considering this research framework. First, the process of the public client has the objective to be integral, although no design guideline is found. It is important to keep in mind that the design process of public infrastructure is owned by different parties overtime, first the ministry and region for the initiation an partly the exploration followed by Rijkswaterstaat for the plan development and contracting phase and finally the contracted party for the detailed design and realization. The integral objective of Rijkswaterstaat is focused on the procurement procedure and not yet on the design process. Same goes for the current guidelines on circularity which also focus on the procurement procedure of assets and not on design an circular asset. Both these processes and the circular design principles are not yet connected and cohere. Additionally, the process of Rijkswaterstaat does not have an iterative character and therefore also no feedback loop as described in paragraph 2.1. Lastly, there is no end of life phase defined in the process and this is therefore not considered during the design process.

4.2 Empirical qualitative research

To gain a more complete perspective on the current practice of circularity in the design process of the public client and the level of implementation of the guidelines, a research among the employees is conducted. The research strategy follows the empirical qualitative approach. The qualitative approach fits as the data is related to the exploration of knowledge gained through experience from different parties and to gain an understanding of the situation. This gives the possibility to explore experience and ideas in-dept (Pennstate University Library, 2020). The empirical research follows the content analysis approach in analyzing the data. The type of content analysis that is used is the directed approach, with the aim to validate or extend conceptually a theoretical framework or theory. This theoretical framework is based on the literature study and determines the initial coding scheme (Hsieh & Shannon, 2005). Furthermore, the data analysis is a repetitive process when, besides the predetermined codes, new codes can be created during the process. New insights in a later coding stage can be of value in earlier interviews. Empirical data for this research is obtained by a qualitative approach with semi-structured interviews. In-depth interviews give insight on the current work flow and state of circularity in the design process of the public client, in this case Rijkswaterstaat.

Desired information and measured variables according to the literature

To structure the data and prevent going astray in information and data, an initial codebook formed. This codebook is shown in Table 4. The codes are based on literature and prior knowledge gained during this research. The data is coded in a thematic way with multiple themes formed that include various codes. In this way, the large number of codes stay structured.

Table 4: Themes and codes

Themes	Literature Codes
Knowledge of CE	Definition of CE
	Knowledge on finite and reusable materials
	Categorization of CE: The place for CE in the process
Integration of design disciplines and lifecycle stages	The integral character of the design process of the public client
	Collaboration with the market/ Integral contracts to enhance circularity
Perception on ownership and responsibility of CE	The responsibility of implementing circularity in the industry
	Ownership of end of life components

Semi-structured interviews

The previous literary study forms the theoretical framework where the interview questions and the predetermined codes themes are based upon. The interview questions can be found in appendix C and Table 4 shows the predetermined codes and themes that refer to the literature study.

For the in-dept interviews, key-players were asked to participate. These are actors involved the implementation of circularity within Rijkswaterstaat and general in the development of assets. To acquire sufficient data and to be able to compare the outcomes, a minimum of twelve actors are interviewed (Guest, 2006). The interview approach used in this research is semi-structured. This gives the flexibility needed in an interview to anticipate on the answers of the participants while remaining in a structured form of pre-set questions. A semi-structured interview provides a level of detail needed to answer the sub-questions as their outcome are largely based on experience (Adams, 2015).

To ensure that a complete impression of the objective, various key-players from different steps in the design process are interviewed to diversify the information gained. The interviewees are categorized in three groups. The first group is the life-cycle phase where the interviewee is involved in, the second group covers the role of the key-player in these phases and the last group is the department of Rijkswaterstaat. GPO is in this the department that concerns the large projects and new construction projects, PPO is the maintenance and exploitation department of Rijkswaterstaat and lastly the regional offices of Rijkswaterstaat that are responsible for the asset management of the region. An overview of the groups and their categories can be found in Table 5.

Table 5: Document groups

Life-cycle phase	Employment	Department
Exploration phase Plan study phase Contract phase Construction phase Exploitation and maintenance phase	Technical Manager Advisor Technical Manager Asset manager Sustainability advisor	PPO GPO Region

4.3 Data processing

The data processing is done by using a qualitative data processing program Atlas.TI. With this program the data is coded following the directed approach of content analysis (Hsieh & Shannon, 2005). Coding the data means choosing labels that act as keywords covering the contents of the data and assigning those labels to the relevant sections of the data. The start point of these codes and code themes are predefined based on the literature, as described in section 4.2. Despite the predefined codes, the coding process is approached in an open and repetitive way. The purpose of coding is to gain insight on the occurrence of various incidents and the patterns that arise. The coding is accomplished by identifying words or groups of words that are important and label those. To recognize the relation between codes, the co-occurrences of codes is used. The groundedness of the various codes shows in an overview of the most significant themes.

Validation

The semi-structured interviews is validated in different ways. First, the transcript of the interview is verified with the interviewees. The transcript was sent to the participant to enable feedback on the document and make sure all the information is interpreted in the intended way. The trustworthiness of the data is validated by interviewing the person in their own environment where they feel comfortable. The note needs to be made that this research took place during the outbreak of the COVID-19 virus, resulting in all interviews being conducted in a digital environment. The interviews are arranged one-on-one, to assure the interviewees feels comfortable to explain their opinion on the topic. To prevent a one-sided perspective on the subject, multiple key-players are interviewed that are involved in different lifecycle-stages of an asset. Besides that, technical managers and various advisors are involved in the research. Finally, an external validation is executed with a case study. The members analyse the results of the data and review on them.

4.4 Analysis and results

The data illustrates the current state of circularity in the workflow of Rijkswaterstaat, the problems that occur and entail the various experiences and attitudes of key-players involved in circularity and in the design of assets. To be able to retrieve results out of the empirical evidence, the data needs to be analysed. The analysis procedure followed leading to the results and the results is discussed in this paragraph.

Analysis

The analysis of the data is preformed using a qualitative method. The program Atlas.TI is used to perform this analysis, as described in 4.3 with the initial code list as a starting point. This chapter describes the steps followed for the analysis.

Step 1: Conduct interviews
To collect data, semi structured interview were conducted and recorded with the consent of the interviewees. The interviewees were selected as they all were involved in the lifecycle process of an asset. All interviewees work for the public client Rijkswaterstaat. In total, 18 interviews are conducted. A saturation of data was achieved at the 14th interview. At this point, no new information was gained. To acquire the right balance in information, the researcher aimed to have the same amount of interviewees for each interview group.

Step 2: Transcribe interview
To process the conducted data in Atlas.TI, the audio-files that were recorded for each interview were transcribed. In this way, the audio-data is processed in text. Transcribing the audio-files was done word for word to get the most trustworthy and genuine data. A total of 103 pages is the result of this transcription and can be acquired on request.

Step 3: Initial code list
To analyze the transcribed data, codes are used. Codes are in this research defined as a label that describes the core of a quote in the transcript. As described in 4.2, an initial code list is set up based on the literature study.

Step 4: Coding the data
Starting with the initial code list, the transcripts were coded. During the coding, new codes were created when the defined codes did not fit the quote. To keep the focus on the design process during coding, the research question was considered to prevent digression. This approach follows the directed approach of content analysis with open coding (Hsieh & Shannon, 2005). This means that during the coding process, new themes and codes can appear. New codes that are obtained

while analysing, are added and codes that do not fit, are discarded. A quotation can be labeled with multiple codes, because it can cover more than one code. This eventually also shows the relation between the codes in the results. As new codes are defined during the process and these can be of use in earlier transcripts, the coding process is done multiple times to optimize the coded transcripts. Also the code list is reviewed multiple times during the process to prevent the exciting of codes that are not related to the research question or to check if codes can merge or be split up. For example, the code 'integral character of the design process' was split up in a code named 'the integral character of the design disciplines' and a code named 'the integral character of the lifecycle stages'. The different themes were reviewed in the same manner. The themes are of a higher abstraction level and covers various codes. A code can be used multiple times in one document which causes a code to be grounded multiple times in one interview. This shows the emphasis that the interviewees put on a certain issue and therefore does not interfere with the validation of the research.

Step 5: Remove redundant codes
To keep the groundedness of the codes as clean as possible, redundant codings are removed. Redundant codes entail two times the same code that are labeled to overlapping quotations. If not removed, this code is counted twice without covering a different fragment of text, causing the groundedness to be less clean. To eliminate these codes, Atlas.TI has a tool to detect these called 'Redundant codings'. Eventually, one redundant code was found and removed in the documents.

Step 6: Review and refine code list
For the final step of the analysis before retrieving the results, the code list is checked again for a possibility to merge or split the codes. The codes are in this stage also checked by their level of groundedness. Codes that are grounded 3 times or less were checked if they could be merged with other codes. This does not mean this can be done with all codes with a groundedness less than 3 as some codes do not fit another code. This is the case with the codes that relate to the categorization of circularity in a project, these codes therefore exists by them self. Another final check is the merge of quotations. In the beginning of the coding process, the codes are kept as separate as possible, even if they are in the same sentence. This appears not to be the most desirable approach because it is unfavorable for the co-occurrence of the codes. Therefore, the transcripts were checked again to see whether some codes should merge into one lager quotation with both codes instead of separate text fragments with different codes. This process was highly dependent on the sentence structure and was different for each text fragment. This can be seen as a learned lesson during the analysis process.

Step 7: Analyze the codes and retrieve results
The final step is to retrieve the results of the coded data. Atlas.TI has multiple tools for this. First, the groundedness of the various codes can be retrieved. This entails the quantity that a code is used in the analysis. In this research it means that the code represents an issue regarding the implementation of circularity in the design process that is mentioned often among the interviewees. A second way to analyze the results is by the co-occurrence of codes. This resembles the amount of time that certain different codes that are labeled at the some quotation. If this number is high, it means that the codes are connected to the same quotation for multiple times together which could indicate a relation between the codes. Lastly, a document-code table is retrieved out of Atlas.TI. This table shows the amount of times a code is grounded, reflected against the document groups composed which presents which codes are highly grounded in each document group and therefore

can indicate the issues for each group of interviewees. The number of interviews is not sufficient to use this for hard conclusions, but it does show an initial trend.

Results

This paragraph describes the results retrieved from the data after analysing as described in the previous section. The results are analysed in three different ways. First, the groundedness of the various codes is researched, this illustrates the quantity of times that a code is mentioned in the data. Followed by the co-occurrence of the codes as describes in the previous paragraph. Lastly, the document group is reflected against the codes to give an indication which codes are most grounded in which document group. The groundedness table, co-occurrence table and the document-code table is presented in appendix C. The codes which are grounded 15 times or above and co-occurrences 4 times or above are described in this chapter. The amount of times a code is grounded or they co-occur is presented in brackets.

Capacity and support

There are two code groups that are most mentioned during the interviews. The first group covers the capacity and support for implementing circularity. This code group also contains the aspect that appears the most out of that data, which is the absence of the capacity needed for the implementation of circularity (48). This capacity involves budget as well as time and personnel. It is noteworthy that this aspect is described as important in the guide for sustainable GWW. The argument has a high co-occurrence (8) with the leading role of the budget and time in projects (groundedness of 30) and the low level of support for implementing circularity (co-occurrence of 8). The interviewees indicated that if the project has the ambition to include circularity in the process, pressure of budget or time often causes this ambition to be deserted. The capacity also has a high occurrence (6) with the timing that circularity is included in the process and the need to integrate circularity in the project assignment.

The other codes in this group that are highly represented is the integration of circularity in the project assignment. This code also has a high co-occurrence (6) with the capacity needed to implement circularity. Considering that circularity is not represented in the project assignment, there is no personnel capacity or budget estimated to implement the ambition and the project team is not accountable for not including it. The unclear responsibility of the implementation of circularity in projects is also highly grounded. The interviewees agreed that Rijkswaterstaat should be, as an organisation, the initiator for a circular economy in the construction sector, but it appears to be unclear how this responsibility is organized within the organisation itself. The ownership barrier described in the literary study, where there is an unknown ownership of end-of-life materials, seems not occur at Rijkswaterstaat. The infrastructure assets that Rijkswaterstaat exploits are owned by the state, which makes that there is no unclear ownership of end of life materials.

The final code in this group that has a groundedness above 20 is the call for a companywide approach on circularity which has a co-occurrence (6) with the need to implement circularity in the project assignment. The participants indicated that that a company-wide approach on circularity support the decisions they make and guides in the possibilities to include circularity.

Other high grounded codes are the indicator that the implementation of circularity in the design of an asset is up to now, highly dependent on the individual motivation of the project manager or technical manager, the low priority (18) and level of support (19) there is for the implementation of circularity in the design process. The final code that is grounded equal or over 15 is the need for a platform and space for second-hand materials (18). To enable the use of second-hand materials, there is a need for a storage space and a platform to identify the available materials. Multiple interviewees indicated that using second hand materials can be a challenge, as the two projects need to have their planning aligned with no room for delays due to the absence of storage capacity, which is accompanied by undesirable risks.

The capacity codes appear to be mentioned mostly in the group that was involved in the plan study phase of the project and mostly with the technical managers and sustainability managers.

Integral character of the lifecycle process

The second group of codes that is represented in a large quantity in the data is the group that covers the integral character of the lifecycle process with 10 codes scoring a groundedness above 15 including 5 codes that score above 20. The highest scoring code in this group is the timing of including circularity in the process. The interviewees indicated that circularity and sustainability are often considered late in the process (30) causing substantial decisions already took place. The code has a co-occurrence with the capacity needed to implement circularity of 6. This is notable as the guidelines of the public client, described in the research framework, does aim to integrate circularity form the very beginning of the project.

With that, the need to design from a circular perspective also scored high in the data (15). This entails the need to design something circular instead of designing the same thing and consider circularity. The need for a feedback loop in the process and more flexibility in the process and in contracts (18) is an aspect that is represented multiple times in the data. This aspect also has a co-occurrence with timing including circularity concepts in the process and the set space for a design team in the process.

The other aspects concerning the integral character is the collaboration with the market (24). Rijkswaterstaat has the philosophy to, instead of letting projects be executed by the market, to collaborate with the market. This move is to be found difficult to include in contracts, which is now often captured in the EMAT criteria, although these are optional (21) to include for the tendering parties and therefore can result in cheap tendered option with no circularity included. Additionally, a contractor will include the possibilities for circularity that are economically beneficial and further investment to enable a more circular asset are reflected on the bonus they can gain on the tendering price. Lastly, this aspect has an interface with the timing of including circularity, as when tendering, influential decisions that affect the circularity did already pass.

In this group codes, the integral character of the lifecycles (19) and the design disciplines (20) is also represented with a high score. These codes also have a co-occurrence (5) in the data. This is also shown in the observation that interviewees pointed to other departments or teams within Rijkswaterstaat 19 times for the responsibility and effectiveness of including circularity in the process, which indicates the level of integral character of the departments of Rijkswaterstaat. Multiple participants indicated that circularity can only be implemented in the design phase of the process because that is where the decisions are made. When the researcher approached circularity as a tool to reduce material use and carbon emissions and elaborated on the importance of lifespan optimization of assets, the participants included in the maintenance phase started to notice their importance in achieving circularity in the construction sector. The lack of integration between the parties of Rijkswaterstaat is remarkable because an integral approach is the objective of the public client. This objective is applied in the procurement process, where an integral design process is not present. The code has a co-occurrence with the need to implement circularity in the project assignments, as a result of multiple interviewees pointing to their project client.

The final codes that scores a groundedness above 15 is the need for a more long-term perspective on an asset to include in the design process to ensure the asset being designed for more functional lifecycles. Participants indicated that it is difficult to anticipate on the developments during the lifetime of an asset. Although various mentioned the possibility to design more robust or adaptive, depending on the asset and the desired lifespan. Lastly, the participants and the Rijkswaterstaat guideline for the design process did not indicate an end-of-life stage to be considered during the process.

Knowledge

The code group 'knowledge' has two high scoring codes (>15). First, the knowledge level concerning how to design an asset from a circular perspective and what are the guidelines to follow is an aspect that emerged from the data and shows that there is a need to rise this knowledge level to implement circularity in the design process. This also associates with the indication that it is hard to measure circularity in a quantitative manner. MKI scores of a concept can clarify this, although the level of detail needed is often not present in the earlier stages and it not applicable for all circular design options. Even though the Guide for sustainable GWW prescribes the use of MKI and DuboCalc in the early phases of the project.. The code occurs most among the technical managers involved in the plan study phase. The sustainability department of Rijkswaterstaat has the aim to include sustainability aspects such as circularity to be an integral part of each department, which is in favor of the integration of knowledge throughout the organization

The second aspect is the knowledge of assets and their precise remaining lifespan. Multiple interviewees indicated that there is a need of more research to the existing infrastructure assets to be able to estimate the remaining lifespan more accurate of the asset or the asset components. The code occurs most in the early stage of the process, the exploration and plan study phase and among the sustainability advisors.

Uncertainty and risks

The final group covers the codes related to the seen risks when implementing circularity in infrastructure assets. The interviewees indicated that the risk avoidance culture does not give an incentive to design circular concepts and reuse materials because the outcomes are not yet definite. This risk avoidance culture is also discussed in the literature study and correlates with the implementation of circularity in the project assignment since the absence causes the project team not being judged or rewarded on the matter.

Another remarkable observation is the perception of what circularity is and the role it fulfills. Where some interviewees considers circularity to be a project goal, a requirement or an awarding criteria in the contract, the circularity specialists consider it to be a means to achieve a lower carbon footprint and less usage of scarce material. This was interesting because most of the interviewees that considered circularity to be a project goal, a requirement or an awarding criteria also thought that it is an aspect that needs to be considered in the plan study phase of an asset. The interviewees that are involved in later phases of the project did not think that circularity can play a role in their phases and can only make a difference in the design of an asset.

Conclusion: Current state of circularity in the process of the public client

As discussed in the research framework showed, the public client drafted multiple guidelines to enhance the consideration of circularity in projects. Although these guides appear to be unknown and insufficient for the project teams and are not followed during the design of an asset. Currently, considering circularity is often late in the design process and is focused on the reuse of released materials and including circularity in the contracting phase. This causes traditional designs where circularity is considered instead of designing an asset from a circular perspective. The guidelines on design and circularity of the public client are written from procurement perspective. A detailed integral design process is absent, which is a difficulty for implementing circularity because this leaves the guidelines on circularity on a more abstract level. Specific design strategies for designing a circular asset are therefore not present. The guide for sustainable GWW and the circular design principles do not yet cohere and for project teams it is therefore unclear how to include circularity in a practical way because which causes a risk avoidance culture towards the matter.

5 Research conclusions: Literature vs. practice

In this chapter, the results of the empirical research that are discussed in the previous paragraph are reflected against the main themes in the current implementation of circularity shown by literature. This study also shows the co-occurrence and links between these barriers.

Integral design and early consideration

The need for an integral design to implement circularity is presented in the state of the art research and also visible in the conducted research. Integrating system thinking, life cycle thinking and structural thinking is the base of the integral design. When considering all relevant aspects, that influence or are influenced by the asset, at the start of the design process a most optimal design can be found. Therefore these aspects, future developments and lifecycle stages need to be found and considered from the start by making a clear overview. Assumptions can be made for aspects that are yet unknown or different varieties are made. Although, to be able to adjust these assumptions when necessary later in the process when more information is gained and therefore create a iterative process, a feedback loop in the design process is of importance. The sustainability department of Rijkswaterstaat aims to integrate in all departments of the organization to make sustainability and circularity an integral part of all disciplines, which is beneficial for the implementation. However, the Rijkswaterstaat design guidelines present the process as a linear process without a feedback loop in contrast to an iterative design process. The research framework shows that the process of the public client has the objective to be integral, although no design guideline is found. The integral objective of Rijkswaterstaat is now focused on the procurement procedure and not on the design process. The disciplines and lifecycles are not optimally integrated in the process and the end of life phase is not defined at all and therefore not considered during the design process. The integral character is of importance for the implementation of circularity because circularity can affect all aspects and lifecycle phases of an asset and therefore puts the timing of considering circularity early in the process. However, the current guidelines on circularity is focused on the procurement procedure of assets. This leads to a late integration of circularity in the process and decisions prior to this procedure to barely or not include circularity which could have a great impact on the aspect. Including circularity early in the process is described in the guide for sustainable GWW, although as stated in the research, often not enforced. The circular design principles, formulated by Rijkswaterstaat and engineering firm Witteveen&Bos and based on the R-method for circular economy, are not yet integrated in the approach on sustainable GWW, which are both not yet broadly applied according to the conducted research. To enable the optimal circularity level for an asset, the aspect needs to be considered early on, prior to the purchase procedure, and as an integral aspect in the process, including the end of life stage of an asset. As part of the integral design process and to fully recognize all circular possibilities, the whole lifecycle of an asset needs to be considered. The Rijkswaterstaat design guidelines do not indicate an end-of-life stage in the lifecycle of an asset and the research conducted confirmed that the end-of-life phase is not considered when the team designs an asset. Including the end of life stage in the design process and connecting this phase with the start of a renovation project, creates a circular design process.

Initiation, exploration and plan development phase

Both literature and the conducted research show that the public clients need sufficient capacity to make the transfer to circular assets. More capacity for the implementation of circularity in the project and therefore more support could be encouraged by implementing circularity in the project assignment. In this way, capacity is calculated in the project planning and the project team is accountable for circularity in their project and therefore will create a sense of responsibility. Whereas now the implementation of circularity depends on the individual motivation of the technical manager. The need to include circularity in the project assignment and procurement requirements to create this responsibility for the whole team, is also found in the literature study on the current state of circularity in the Dutch construction sector. Additionally, the necessary steps that need to be taken to design circular assets are unfamiliar and sometimes unknown. This level of knowledge is also presented in the literature and is highly represented in this research. This aspect causes, together with a lack of capacity, a lower level of support. Within the public client, especially among the design team members, there is a lot unclear about the possible decisions they can make to achieve a more circular design and where to start. A circular design varies for different types of assets and for a short or longer lifespan. The desired lifespan of an asset is a crucial functional aspect that has a great influence on the starting point for the circular design approach of the asset. The distinction for circular design strategies guided by the aimed lifespan or other requirements is not present in the current strategy of the public client and the circular design principles do not elaborate on the necessary steps to implement these principles. As the research shows, it is yet unclear how to design something circular instead of designing the same thing and consider circularity. The need for capacity and sufficient knowledge and affinity with circularity are acknowledged in the guide for circular GWW but often appears to not be enforced. A notable outcome of the empirical research is that the ambition to include circularity in the process is often deserted due to pressure and a leading role of budget or time in the project.

Collaboration with the market and risk avoidance culture

The literature on the current practice of circularity in the Dutch construction sector shows the urgency for a clear and long-term tangible ambition and approach on circularity for the public client. This should be an internal uniform organisational approach as well as a clear and uniform intention toward the market. A company-wide approach on circularity supports the decisions the project team makes and provides guidance in the search for ways to include circularity. This can also contribute to lift the risk avoidance culture in the organization and the perceived uncertain outcomes of circularity that interfere with the sustainability ambitions. Another point of attention is the collaboration with the market. As the societal challenges are becoming more complicated and technological developments are accelerating, a different role and method of Rijkswaterstaat is required. A role and working method where not 'the market, unless' but rather 'together with the market' is central. Therefore a clear and unambiguous representation towards the market on the circularity ambitions is important to make the transfer from a linear to a circular way of thinking. This requires a long term vision. The public client needs to broadly support the application of circularity while propagating a clear ambition and a uniform inquiry for the market parties.

Ownership and responsibility

The unknown ownership of materials, a barrier described by the literature, is not represented in the research because this is not applicable for Rijkswaterstaat as in Dutch infrastructure. The infrastructure assets that Rijkswaterstaat exploits are owned by the state, which makes that there is no unclear ownership of end of life materials. Rijkswaterstaat acknowledges its role as initiator for a circular economy in the construction sector, but it appears to be unclear how this responsibility is organized within the organisation itself. Although, as an owner of the materials, the public client could also be the initiator of the material passport and monitoring existing structures to enhance the use of second-hand materials and assure the materials quality information.

To conclude, some aspects to include circularity in the process of the public client are included in the literature and guidelines dictated by the public client but not yet implemented to its full potential. The ambitions for an integral design approach, for including circularity in the from the start project process and for sufficient knowledge and capacity on circularity to be engaged in the project, are all included in the guidelines but appear to often not be enforced. The measurability of circularity is now captured with Dubocalc in the MKI scores although the level of detail for this is often not present in the early stages of the project. Neither can the tool calculate a representative score for robust design alternative with multiple lifecycles and the guideline to use these tools are focused on the contracting phase, not on earlier design phases. Additionally, some aspects that are concluded in the literature, are not included in the current practises and guidelines of the public client. These aspects help or enable a circular design of an asset such as the integration of circularity in the project assignment, a platform and space facilities for second-hand materials, a feedback loop and more flexibility in the process. A long-term perspective including the end of life stage of assets, a companywide approach and ambition on circularity to guide project teams and create clarity for the market and the integration of knowledge level and experience on circularity to counteract the risk avoidance culture present with the public client are also not yet optimally present in the process of the public client. Lastly, the research shows some new aspects such as the need for circular design strategies that enable designing from a circular perspective instead of designing the same and consider circularity at the end. Additionally, the currently often deserted ambition to include circularity due to pressure on the budget or planning and the need for more deep knowledge and information of assets and their precise remaining lifespan.

The results of the conducted empirical qualitative research overlap with the findings in the literature and where therefore expected. However, few additional aspects also surfaced.

Comparing current practice of the public client to the proposed flowchart for implementing circularity in the design process

To give insight in the current state of circularity in the design process of the public client, the flowchart presented in chapter 2 which can be found in appendix B is used as a baseline and shows the fundamentals for implementing circularity in the design process. The flowchart presented in this chapter, can be found in appendix D and shows which aspects are already present (shown in blue) in the process of Rijkswaterstaat, which aspects need to be improved or implemented according to the findings of the research (shown in grey) and which aspects are partly considered in the current process but not yet optimally implemented (shown in grey-blue). Additionally, the flowchart shows the additional findings from the conducted research (shown in yellow) which the employees indicated as a currently present barrier for the implementation of circularity. Some of these barriers are already considered, but not optimally and often too late (shown in grey-yellow). The flowchart starts with the preliminary aspects to consider and commence when wanting to enforce circularity in the design process optimally. These preliminary aspects concern the organizational ambition and companywide approach to support circular design and the knowledge and insight needed throughout the organization to realize circular designs. The research shows that the Dutch construction sector, including the public client, has the ambition to work circular in the coming years but did not yet formulate a uniform approach on how to achieve a circular construction sector. Additionally, most public client project team members are not familiar with the concept and do not know how to design a circular asset and how to include the aspect in the design. However, the sustainability department of Rijkswaterstaat aims to include sustainability aspects such as circularity to be an integral part of each department, which is in favor of the integral character of circularity.

The next part of the flowchart concerns the circular design process. The phases of the project are adjusted according to the phase distinction of the public client, however the content of the phases remain the same. The exploration phase is added and covers part of the content of the initiation phase. This has no influence on the essence of the design process. The baseline design steps used in the flowchart are the six steps in sustainable GWW, which is the prescribed sustainability design process of the Dutch public client, although not yet implemented in the organization. The circular design principles are linked with this approach to form a design cycle that considers circularity. This flowchart is based on the premises that there is sufficient capacity in time, budget and team members for the project and there is an integral design approach. The findings of the research show that all these premises are not yet consistently integrated in the work process of the public client. Capacity appears to be one of the main barriers for including circularity in the projects of the public client. This entails a lack in circularity advisors as well as in time to explore circular solutions. Especially in this beginning stage of implementing circularity and making it common practice, these aspect are of capacity are of importance. Additionally, an integral design approach is not prescribed and formulated in the documentation and guidelines of Rijkswaterstaat.

The second part of the flowchart considers the integral design process. It is of importance to include all relevant aspects that effect or are effected by the design of the asset and consider their impact or opportunities on circularity, which is now often not the case which results in circularity being considered too late in the process. The design cycle is walked through every phase and can be run multiple times to find the most optimal solution through iteration. The design cycle also works in a cyclic way with different detail levels, from system to component. In this way, circularity is considered for each decision made. The research shows that the approach of the public client does not include a feedback loop. The public client does have a cyclic approach on a project, although early scoping and decision-making often takes place, which interferes with the desired integral character. A uniform organizational approach and design strategy would fit this scheme, and a proposition is made for a design strategy based on desired lifespan and certainty of future developments. A circular design can look different for different types of assets and for a short or longer lifespan. The desired lifespan of an asset is a crucial functional aspect that has a great influence on the starting point for the circular design approach of the asset. This lifespan is composed of the required lifespan of the asset, whether it is a temporary construction or a permanent construction, and the uncertainty of future developments. When future developments in the area are highly uncertain, an asset could be designed as adaptable or reusable to ensure multiple functional lifecycles. An asset with a relatively certain future can be designed more robust so it can withstand more capacity than the design value if future growth is expected after the lifespan. In this way, the asset might be able to withstand another lifecycle when renovated, instead of the necessity of a new structure. This also requires clear insight into the remaining lifespan of an asset, in the present and future. Thorough monitoring and early research is therefore essential for optimal use of the assets' value. Circular design strategies guided by the aimed lifespan or other requirements are not present in the current strategy of the public client and the circular design principles do not elaborate on the necessary steps to implement these principles.

The collaboration with the market differs for each type of contract, although early engagement can offer more expertise and innovation. The public client is now experimenting with new contract forms to enable early engagement with the market. This however, should not result in premature scoping of the project. A clear and uniform ambition towards the market enables a more efficient learning process and support. The contract should include circularity in a non-optional form while keeping some room to learn and innovate. Both these aspects are not yet present or widely implemented. For the public client it is important to verify the circularity ambitions throughout the entire duration of the contract to avoid undetermined and unproven numbers on circularity at the end of the contract period, which is now often not possible due to the limited capacity of the public client.

Verification of the flowchart: Case study

The flowchart is verified and tested using a case study. The aim of this step is to apply the flowchart to a current project in collaboration with the project team and gather their experience and feedback to verify and improve the flowchart.

The case study consists of two sessions with the project team. During the first meeting, the researcher explained her findings and the flowchart. Then the team members were given a week to assess the flowchart for themselves and consider it in the context of their field of expertise. In the second session, the researcher and the team members walked through the flowchart together and applied it to the project weir Grave. This second session, the researcher gathered the feedback, experience and points of improvement. This feedback and experiences are processed in the flowchart or are recommendations for future research.

6. Case Study: Circularity in the weir Grave

6.1 Weir grave

The river Meuse enters the Netherlands at an altitude of 45 meters and descents to sea-level where it flows out into the North sea. The seven weirs in the river Meuse are enabling shipping on the river and were constructed beginning last century. An overview of the river Meuse and the Weirs is presented in Figure 9. The weirs are at the end of their live time between 2030 and 2040 and therefore need to be replaced or renovated. The weir nearby Grave in the province of Noord-Brabant is expected to be the first on the agenda to be reconditioned. Therefore the case study of this research is scoped to hydraulic infrastructure structures with the focus on the weir. The reason behind this is the relative long lifespan of hydraulic infrastructure compared to linear infrastructure such as roadway systems. A shorter lifespan results in components that are replaced sooner. This gives the opportunity for a fast transition towards a high degree of circularity. Hydraulic infrastructure, although containing several subcomponents with a shorter lifespan, have a relatively long lifetime which makes a fast transition toward circularity more challenging. Therefore there might be other needs and principles regarding circularity with these types of assets.

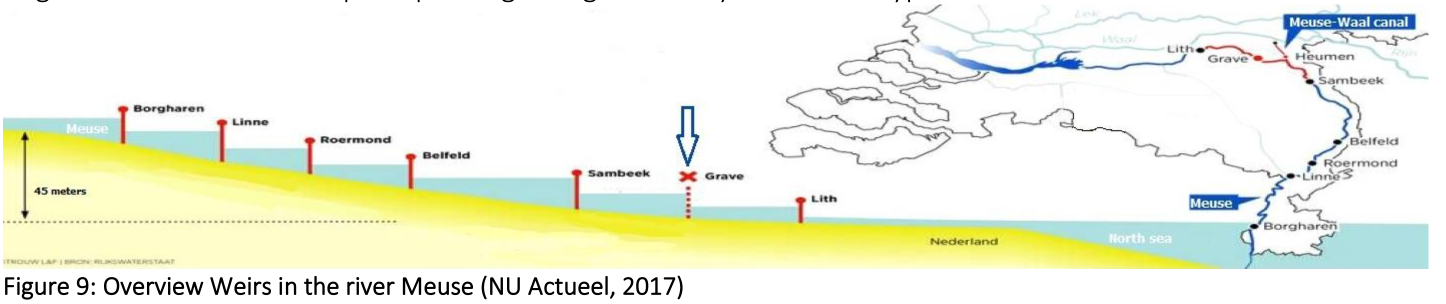

Figure 9: Overview Weirs in the river Meuse (NU Actueel, 2017)

The weir Grave and the adjacent lock form a complex in the Meuse located at Grave and Nederasselt. The road bridge, the John S. Thompson Bridge, crosses the river and works as a suspension for the weir. The complex was put into operation in 1929. A new, second lock was opened in 1974. The weir and bridge are built as one multipurpose construction and therefore integrated, which makes the weir in the Maas unique in the Netherlands. The weir consists of two openings with a width of 60 meters, available for shipping. These flow openings are closed by 20 yokes with 60 sliding panels. Three panels are placed on top of each other in the yokes and can be adjusted and moved, depending on the discharge of the river. An overview of the weir-bridge complex is shown in Figure 10. The weir-bridge complex has a monumental status and a high cultural historic value.

Figure 10: Weir complex Grave (van der Zee, 2017)

6.2 Current state: Orientation phase

The project for the renovation and renewal of the weir Grave is currently in the orientation phase of the design process. The project has multiple interfaces with other projects, such as the renovation of the bridge, the other to be renovated weirs in the Meuse, a new proposed lock and the area vision of the waterways. Currently, the orientation phase is finalized and the possible types of weirs were researched and assessed. The large number of interfaces and aspects and the unfamiliarity with circularity increase the difficulty to design an optimal and circular solution.

To gain insight in the process of the design team, the team was followed for half a year. Multiple aspects that appear in the conducted qualitative research also emerged in the project for the weir Grave. First, information about the current weir and its drawings of the design and foundation appeared to be missing or difficult to retrieve. This made it difficult to determine whether the foundation could be reused or combined with the foundation of the bridge. Another remarkable point was the distinction in multiple projects of the bridge-weir-lock system. A different project team was working on the urgent reinforcement of the bridge due to the recent load restrictions and the sluice was not yet considered for renovation. The system was therefore not integrally considered and due to the assigned project procedure, it is difficult to achieve the desired level of integrality with the bridge and sluice. An aspect that has a great influence on the integrality of the weir Grave, the lock and other weirs in the Meuse is the navigability. It was not yet clear whether the weir should be passable for ships, which has a decisive role in choosing the type of weir and also has consequences for the other assets in the system. The decision on this aspect is not on the authority of the project team but for the ministry and region, which makes it more difficult to act on. Additionally, design decisions and a variant tradeoff is made without having full insight on this and other aspects. The formulation of requirements and criteria therefore intertwined with the design process.

In a meeting with the design manager of the design team, it was confirmed that there is no Rijkswaterstaat integral design guideline and the design process of the project is coordinated with knowledge and experience that the technical manager gained in previous functions at an engineering firm. The design department of Rijkswaterstaat is relatively new and has the objective to gain knowledge on the design of different types of infrastructure assets. In addition, she pointed out that the region determines the budget and scope of the project. This budget is retrieved from funds for a certain overarching project procedure, in this case 'renewal & renovation' (V&R[7]), determined by the ministry. When it appears to not be the best fit for the project, due to narrow scoping for example, it is difficult to change the chosen project procedure in, for example, a more integral procedure as MIRT. Additionally, the project team indicated the importance of reporting the made considerations and decisions to enable trackability for future project teams and their members. In their experience, this is not always the case in projects which causes difficulties as there is no clear insight on the made decisions and considerations.

The project team did not have clear guidelines concerning sustainability and circularity and therefore did not integrally considered these for each discipline. To include circularity in the project at an early stage, a circularity advisor joined one of the design meetings to help gain insight in the opportunities for the design. She indicated the importance of an integral consideration of the weir together with the bridge and lock and with the other weirs in the river Meuse to enable an optimal solution. Regarding the integrality of lifecycles, the circularity advisor indicated the need for a design which can be easily and sufficiently maintained. This aspect of maintainability is considered part of a decent design by the project team members and is therefore more familiar, although not from a circular perspective. Additionally, the advisor pointed out that there is a budget available for circular purpose in design solutions which was not known among the project team members. Due to the long desired lifespan of the weir, a robust design and capacity was advised to enable optimal use of the materials necessary. To further enhance circularity, it would be preferable to calculate the Environmental Cost Indicator (MKI[8]) for each design variant and include this score in the tradeoff of the variants. This turned out to be difficult at this stage of the design, due to the low level of detail. To calculate the MKI in the calculation tool Dubocalc, more detailed aspects of the design are needed such as the amount of steel or concrete. This was not yet clear in this stage of the design process and therefore is the calculation of the MKI advised to research in the next phase of the design.

6.3 Case study: Implementing circularity in the design process of Weir grave

The flowchart is verified and tested using the weir Grave as case study. The flowchart is applied to the design together with the team members. The experience and feedback of the design team is used to improve and verify the flowchart.

Case study session 1 (carried out on 17.03.2021):

In the first session of the case study, the researcher presented the conducted research. The different results from the literature and the approach of Rijkswaterstaat were presented, as well as the results from the empirical research. This was followed by an explanation of the flowchart. The project team members were asked to study the research and the flowchart through the lens of their own discipline in the coming week and examen its pros and cons.

Case study session 2 (carried out on 24.03.2021):

In the second session with the project team, the researcher walked through all the steps of the flowchart together with the project team. They indicated that the premise of the flowchart 'sufficient capacity' is not yet an evident part of the projects of Rijkswaterstaat. In addition, they

[7] In Dutch: Vervanging & Renovatie

[8] In Dutch: Mileukosten indicator

indicated that, as the preliminary aspects indicate, they indeed struggle with knowing what circularity is and how they can apply it in their project as there are no examples of a circular weir. When considering organization wide guidelines for circular choices, a project team member indicated that there should be a distinction made for the different phases of a project because the team noticed that these are mostly indicated for more detailed phases of the project, which made it unclear how to implement circularity in the exploration phase due to the current abstraction level. Therefore, more guidance and insight in how a circular design is made is essential. Additionally, the project team agreed that the support and enforcement of the consideration of circularity in projects starts with integration in the project assignment because the assignment determines what is constructed and the project team gives substance to this assignment. This is also the case for all the other aspects that need to be included in the project Weir grave such as water safety. When circularity is not in the project assignment and does require more capacity, it often is abandoned and other aspects are considered to be more important. A team member in charge of the regional aspects of the project indicated that the requirement for circularity is imposed by the ministry and not by the region, which shows the fragmented structure.

When considering the integral character of the design process, the design team indicated that the separation of the bridge, weir and lock is not desirable for the integrality and circularity, although more desirable from a planning perspective as it is easier to design and less aspects can interfere with the design. This is an often seen aspect with Rijkswaterstaat where efficiently and fast progress on the short term is important and the long term perspective often has not yet been considered, which can result in suboptimal solutions. Additionally, few aspects to integrally include circularity in the project are already guided for optimal use of energy and material although not from a circularity perspective but for the purpose of minimizing costs. This can benefit circularity or work against it. The latter occurs when considering material optimalisation and the design is made for the cutting edge of capacity and there is no room to increase when needed, which shortens the functional lifespan of an asset and is something to avoid when considering a high level of circularity. The steps that might benefit the circularity over the lifespan of the weir are not consciously made from a circular perspective and currently circularity is seen as extra risk and cost. The team also pointed out that willingness to design a circular Weir is present, although examples are missing.

The project team members did indicate that the flowchart helps and gives insight in the timing of the possible inclusion of circularity and the important steps in the design process to achieve this. They indicated that it is preferable to already follow a design loop in the initiation because it creates more insight in the project objective and feasibility. Therefore, the question presented to the market also becomes clearer. The team did recommend to make a clear distinction between the functional and technical lifespan in the flowchart. The team members also indicated that the consequence for future area developments are not yet optimally embedded in the design. The climate prognoses and future peak discharge of water are known, although the consequences for the design are not completely clear and these steps are not yet explicit. The choice to design the weir to be adaptable or robust is not explicitly made and not secured in the design. The presented flowchart is therefore valuable to get more insight in this aspect and the consequences for the design.

The team provided feedback and advise on the layout of the flowchart. First of all, a Dutch translation enables the flowchart to be implemented at Rijkswaterstaat. Additionally, the cyclic and iterative character of the design process was not clear as there are too many arrows and the that blocks are not organized in a cyclic way. A team member also indicated the complexity and amount of information on the flowchart and how this can withhold project teams from using it. Therefore he advised to simplify the flowchart and write a guideline for the use of the chart. A legend to explain the colors is also recommended.

To conclude, the case study with the design team weir Grave increased the awareness of circularity among the team members. This shows the benefits of an increase in engagement on the topic by more guidance and more means to bring circularity to the attention of all members of a project team. The design team Grave also discussed and will research the possibilities to integrate circularity in the currently formulated basis specifications for weirs. Lastly, the question was raised whether or not the flowchart is applicable for all different project procedures of Rijkswaterstaat such as a MIRT or V&R process. The flowchart does not differentiate these procedures as it is focused on the design process and not the management procedures. However, the used documentation is of the MIRT process and it could be that the second and third circular design principle are less relevant for projects with no existing asset. Although, the flowchart leads the team to the following circular design principles which are relevant. Therefore, the flowchart is largely applicable for all project procedures although more research should be done to validate this.

The feedback and results of the case study are processed in the flowchart and result in a simplified version of the flowchart with a guideline for additional information. This flowchart and the guideline are drafted in English and Dutch and can be found in Appendix E.

7. Discussion

The objective of this research is to find a way to include circularity in the design process of the public client and find the current hurdles to overcome. In this research several obstacles and missing aspects are found that hold back the implementation of circularity back. These obstacles and aspects cover different parts of the process of the public client and are categorized according to the presented flowchart for clarity: ambition, design process and market collaboration.

Ambition

The first category and step in the implementation of circularity in de design process is the ambition of the public client. Rijkswaterstaat has a clear long-term ambition on circularity and aims to tender all project circular in 2030 and be fully circular in 2050 and feels the responsibility to initiate a circular Dutch construction sector, however short term steps on how to achieve this ambition are unclear. Therefore, tenders including circularity are minimal and fully circular tenders are exceptional. To enable a transition towards a circular construction sector, the objective of the client needs to be clear, supported throughout the organization and presented to the market parties. A companywide approach on circular design strategies is one of these aspects. This approach enhances the circular way of thinking and also guides the design team to make substantiated choices considering circularity instead of designing with the current linear mentality with circularity as something extra. A companywide approach also contributes to counteract the risk avoidance culture in the organization and the perceived uncertain outcomes of circularity that interfere with the sustainability ambitions. A final aspect in this category is to include circularity in the internal project assignments of the public client, which creates an accountability and responsibility for the aspect. Another aspect that goes beyond the borders of the design process is the need for facilities, such as a platform and storage space, for second-hand materials and more deep knowledge and information of assets and their precise remaining lifespan.

Design process

The next category to enhance circularity is in the process of the public client. The current documentation of Rijkswaterstaat on implementing circularity are written from a procurement perspective and not from a design perspective. This leads to a late integration of circularity and decisions prior to this procedure to barely or not include circularity even though they can have a great impact on the aspect. Additionally, the literature pointed out that an integral design approach is of importance when aiming for a circular design because circularity can have an effect on all lifecycles and aspects of the asset and therefore should be considered when designing a circular asset. Although Rijkswaterstaat has the intention to have an integral process, no integral design guideline is found as designing is usually done by market parties. During the design of an asset, from initiation until detailed design, the project has three different owners. This can when not managed properly also interfere with the integrality of the process. Therefore, an integral design approach, including the role of the ministry and market, should be clarified and implemented within the organization as a base for the implementation of circularity. Additionally, a characteristic of the integral design process is the iterative and cyclic practice which enables optimalisation in design decisions and adjusts them if necessary. This appears to be absent in the process of the public client and decisions made turn out to be difficult or impossible to reassess. Another important aspect for implementation is the moment in the design process when circularity is considered. Currently, this often happens in the late design and contracting phase, even though multiple decisions that highly effect the circularity of an asset are already made prior to these phases. When circularity is included from the start of the design process, the possibilities to sufficiently include this aspect increases. To explore the possibilities for sustainability, sufficient time needs to be budgeted. Another evident aspect that the research showed is the knowledge needed to implement circularity in a project. Lack of capacity often causes the ambition to include circularity in the process to be deserted due to pressure and leading role of budget or time. This obstacle is partly settled when circularity is included in the project assignment although this does not solve the deficiency in knowledge on circularity throughout the organization. Implementing present guides and conducting more research on the topic together with widely spreading the circular ambitions and implementation steps could improve this. This also decreases the risk aversion on the topic simultaneously. Finally, to enable a circular way of thinking in an integral process, the end of life stage of an asset and its managing strategy should be considered and a thought-out long term vision of the assets whole lifecycle should be included. Summarized, the absence of clear handbooks on designing circular and integral design processes are holding back the implementation of circularity. The aspect is now mainly considered in the contracting phase while the decisions prior to this phase have substantial impact on circularity.

Market collaboration

The final category to consider when implementing circularity is the collaboration with the market. Until recently, Rijkswaterstaat tendered integrated contracts to the market, including the design and construction of an asset. Rijkswaterstaat has the ambition to have a more collaborative relation with the contractor compared to the current supervisory relation and therefore has the objective to gain knowledge on the design process of assets. Currently, circularity is often captured in the EMAT criteria however at a relatively low reward. Capturing circularity in the EMAT criteria also created these aspects to be optional and not strictly required to include for tendering parties. This can therefore result in a cheap tendered option with no circularity included. To optimally include circularity, it should be included in the project assignment of the tender. This relates to the wish from the market for a clear and uniform ambition and approach on circularity and enables them to adapt and improve more rapidly in the field of circularity and sustainability. Lastly, another obstacle found in literature concerning the risk avoidance culture of the public client is the often little room in a contract to let the contractor to learn and experiment. The contractor therefore has often little space to innovate new solutions, which can withhold the innovations for a circular construction. The contract should include circularity in a non-optional form while keeping some room to learn and innovate, which is currently not the case due to the risk avoidance culture of the public client. Additionally, it is important for the public client to verify the circularity ambitions throughout the contract duration to avoid undetermined and unproven numbers on circularity at the end of the contract period.

To give guidance for the implementation circularity in the design process of the public client, a flowchart is formulated that includes the most significant findings of this research. The flowchart starts with the preliminary aspects to consider and commence when wanting to enforce circularity in the design process optimally. These preliminary aspects concern the organizational ambition and companywide approach to support circular design and the knowledge and insight needed throughout the organization to enable circular design and reach the ambition. The next part of the flowchart concerns the circular design process. The design cycle is walked through every phase and can be run multiple times to find the most optimal solution trough iteration. The design cycle also works in a cyclic way with different detail levels, from system to component. In this way, the circular design principles are considered for each decision made and at different detail level. It is of importance to include all relevant aspects that effect or are effected by the design of the asset and consider their impact or opportunities on circularity. The current practice of the public client is reflected against this flowchart for implementation of circularity in the design process, which shows the aspects that need to be implemented or improved in order to implement circularity in the design process of the Dutch public client. The aspects are shown in grey and give a clear view on the points of attention for the public client when considering the implementation of circularity in the design process. The flowchart is verified with a case study on the project Weir Grave. This case study showed that the flowchart is valuable for the implementation of circularity and includes the significant aspects to consider. The flowchart did appear to be difficult to read as there is a lot of information on the chart and the layout does not empowered the flow of the design process. To improve this, some adjustments are made although for a successful implementation of the flowchart, it should be made more user-friendly. Additionally, it was recommended to translate the flowchart in Dutch when used at Rijkswaterstaat. The flowchart is at this point more a representation and visualization of the important aspect to include circularity in the design process and not yet an applicable chart for design teams. Therefore, the flowchart is simplified and translated together with a formulated guideline to use it.

Recommendations for the public client Rijkswaterstaat

To implement circularity in the think-, work- and design process of the public client, there are several steps to undertake. The first remarkable finding is the absence of a design process. To implement circularity in the design process, it is of importance to define a clear and applicable integral design process where all relevant aspects that can influence the design and can be influenced by the design are considered including the end-of-life phase and an integral consideration of circularity and sustainability. This can be a relatively simple but significant first step to implement circularity and gives more guidance to project teams during the process. However, the actual implementation of a more integral character is a more challenging step to undertake as it involves a change in the current work culture. A second recommendation and step for the public client is the increasing the knowledge, insight and awareness on circularity. A companywide approach on circularity and guidelines for circular design strategies can be beneficial, and reduces the risk avoidance culture. This uniform approach on circularity should be communicated with market parties to enable a more efficient learning process on circular construction. The increase in knowledge and guidance on circularity are aspects that can be a bigger obstacle to overcome due to the number of actors involved and the still to be formulated guidelines and processes. Additionally, more research on the outcome and possibilities on circularity in the construction sector should be conducted to expand the knowledge and decrease risk aversion. Lastly, circularity should be integrated in the project assignment for the internal projects of the public clients as well as the tender towards the market to give a sense of responsibility and empower the accountability for the aspect. This however, can only be optimally fulfilled when there is sufficient guidance and knowledge on circularity.

8. Conclusion

The public client aims to include circularity in their design process. The objective of this research is to find a way to do this and find the current hurdles to overcome. In this research several obstacles and missing aspects are found that hold back the implementation of circularity. An uniform and companywide approach on circularity and sufficient guidance together with including circularity in the assignments and tender is one aspect that appears to be important for the implementation of the aspect. Sufficient knowledge on circularity and integration of this knowledge throughout the organization and among decisionmakers is a second important aspect, as well as knowledge and insight on the existing infrastructure and their properties during and after exploitation. Finally, an integral approach on design including circularity and considering all relevant aspects and lifecycles that influence and are influenced by circularity is essential to realize circular assets and create a more circular construction sector. The result of this research is a flowchart that captures the steps necessary for the implementation of circularity in the design process and guides the project team in finding circular solutions.

This research is conducted at Rijkswaterstaat, the biggest public client of the Netherlands. The current state of circularity with the public client is based on documentation from the Ministry of Infrastructure and Environment and collaborations within the construction sector which are also widely spread within the Dutch construction sector. This research therefore gives a valid representation for the implementation of circularity within the design process of the Dutch public client. However, the individual experiences of employees interviewed on circularity in projects can differ at other public clients in the Netherlands such as provinces, municipalities and waterboards. At Rijkswaterstaat, various aspects are already included in the documentation but are not yet optimally implemented and applied in the process of the project teams. This can also differ for other public clients.

The project Weir Grave is a project that is carried out by a RWS-design team. The RWS-design department is a relatively new department with the objective to regain knowledge on assets and the design process to enable a more desirable position and collaboration with market parties and to get more insight in the project scope and inquiry. This department is however not yet involved in all projects of Rijkswaterstaat and might therefore not be completely representative as a Rijkswaterstaat project. Projects of Rijkswaterstaat that do not include an RWS-design team outsource this design process and phase and are therefore not applicable as a case study for this research. However, the aim of this research is to implement circularity in the design process of the public client and this department is responsible for designing and the design process.

Additionally, this research is conducted during the SARS-CoV-2 pandemic, which had an influence on the research approach resulting in all interviews being conducted in a digital environment. It would be preferable to conduct the research in a face to face expert meetings to interview the employees and to discuss the findings. Unfortunately, this was not possible due to the measures.

Recommendations for future research

The outcome of this research lead to multiple aspects that are still undefined. Future research on these topics can therefore benefit the implementation of circularity in the construction sector.

1: Measurability of circularity in early design phases

One of these aspect is the measurability and quantification of circularity to enable a more specific and clear in the tradeoff of design alternatives. DuboCalc and the MKI scores of a design alternative can clarify this, although these tools are now focused on the late design and contract phase because there is a lot of design detail required which now often leads to a late consideration of circularity. To enable some distinction in circularity in an early stage of the process and the trade-off, the measurability of circularity in the exploration phase should be made possible. Additionally, DuboCalc cannot yet calculate a robust design for multiple lifecycles and gives the robust design a higher MKI score due to a higher use of material. A way to include multiple lifecycles and the cost of adaption, renovation or replacement in a later stage in the calculation tool would therefore be required to make a decent comparison between variants. Additionally, more research should be done on including circularity in, for example RAMSHEEP and LCA.

2: Contract model to enhance circular design

A second subject for future research is the contract model to enhance circularity and other sustainable aspects. It is desirable to include the market party in an early stage of the project to include their expertise and innovation, without losing control over the project and without scoping the project too early. Secondly, circular and sustainable aspects should not be optional for the market parties, which is now often the case with the EMAT criteria, but should be required.

3: Knowledge on existing infrastructure

A final recommendation for future research concerns the need for and the increase of knowledge on materials and structural aspects of existing infrastructure and the call for a platform to give insight in developments and enhancing the second hand material industry. This could be for example be a BIM model that includes the assets and their materials, maintenance, monitoring data an technical drawings. This then functions as a material passport and, together with a platform for the supply and demand for secondhand materials and a facility to store materials, can simplify the use for second hand materials.

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Appendix A: Models for design

In the past years, there have been multiple representations of the actions that are taken during a the process of designing. Design models capture the philosophies or strategies proposed and show how a design is or could be made. The models can be illustrated with a flow diagram, that shows the iterative character of the process with a feedback link (Erbuomwan et al., 1996). In literature, it seems like there is an ample of variety on design models, although this is mainly a terminology issue. The design processes are characterized as a iterative process that works in a funnel form (Boeijen & Daalhuizen, 2017; De Groot, 1994). This entails that the design works from broad to detailed. Most models have in their base the same cyclic approach to solving the problem. There is a difference between iterative steps and cyclic steps in the design process, where a iterative step is a rerun with more knowledge, are cyclic steps the same steps but in a more detailed manner (Voorendt, 2017). Furthermore, requirements and criteria are factors that highly influence the design solution. These requirements are the base of the design and the trade-off of the alternatives. These requirements and ambitions are set at the very beginning of the process when the situation is analyzed and mapped with the available knowledge. It is important to make a clear distinction between the requirements and criteria. Requirements are characteristics that form the baseline for the design and all the concepts need to be in line with these requirements. Criteria are the aspects that give added value to the design and are not as mandatory as requirements (Voorendt, 2015, 2017). This paragraph dives in the different models for design that arose in the past years to eventually elucidate the possibilities for implementation of circularity in the design models. There are multiple models to design, such as the empirical cycle, the Delft Design Method, ect. (Boeijen & Daalhuizen, 2017; Enno Zuidema Stedebouw et al., 2011; Hertogh et al., 2018; Voorendt, 2017). These are elaborated upon in this appendix.

Empirical cycle in reflection

The Dutch psychologist Adriaan de Groot (1994), described the design cycle as the empirical cycle in reflection and characterized it by five basic stages:

1. observe
2. presume
3. expect
4. verify
5. evaluate

The design cycle according to De Groot starts with observing the situation at that point in time. Presumptions are made with the available knowledge and skills about the possible solutions for the problem that have an expected effect on the situation that is observed. Following, the expected effects are verified whether they are in line with the desired effects. Lastly, an evaluation is carried out by evaluate what was learned in the process and how these lessons can be valuable for the next cycle. The process described is in line with a logical line of reasoning and various psychological theories show that the cycle is generic and even unavoidable (De Groot, 1994).

On the Delft University of Technology this theory of de Groot is applied on engineering design and distinguishes similar main design phases. Create as an activity is explicitly mentioned (Voorendt, 2017):

1. observe;
2. model;

3. predict;
4. do and verify;
5. improve the model if needed.

Similar to the theory of de Groot, process is also in line with a logical line of reasoning (De Groot, 1994). The model has an intuitive character which is helpful for relative simple design tasks. For more complex problems, design skills, knowledge and understanding is needed in addition as well. The systematic way of designing has multiple advantages such as, the minimizing of jumping into solutions to soon and overlooking essential aspects. Additionally, it organizes the design process and provides an overview of the design activities.
Finally, it facilitates the decision-making which increases the chance of creating an effective product or system. The systematic approach of designing also brings disadvantages, such as limited room for creativity which results in a reduce in solution space. Ill-defined and complex problems also face problems with the systematic approach and the possibilities to learn from the design process is reduced. *The obstacle was the incentive for architects to develop their own approach as a scientific discipline* (Siers, 2004).

The Delft Design Approach

The engineering approach used in civil engineering is usually focused on a system. The project needs to be a solution for a societal problem. This problem is first investigated, followed by setting the design objective that solves the problem. The objective is formulated in an abstract manner and is described as the desired function of the product. The design process transforms this objective in a design.

This 'Delft design method' is taught to multiple generations of engineering students of the Delft University of technology and they brought it into their later carrier as an engineer. The approach is a typical engineering method and does not differ much from other methods. The approach starts with the desire to solve a problem in society. Firstly the exact problem is analyzed and what the desired situation should be, which results in the formulation of a design goal.

The characteristics of this Delft engineering method are that the problem is analyzed, which prevents jumping into solutions. Defining the system objective as a function also enables this. Additionally, the definition of requirements and boundary conditions makes the process comprehensible. The advantage is that the method is intuitive but also has a sequence of design phases that is logical and necessary for a design approach (Voorendt, 2017). The transformations of the functions into specific systems or structures is formed from broad to more detailed. The start of the design process can include concepts that are not the ideal picture or don't fit all the requirements, during the process these drawings are more elaborated and made fit into solutions that detailed, verified and evaluated, also known as innovative abduction (Roozenburg & Eekels, 1995). This process entails the development and optimization of multiple concepts that are evaluated and traded off. The concepts are improved with every design cycle as the iteration is done with more knowledge and insight. This could also be the case for the system definition. The cyclic character of the process gives more detail to de design as the process continues (Voorendt, 2015, 2017).

This cyclic process starts with the first cycle that focusses on the complete system. The cycle is repeated for the subsystems followed by the elements of the sub-subsystems. By phasing the design process and organizing the various activities that are needed to come to a solution, the various steps are clearly distinct and the process is well-ordered. In 1980, prof.ir. Jan Stuip distinguished the phases in the design process into formulating the problem definition, structuring, finding, shaping and dimensioning. These steps should be elaborated upon in numerous design cycles and with different levels of detail. This starts with the system level and ends with a very detailed design on component level (Voorendt, 2017).

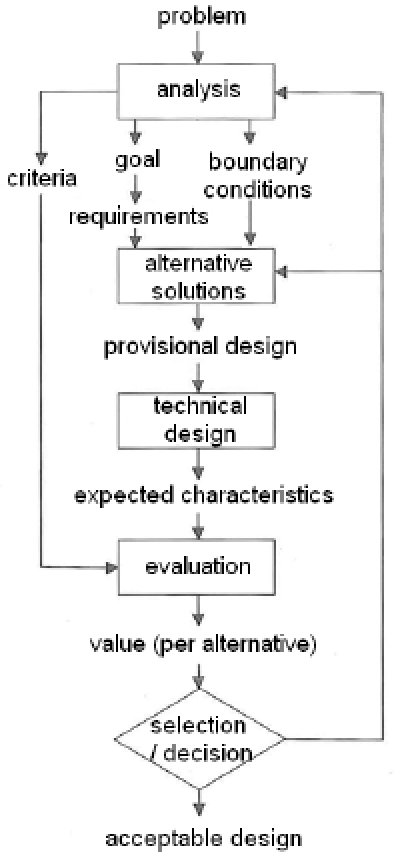


Figure 11: Visualization of the Delft Design method (Voorendt, 2015)

In the occurrence of a societal problem regarding infrastructure, there is an initiation to solve the issue. This is the starting point of the design cycle. In the Analysis phase, this problem is investigated and explored. It is important to know who are the holders of the problem and in which conditions it occurs. Besides this, the goal is formulated that states the desired situation and performance. According to this goal, functional requirements and boundary conditions of the desired system are formulated. The stakeholders and their interests are analyzed and the risks are inventoried. With the information gathered, a planning for the project is drawn up.

During the Synthesis, concepts are formulated that fit the solution space of the problem. If these concepts are realistic and fit all the requirements is not yet essential. To give as much design space as possible allows to give room for creativity and outside-of-the-box thinking. The design definition is in this phase transformed in shaped and materials through, for example, brainstorm sessions. Eventually, the concepts need to be verified and checked if the fit the goal, requirements and boundary conditions which happens in the next stage of the process.

The verification, as described, happens in the **Simulation** phase. The concepts that where created in the previous phase are checked against the project objective, requirements and boundary conditions formulated in the analysis phase according to the level of detail of the executed design loop. This can be done with models that represent reality or structural calculations to ensure the stability of the solution and determine its dimensions, depending on de detail of the design loop. When the concepts don't fit the requirements, they can be altered or dismissed if it isn't possible to make them a fit solution. There is also the possibility to combine elements from the different concepts into one or multiple new concepts that fit the requirements. The concepts that fit the requirements and are realistic become alternatives. The simulation phase therefore focusses on the feasibility of the concepts.

Following is the **Evaluation** phase, that is centered a review and feasibility of the alternatives. They fit the requirements but in this phase they are reviewed against the desires of the client and stakeholders. The added value of the different alternatives is reviewed according to various evaluation criteria that can have different level of importance. These values are countered against the cost to realize them. The costs and added value results in a ranking of the alternatives according to societal support. The evaluation phase can be carried out for example, with a multi-criteria analysis, cost benefit analysis or a broad debate, depending on the size and impact of the project.

The highest valued alternative can be selected in de **Decision** phase to elaborated upon in more detail in the next, more detailed, design cycle. This alternative is proposed to the client together with the benefits and consequences of choosing it. The next design cycle is based on the decision therefore it is important to be able to make a substantiated decision to avoid future re-engineering costs. This decision is usually a formal moment and reporting where stakeholders can oppose against if desired (Boeijen & Daalhuizen, 2017; Hertogh et al., 2018; Roozenburg & Eekels, 1995; Voorendt, 2015, 2017).

The design cycle in the model includes iteration steps that enable a feedback loop. When a solution from the previous steps in not desirable, because it doesn't comply with the requirements, the cycle should be redone and the previous steps are walked through again. This can be done at three points. Firstly, through the synthesis phase, where new solutions and concepts are generated with the new knowledge compared to the previous design cycle, therefor it has a large change of succeeding. The second option is to redo the cycle from the analysis phase, where new and more desirable criteria are formulated. This has also a good chance of succeeding because of the increase of knowledge compared to the previous design cycle. The final option is to restart both steps in the design cycle. In this case, more desirable requirements are generated and new concepts are created, both with more knowledge than in the previous design cycle. (Hertogh et al., 2018)

The design process is a cyclic process that works from broad to detailed. The level of detail is dependent of the starting scale of the content. In civil engineering we often distinguish 3 levels of scale: system level or macro scale, component level or meso scale and element level or micro scale. The system level is associated with large systems such as harbors, flood protection and rail- and highway infrastructure. These systems consist of multiple components that work together. These components can be associated with civil engineering objects such as bridges, buildings and weirs. The final scale is are the elements of these components. This is the detailed level of the elements and their coherence. It entails a more detailed description of the materials used, measurements and constructive connections. These scales can be used in the design method as levels of detail in the design, because the phase in designing also work from a broad system level to a detailed level. These design phases are the conceptual design, provisional design, final design and detailed or execution design and can be linked to the scale levels explained previously. The end of these phases are marked with a milestone that is characterized by the decision if the team can continue to the next design phase and an evaluation of the current phase (Hertogh et al., 2018).

The students of the faculty of Architecture at Delft University of Technology follow approximately the same stages of the of the Delft Design Approach. The difference in execution is that the steps are less explicit and a societal issue is not always the intention for starting the project. Students of the faculty of Industrial Design students use the approach formulated by Norbert Roozenburg and Johannes Eekels. This approach does not differ significant from the classic Delft method, with the exception for the terminology and the less importance of formulating various concepts (Voorendt, 2015).

Mark Voorendt: Design process for multipurpose flood defences

Dutch researcher at the Delft university of Technology, Mark Voorendt proposed a design process for multipurpose flood defenses that, besides the structural and flood defending aspects, integrates and considers the spatial aspects of the asset. The engineering design process is based on the approach of Roozenburg and Eekels (1995) . Voorendt considers these steps to be logical and essential for an effective and efficient design approach. The difference when spatial engineering is combined with flood defenses design is to ensure that in an early stage of the process it does not became too analytical, as this can leads to limiting the solution space unnecessary. The process should also not be only centered around creative activities as this results in an inefficient process that could leads to infeasible solutions. The design engineering method has an iterative character that gives the possibility to learn, improve and experiment in the early steps of the design. The design process for multipurpose flood defenses by Mark Voorendt is characterized with seven phases.

Phase 1: Exploration of the Problem

The design process starts with the exploration of the problem which is centered around the familiarization with the problem and its special context. Compared to the process of Roozenburg and Eekels, this phase is a lot less analytical. This makes this phase less prescriptive and explicit which leaves room to develop the concepts in phase two more creatively, leaving a wider solution space. The aim of this design phase is to formulate a initial design objective that gives an understanding of the problem faced and the expected performance of the solution in an abstract and functional manner and should also give guidance in desired sub-functions. Therefore it is important to understand who experiences the problem, when they experienced it and what are the circumstances, which results in the problem statement. Both the problem statement and the design objective are the starting point of the next phase.

Phase 2: Development of concepts

The second phase of the design approach is where the abstract design objective is converted into design concepts that includes shapes and materials. Multiple designs are creates in a conceptual manner and with a lot of space for creativity. This can be done in multiple way, for example with brainstorm sessions. The designs are sketched with the problem statement and the design objective in mind but this should not restrict the concepts to much as that could reduce creativity and the feasibility of them will be checked in a later stage of the process.

Phase 3: Functional specification

The third phase of the design method for multipurpose flood defenses is the functional specification. In this phase the design objective is specified. Besides specifying the desired function of the system in more detail, the circumstances in which it should function and the corresponding risks should be specified too. In This phase a *program of requirements & evaluation criteria* is drawn up. Besides this, an inventory of the boundary conditions, laws and regulations and risks is initiated and further developed. The level of detail of the functional specification should be corresponding to the detail of the design loop that is considered. The results are validated by the client.

Phase 4: Verification of the concepts

In the fourth phase, the concepts that are created in the second phase are verified against the requirements, risks and boundary conditions that are formulated in the previous phase.

Phase 5: Evaluation of alternatives

The method distinguishes concepts from alternatives. Concepts are defined by alternatives that are not yet verified. This results in that concepts can exists without meeting all the requirements. Alternatives are concepts that are approved in meeting the requirements throughout this phase of the design method, which is the first step. Secondly, by weighing out the values that will be created against the sacrifices these values need, the feasibility of the alternatives solutions is evaluated. Lastly, the alternatives are traded off against each other, for example with a multi-criteria analysis and the cost-benefit analysis.

Phase 6: Validation of the purposed solution

This design approach can be used at various levels of detail in the design process. Therefore it is of great importance to validate that the best alternative fits in the systems as a whole together with the costs, planning and spatial aspects. This validation is the affirmation that the intended functions are performed by the proposed system. To check whether the system objective and the upon based requirements still fits the desired solution is recommended.

Phase 7: Decision

The final phase of the method is where the preferred solution is presented and substantiated. If the client is satisfied with the preferred solution, a new design cycle can be started with a deeper level of detail (Voorendt, 2017).

Systems engineering design approach

Systems Engineering finds its origin in the 'General Systems Theory' of the English economist Kenneth Boulding and the biologist Ludwig von Bertalanffy. In order to understand complex issues, the theory utilize a system approach that focuses on the structure of the system. The approach structured engineering projects in a vertical and horizontal way, shown Figure 12 . The vertical path corresponds to the life phases of the structure where the horizontal path complements with the problem-solving processes. Dividing a project into phases created numerous interfaces, which can cause interface problems. It is of great importance to address these potential interface problems in the design stages of the system. The design method of civil engineering systems is described in the Dutch Guideline Systems Engineering (2013) is shown in Figure 13 and describes the design approach for engineering systems as an interdisciplinary approach to realize successful systems. The customer needs and required functionality are defined early in the development cycle. Followed by the design synthesis and system validation while considering the complete problem (Werkgroep Leidraad Systems Engineering, 2013). The Systems Engineering method considers the entire lifecycle of the system, from initiation to demolition or re-use and includes the organization of the full process (Voorendt, 2017). Although the entire of lifetime of the system is considered, this thesis focuses on the design of systems in the System Engineering method, this can be seen in the left part of Figure 12.

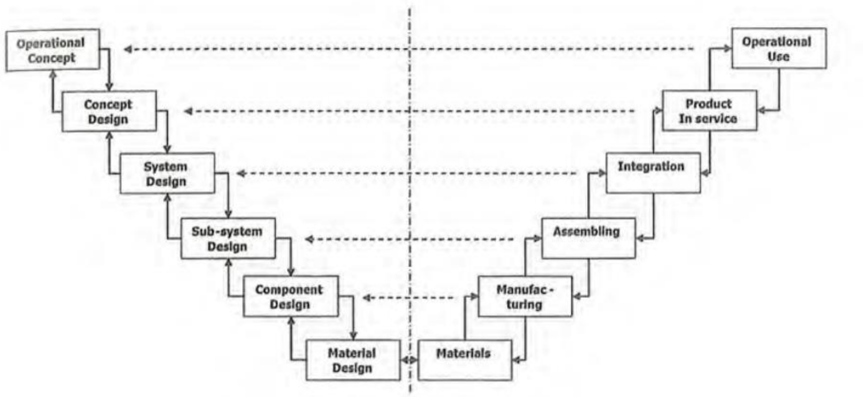


Figure 12: Systems Engineering V-model for the design and realization of systems (Wasson, 2016)

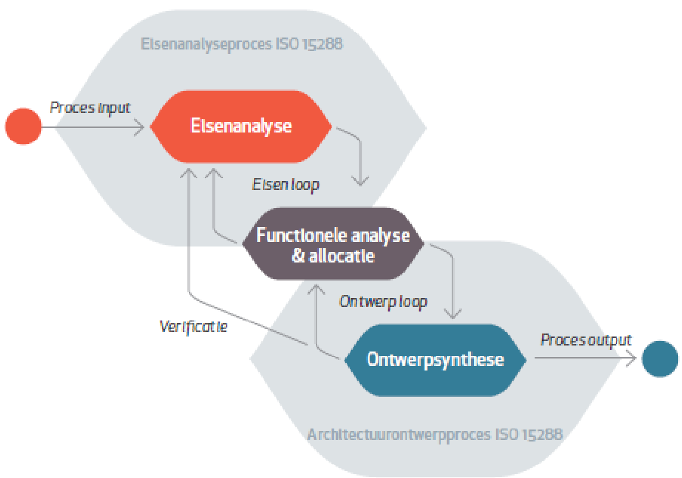


Figure 13: Design loop for Systems Engineering (Werkgroep Leidraad Systems Engineering, 2013)

The process for designing used in the Guideline Systems Engineering (2013) has similarities with the Delft Design method and the design method described by Roozenburg and Eekels. The same phases are followed although the Guideline Systems Engineering uses different terminology. Instead of design, the Guideline uses development and determining the requirements and possibilities is called specifying. Another difference is that the guideline does not distinct the stakeholder interest and the clients' interests as all the interest are included in the Customer Requirements Specification[9]. This specification describes the proposed functionality and the clients' the system of interest next to stakeholders requirements and the solution space that is available. Throughout the systems development, the specification is continuously updated and maintained and the specification is the

[9] In Dutch: Klant-Eisen Specificatie

base for developing the system. Integration of the various aspects of the system is not explicitly addressed, which is an important aspect to realize when applying the model.

The aspect of Validation & Verification is where Systems Engineering mostly differs from other models. The guideline describes the steps that are necessary to ensure and proof that the solution meets the clients' needs and is in line with the requirements. Verification in this sense means the check if the solution/ system can be well constructed and validation is the check if the right system is constructed (Voorendt, 2017).

Rijkswaterstaat MIRT Approach

In 2007 the Dutch government organized nationwide infrastructure in a multi-year program for infrastructure, Area and Transport[10] (MIRT). The investment includes the projects and programs in the spatial domain of the Ministries of Infrastructure and Environment, Economic Affairs, Agriculture and Innovation and Internal Affairs and Kingdom Relations in the field of housing, neighborhoods and integration. The aim of this program is to integrate the decision-making on nationwide infrastructure and spatial planning in a more efficient way and to improve the collaboration and alignment between the national government and regional government

PDCA-Cycle

To enable the quality assurance of MIRT projects, the design of an system works through a cyclic phasing with 4 steps. Each phase in the design process, the steps are repeated in with a deeper detail level. There steps are executed following the Plan, Do, Check, Act cycle. The first step is to Plan, which entails to organize the project by making requirements and ambitions explicit, determining a purchasing strategy and organizing the design process on the side of the client. Following, the next step is Do where the spatial design carried out by professional designers. In the third step, Check, the design is tested or assessed by experts, based on procurement requirements. If necessary, expert advice might be obtained. The final phase is Act, where the design results are accepted and determined the by the client. The design space and freedom for the next phase and the more detailed objective are discussed with the client (Enno Zuidema Stedebouw et al., 2011). The PDCA cycle of Rijkswaterstaat can be found in the guideline for 'Designing in MIRT' (Enno Zuidema Stedebouw et al., 2011). Although the Dutch Flood Protection Program tells to use a different method, more in line with the previously described Delft Design approach (Boeijen & Daalhuizen, 2017; Hertogh et al., 2018; Voorendt, 2015) and the method of Roozenburg and Eekels (1995).

The PDCA cycle is an approach for improvement that consist of 4 steps: Plan, Do, Check, Act. Multiple studies categorize this cycle as an management or process approach, not as a design cycle. It is discussed in this study because Rijkswaterstaat uses the approach as a method to improve their design. The method had a iterative character and can be repeatedly executed throughout different detail levels. The method starts with the **Plan** phase where the problem definition is formulated and the objectives to enable a desired result is formulated. Additionally, the occurring situation is studied and a cause-effect analysis is carried out. In the next **Do** phase the solutions are thought of and, depending on the detail level, carried out. In the following **Check** phase, the effects of the solutions

[10] In Dutch: Meerjarenprogramma Infrastructuur, Ruimte en Transport

are researched and in the final **Act** where the results are evaluated and the solutions are improved and adjusted (Hardjono & Bakker, 2011).

Six steps for sustainable GWW

The ministry of Infrastructure and Water management kickstarted the implementation of circularity with the guide to sustainability for MIRT projects. The aim is to implement these subjects by utilizing the six steps in the approach for sustainable land, road and water engineering (GWW[11]). These steps are visualized in Figure 14 and shows the outline of the sustainable GWW approach. The steps are arranged in a phase but are also followed, on a more detailed level, within each phase (Ministerie van Infrastructuur en Waterstaat, 2017). It is remarkable that the arrangement in phases can differ per studied document as the figure shows. In the guide for sustainable MIRT projects the exploration and the plan development phase start with an analysis of the demand and the ambitions, followed by investigating the opportunities and establishing project-specific ambitions with the required level of detail of the specific phase (Rijkswaterstaat, 2018b). The course for the use of the sustainability calculation program DuboCalc shows a different distinction in phases for MIRT projects where the first three steps are made in the exploration and plan phase and the final three steps are for the contract preparation phase (Rijkswaterstaat, 2019b). The core of the design process with the public client is funnelling by starting broadly and work towards a detailed, feasible project through transparent decision-making. At the end of a phase, directors involved decide which solutions needs more detail in the next phase and which one do not go to the next phase. The funnel changes the abstract level at which sustainability is given substance: from urgency and ambitions in the initiation phase, trough spatial impact in the exploration phase to measures and a design in the plan phase. The guide for sustainable GWW describes the design process in six steps, showed in Figure 14. A more detailed description of each step is not encountered, however the implications of each step are similar to the design approach described by Roozenburg and Eekels and the Delft Design method. However, the approach does not distinct a feedback loop, which is of importance to find an optimal design. The steps can be used for the different phases, but can also be walked through cyclic and multiple times within each phase (Ministerie van Infrastructuur en Waterstaat, 2017). This design process is used as a starting point for this research because it is already known among the Dutch public clients.

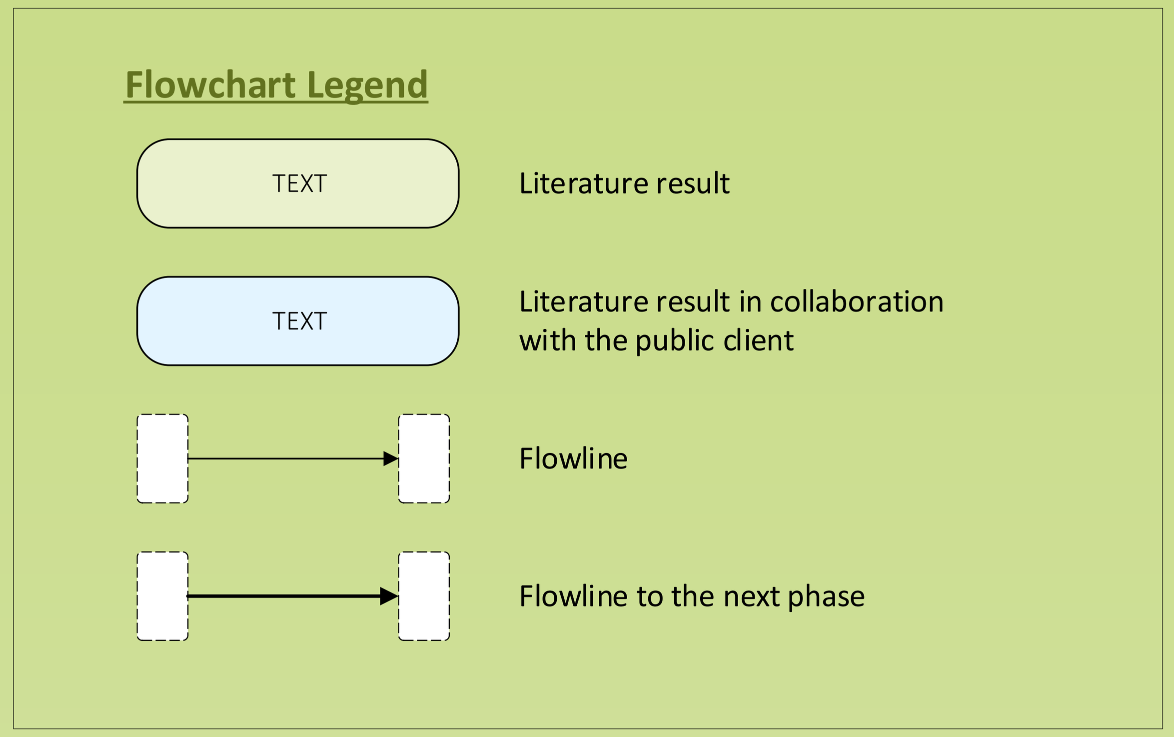
Figure 14: Six steps for sustainable GWW (Ministerie van Infrastructuur en Waterstaat, 2017)

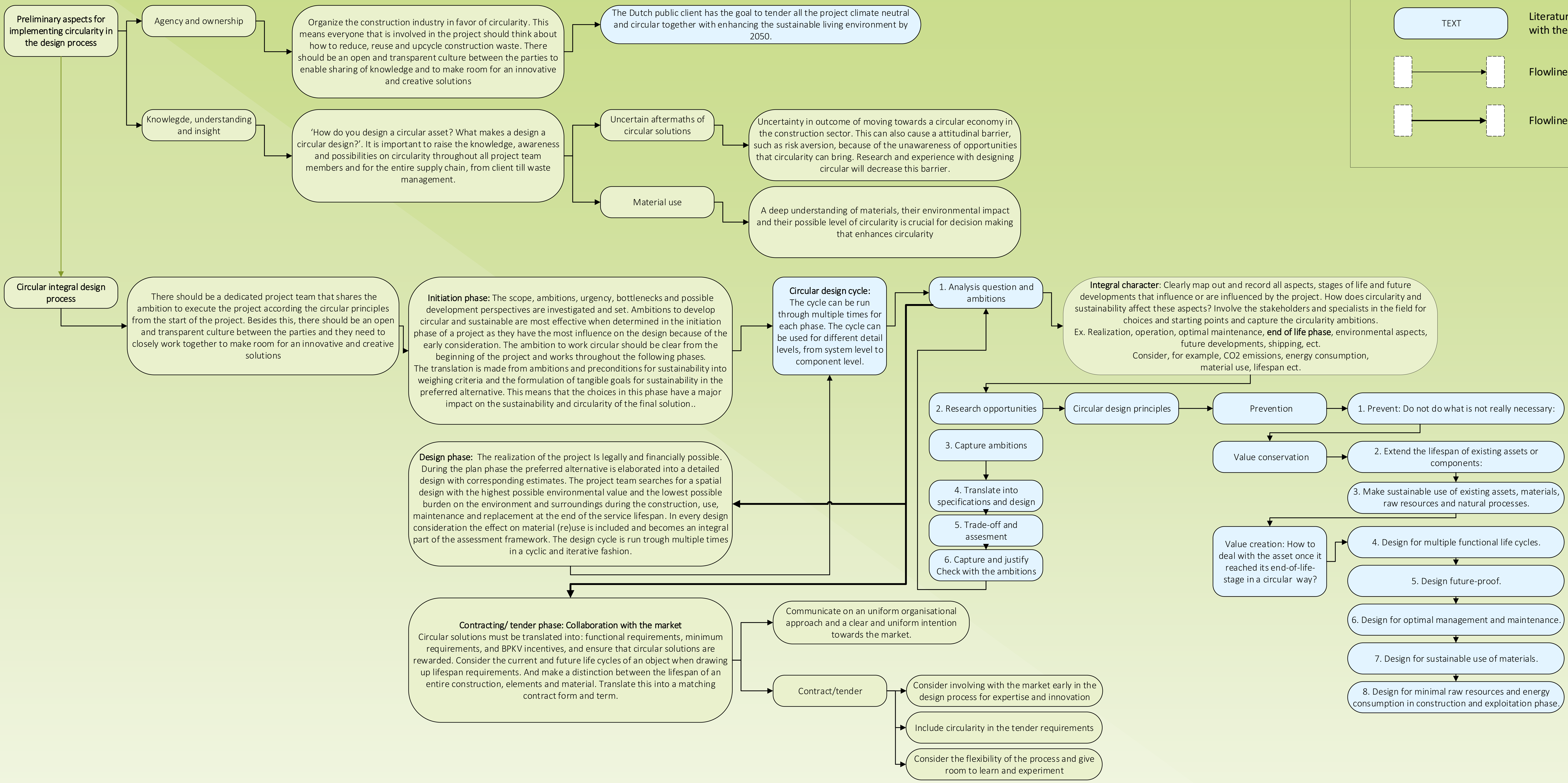
[11] In Dutch: Grond-, Weg- en Waterbouw

Appendix B: Flowchart for implementing circularity in the design process of the public client (Literature based)

Flowchart: Implementing circularity in the design process of the public client (Literature)

Premises:
- An integral design process
- Sufficient capacity (Time/people/budget)





Appendix C: Research results

Interview protocol

<u>Mijn achtergrond / onderzoek</u>

- HBO CT / CME TU Delft
- Master scriptie
- Duurzaamheid erg belangrijk, geïnteresseerd in het ontwikkel proces van een asset.
- Hoe kan circulariteit een plek krijgen in het ontwerp proces van de publieke opdrachtgever?

Doel van het onderzoek is om circulariteit een effectieve plek in het ontwerp proces te geven, daarom zou ik graag met u spreken over de ervaringen die u heeft met circulariteit en hoe u dit toepast binnen uw werk. Ik ben benieuwd naar uw eigen inzichten vanuit uw afdeling/werk.
Ik zal het interview gebruiken voor mijn resultaten maar geen namen of quotes noemen, alleen algemene uitkomsten. Mocht u het fijn vinden kan ik de uitkomsten van dit interview of van de totale interview naar u toesturen.
Ik zou graag over een aantal topics met u spreken. Als eerst over uw eigen werk en positie binnen Rijkswaterstaat, het ontwerp proces van Rijkswaterstaat en de plek die circulariteit daarin inneemt. Ik zie graag antwoorden op vragen vanuit uw eigen werk en eigen ervaring.
Aanvinken welke van toepassing is in dit interview:

- Technisch manager
- Advies manager
- …………………………

- Scope / Gebiedsagenda
- Verkenning
- Planstudie
- Contract
- Realisatie
- Onderhoud
- Groot onderhoud / Renovatie
- Circulariteit

Ik zou graag dit onderzoek willen opnemen, heeft u hier bezwaren tegen?

Kunt u kort uw dagelijkse werkzaamheden beschrijven, kort uw werk toelichten en de ontwerp fases waarin u betrokken bent?

Kunt u iets vertellen over uw ervaringen van het ontwerpproces van RWS?

- Kunt u voor mij het RWS ontwerpproces omschrijven? Hoe ontwerpt RWS nu?
- Hoe integraal zou u de projecten van Rijkswaterstaat omschrijven?

Wat is uw ervaring met de implementatie van circulariteit binnen de projecten van RWS?

En hoe ziet u de implementatie van circulariteit binnen her ontwerpproces van RWS en de plek die het inneemt?

- Bent u bekend met de besluitvorming van de overheid op circulariteit?
- Wat is uw mening over de manier waarop circulariteit op dit moment in uw werk geïntegreerd is?
- Welke tools gebruikt u nu om circulariteit in uw werk mee te nemen?

Kunt u aangeven wat u verstaat onder duurzaamheid / circulariteit in uw werk?

- Waar denkt u dat circulariteit thuishoort in het ontwerp proces?
- Welke rol denkt u dat contract vormen spelen bij de implementatie van circulariteit?
- Hoe ziet u de samenwerking met de markt wat betreft de verantwoordelijkheid voor de implementatie van circulariteit in infrastructuur projecten?
- Hoe ziet u circulariteit?:
    - onderdeel van het project doel
    - ambitie,
    - randvoorwaarde,
    - eis
    - criteria
    - functie
- Denkt u dat er genoeg kennis in huis is voor het implementeren van circulariteit?

Waar denkt u dat de obstakels zitten voor het implementeren van circulariteit in het ontwerp proces?

Zou u het op prijs stellen om de conclusies uit uw of de algemene conclusies over dit onderzoek te ontvangen?

1. Groundedness Table

2. Co-occurance Table

3. Document-code Table

Code	Grounded
Group: Integral character	
Timing of including CE in the process	30
Integration in the project assignment	29
Collaboration with the market	24
Leaving it as optional to the market	21
Integral character of the disciplines	20
Integral character of the lifecycles	19
Pointing to other RWS departments	19
Need for a feedback loop and flexibility in the process	18
Need for a long term perspective	16
No design from a CE perspective	15
Need to connect projects	11
Need for good maintenance	9
Verification on CE with the contractor	9
Broader vision on sustainability, including all aspects	9
End-of-life state not considered	8
Trade off on CE	8
Integral contracts	7
Cost considered but not the opportunities	5
Group: Knowledge	
Lack of CE knowledge and guidelines	18
No/hard measurability of CE	14
Unclear/wrong definition and purpose of CE	14
Promote and monitor CE pilots	13
Learn and share experience	11
Capacity CE advisors	8
Focus on line-infrastructure with CE and not on hydraulic infrastructure	5
Lack of knowledge of assets	15

Code	Grounded
Group: Capacity and support	
Capacity needed for CE implementation	48
Budget and time is leading	30
Integration in the project assignment	29
Responsibility of implementing CE	29
Need for a company wide-approach on CE	22
Depending on individual motivation for CE	19
Support for implementing CE	19
Low priority of CE	18
Need for a platform and space for reusable materials	18
Promote and monitor CE pilots	13
Learn and share experience	11
Conservative culture	9
Capacity CE advisors	8
No CE in current work	6
No support in using used materials	6
Group: Uncertainty and risks	
Risk avoidance and uncertain outcomes	17
Uncertain future developments	11
Conservative culture	9
Group: Category of CE	
CE as criteria/ requirement	4
CE as a tool	4
CE as a project goal	3

	Budget and time is leading Gr=30	Capacity CE advisors Gr=8	Capacity needed for CE implementation Gr=48	Collaboration with the market Gr=24	Conservative culture Gr=9	Depending on individual motivation for CE Gr=19	Integral character of the disciplines Gr=20	Integral character of the lifecycles Gr=19	Integral contracts Gr=7	Integration in the project assignment Gr=29	Lack of CE knowledge and guidelines Gr=18	Lack of knowledge of assets Gr=15	Learn and share experience Gr=11	Leaving it as optional to the market Gr=21	Low priority of CE Gr=18	Need for a company-wide approach on CE Gr=22	Need for a feedback loop and flexibility in the process Gr=18	Need for a long term perspective Gr=16	Need for a platform and space for reusable materials Gr=18	Need to connect projects Gr=11	No design from a CE perspective Gr=15	No set space for RWS Ontwerpt Gr=9	No/hard measurability of CE Gr=14	Pointing to other RWS departments Gr=19	Promote and monitor CE pilots Gr=13	Responsibility of implementing CE Gr=29	Risk avoidance and uncertain outcomes Gr=17	Support for implementing CE Gr=19	Timing of including CE in the process Gr=30	Uncertain future developments Gr=11	Unclear/wrong definition and purpose of CE
Budget and time is leading Gr=30	0	1	8	3	0	1	1	0	0	1	0	1	1	1	2	3	2	2	0	1	0	0	0	1	1	2	2	2	1	2	0
Capacity CE advisors Gr=8	1	0	3	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	3	1	0
Capacity needed for CE implementation Gr=48	8	3	0	4	0	1	2	1	0	5	1	3	2	2	4	4	2	1	1	1	0	1	1	1	2	4	2	8	6	0	0
Collaboration with the market Gr=24	3	0	4	0	1	0	0	3	2	0	0	1	0	3	0	0	0	0	0	0	0	1	0	0	0	1	2	0	0	0	0
Conservative culture Gr=9	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	3	0	1	0	0
Depending on individual motivation for CE Gr=19	1	1	1	0	1	0	1	0	0	5	0	0	0	2	0	4	0	0	0	0	0	0	0	0	0	4	1	5	1	0	0
Integral character of the disciplines Gr=20	1	0	2	0	0	1	0	5	0	3	0	0	1	1	1	1	1	2	0	2	2	1	0	3	0	1	1	0	1	0	0
Integral character of the lifecycles Gr=19	0	0	1	3	0	0	5	0	0	3	0	0	0	1	0	1	1	3	0	0	1	1	0	3	0	2	0	0	1	0	1
Integral contracts Gr=7	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	1	0	0	2	0
Integration in the project assignment Gr=29	1	0	5	0	0	5	3	3	0	0	0	0	0	3	3	6	1	3	3	0	1	0	0	4	0	7	2	2	3	0	1
Lack of CE knowledge and guidelines Gr=18	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	4	0	0	1	2	0	2	1	2
Lack of knowledge of assets Gr=15	1	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	0	0	0	0	0	3	2	0	1	2	0	0
Learn and share experience Gr=11	1	0	2	0	0	0	1	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	1	0	7	2	0	0	0	0	0
Leaving it as optional to the market Gr=21	1	0	2	3	0	2	1	1	0	3	1	0	0	0	1	2	0	0	0	0	1	0	1	0	0	1	0	0	1	0	0
Low priority of CE Gr=18	2	0	4	0	0	0	1	0	0	3	0	0	0	1	0	0	1	0	0	0	4	2	0	0	0	1	1	1	0	0	0
Need for a company-wide approach on CE Gr=22	3	1	4	0	0	4	1	1	0	6	1	0	1	2	0	0	1	2	2	2	0	0	1	1	1	4	0	1	1	0	0
Need for a feedback loop and flexibility in the process Gr=18	2	0	2	0	0	0	1	1	3	1	0	2	2	0	1	1	0	0	0	0	0	4	1	1	1	2	0	0	4	2	0
Need for a long term perspective Gr=16	2	0	1	0	0	0	2	3	0	3	0	1	0	0	0	2	0	0	0	0	0	0	1	1	0	0	1	0	0	3	0
Need for a platform and space for reusable materials Gr=18	0	0	1	0	0	0	0	0	0	3	0	1	0	0	0	2	0	0	0	5	0	0	0	0	1	3	2	0	1	0	0
Need to connect projects Gr=11	1	0	1	0	0	0	2	0	0	0	0	0	0	0	0	2	0	0	5	0	0	0	0	1	0	0	0	0	0	0	0
No design from a CE perspective Gr=15	0	0	0	0	2	0	2	1	0	1	0	0	0	1	4	0	0	0	0	0	0	1	0	0	0	0	0	0	3	0	0
No set space for RWS Ontwerpt Gr=9	0	0	1	1	0	0	1	1	0	0	0	0	0	0	2	0	4	0	0	0	1	0	0	0	0	1	0	0	0	0	0
No/hard measurability of CE Gr=14	0	0	1	0	0	0	0	0	0	0	4	0	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	2
Pointing to other RWS departments Gr=19	1	0	1	0	0	0	3	3	0	4	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	1	0	0	2	0	3
Promote and monitor CE pilots Gr=13	1	0	2	0	0	0	0	0	0	0	0	3	7	0	0	1	1	0	1	0	0	0	0	0	0	4	0	1	0	0	0
Responsibility of implementing CE Gr=29	2	0	4	1	0	4	1	2	0	7	1	2	2	1	1	4	2	0	3	0	0	1	0	1	4	0	2	3	2	0	0
Risk avoidance and uncertain outcomes Gr=17	2	0	2	2	3	1	1	0	1	2	2	0	0	0	1	0	0	1	2	0	0	0	0	0	0	2	0	2	0	1	0
Support for implementing CE Gr=19	2	1	8	0	0	5	0	0	0	2	0	1	0	0	1	1	0	0	0	0	0	0	1	0	1	3	2	0	1	0	0
Timing of including CE in the process Gr=30	1	3	6	0	1	1	1	1	0	3	2	2	0	1	0	1	4	0	1	0	3	0	0	2	0	2	0	1	0	1	0
Uncertain future developments Gr=11	2	1	0	0	0	0	0	0	2	0	1	0	0	0	0	0	2	3	0	0	0	0	0	0	0	0	1	0	1	0	0
Unclear/wrong definition and purpose of CE Gr=14	0	0	0	0	0	0	0	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	2	3	0	0	0	0	0	0	0

	Exploration phase Gr=95; GS=6	Planstudy phase Gr=184; GS=8	Contract phase Gr=91; GS=4	Construction phase Gr=38; GS=2	Exploitation and maintenance phase Gr=65; GS=3	TM Gr=153; GS=7	ATM Gr=83; GS=5	Assetmanager Gr=19; GS=1	Sustainability advisor / CE advisor Gr=113; GS=4	GPO Gr=82; GS=3	PPO Gr=85; GS=5	Totals
● Broader vision on sustainability, including all aspects Gr=9	7	7	3	2	0	0	6	0	3	0	0	28
● Collaboration with the market Gr=24	8	10	10	3	6	9	2	0	13	1	8	70
● Cost considered but not the opportunities Gr=5	3	4	2	0	0	1	1	0	3	1	0	15
● End-of-life state not considered Gr=8	2	6	1	1	0	5	2	1	0	4	1	23
● Integral character of the disciplines Gr=20	5	9	6	5	2	10	4	1	5	4	6	57
● Integral character of the lifecycles Gr=19	6	9	4	1	6	11	4	1	3	5	8	58
● Integral contracts Gr=7	0	6	0	0	6	2	5	0	0	1	1	21
● Integration in the project assignment Gr=29	7	14	5	4	6	16	6	1	6	7	9	81
● Leaving it as optional to the market Gr=21	4	5	9	5	2	9	3	2	7	1	8	55
● Need for a feedback loop and flexibility in the process Gr=18	8	14	1	0	6	2	12	2	2	7	1	55
● Need for a long term perspective Gr=16	11	12	5	3	0	3	9	0	4	1	2	50
● Need for good maintenance Gr=9	0	1	3	1	4	7	0	0	2	1	6	25
● Need to connect projects Gr=11	4	7	3	1	0	4	2	0	5	3	1	30
● No design from a CE perspective Gr=15	1	11	3	2	4	8	3	0	4	7	1	44
● Timing of including CE in the process Gr=30	6	16	5	2	2	11	5	6	8	10	2	73
● Trade off on CE Gr=8	2	5	2	1	0	3	1	0	4	3	0	21
● Pointing to other RWS departments Gr=19	0	2	12	4	4	18	0	1	0	2	16	59
● Verification on CE with the contractor Gr=9	0	4	3	2	0	5	0	1	3	4	1	23
● Budget and time is leading Gr=30	10	16	9	3	2	11	8	2	9	6	6	82
● Capacity needed for CE implementation Gr=48	11	23	13	5	8	19	8	1	20	10	10	128
● Capacity CE advisors Gr=8	0	5	1	1	0	5	0	1	2	5	0	20
● Lack of CE knowledge and guidelines Gr=18	2	10	1	1	3	11	2	1	4	8	3	46
● No/hard measurability of CE Gr=14	7	7	2	2	3	3	7	0	4	4	3	42
● Unclear/wrong definition and purpose of CE Gr=14	4	7	5	3	4	8	4	0	2	4	6	47
● Uncertain future developments Gr=11	4	8	3	3	2	2	6	0	3	2	0	33
● Lack of knowledge of assets Gr=15	10	10	9	1	0	2	3	0	10	0	2	47
● Risk avoidance and uncertain outcomes Gr=17	6	10	3	1	4	0	8	0	9	0	0	41
● Responsibility of implementing CE Gr=29	8	15	9	4	4	12	6	4	7	5	7	81
● CE as a project goal Gr=3	1	2	0	0	1	2	1	0	0	2	1	10
● CE as a tool Gr=4	1	1	3	2	0	0	0	0	4	0	0	11
● CE as criteria/ requirement Gr=4	1	3	0	0	1	3	1	0	0	2	1	12
○ Conservative culture Gr=9	2	8	0	0	5	1	7	0	1	1	0	25
○ Depending on individual motivation for CE Gr=19	3	7	3	1	3	8	1	0	10	4	4	44
○ Focus on line-infrastructure with CE and not on hydraulic infrastructure Gr=5	2	4	0	0	1	3	2	0	0	2	1	15
○ Learn and share experience Gr=11	4	5	1	1	1	1	5	2	3	3	1	27
○ Low priority of CE Gr=18	3	7	4	3	5	12	3	0	3	5	8	53
○ Need for a company-wide approach on CE Gr=22	9	15	5	3	2	10	7	0	5	8	4	68
○ Need for a platform and space for reusable materials Gr=18	3	8	6	3	1	8	3	1	6	4	4	47
○ No CE in current work Gr=6	1	1	2	0	3	5	1	0	0	0	5	18
○ No set space for RWS Ontwerpt Gr=9	5	6	0	0	3	4	5	0	0	6	3	32
○ No support in using used materials Gr=6	3	3	2	1	0	0	2	0	4	0	0	15
○ Problem with design guidelines Gr=12	1	9	1	0	3	7	2	1	2	6	1	33
○ Promote and monitor CE pilots Gr=13	5	6	1	0	2	1	5	2	5	2	1	30
○ Support for implementing CE Gr=19	6	8	6	1	1	4	1	0	14	2	2	45
Totals	186	346	166	76	110	266	163	31	199	153	144	1840

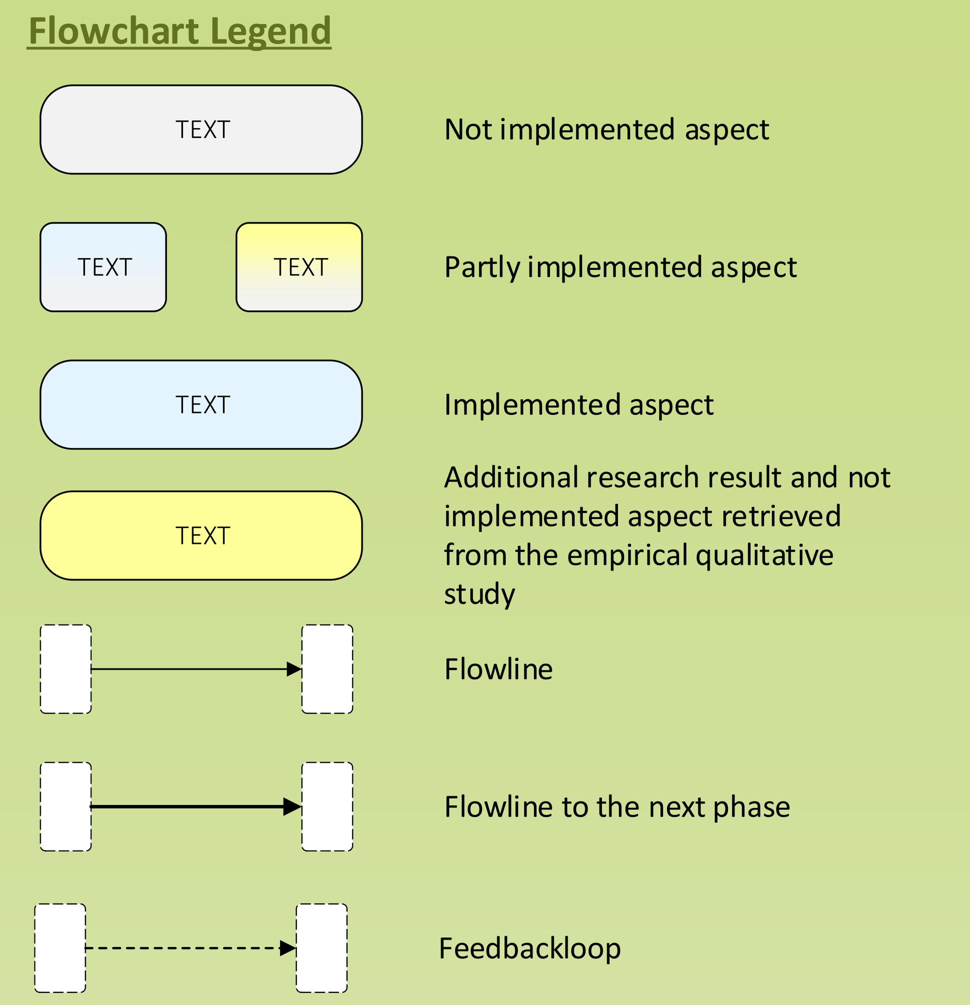
Appendix D: Flowchart for implementing circularity in the design process of the public client (Literature VS Rijkwaterstaat)

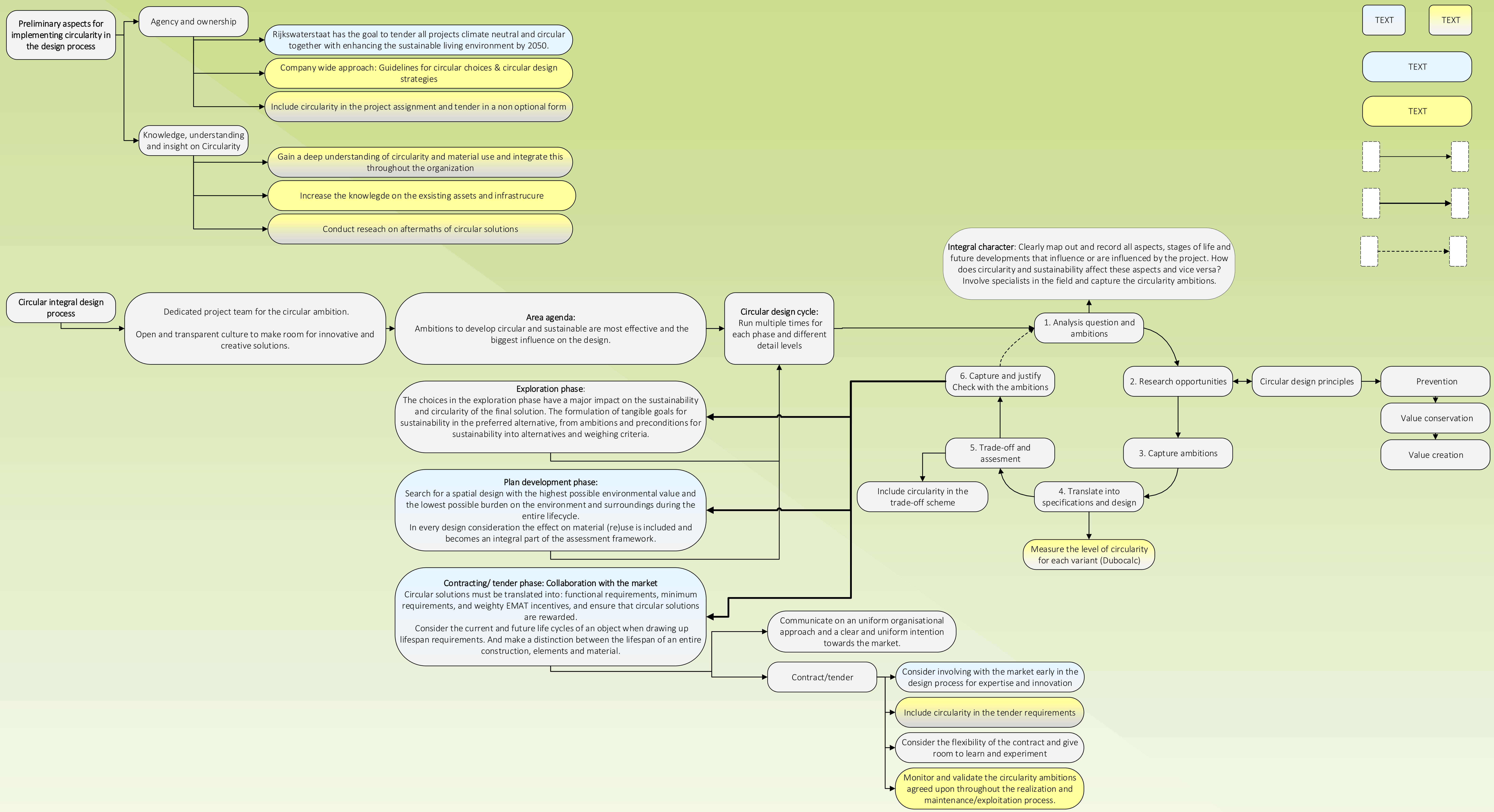
Flowchart: Implementing circularity in the design process of the public client (Current practice)

Appendix E: Flowchart for implementing circularity in the design process of Rijkwaterstaat (Inluding guidelines)

Flowchart: Implementing circularity in the design process of the public client

Premises:
- An integral design process
- Sufficient capacity (Time/people/budget)





Circularity in the Design process of the public client:

To include circularity in the design process of the public client, a flowchart is drafted. This document is a guideline for the use of the flowchart. This flowchart is based on the premises that there is an integral design process in which circularity needs to be included and there is sufficient capacity in time, people and budget to explore the possibilities of a circular design. Once circularity is embedded in the common practice of the public client, this capacity will probably be less crucial.

Preliminary aspects

To include circularity, two preliminary aspects for implementation should be considered:

- A clear responsibility for circularity. To organize the construction industry in favor of circularity, everyone that is involved in the project should consider how to reduce, reuse and upcycle construction waste. There should be an open and transparent culture between the parties to enable sharing of knowledge and to make room for an innovative and creative solutions
  - Rijkswaterstaat has the goal to tender all projects climate neutral and circular together with enhancing the sustainable living environment by 2050. The steps to achieve this should be clear for the whole construction sector so they can anticipate on this.
  - Companywide approach: Guidelines for circular choices & circular design strategies to guide the project teams into making circular choices in the design process in each phase from the start.
  - Include circularity in the project assignment and tender in a non-optional form

- Knowledge, understanding and insight on circularity. How do you design a circular asset and what makes a design a circular design, are questions that need to be clear for project team members. It is important to increase knowledge, awareness and possibilities on circularity throughout the entire supply chain, from client until waste management.
  - A deep understanding of circularity, materials, their environmental impact and their possible level of circularity is crucial for decision making that enhances circularity.
  - Research and monitoring to the existing infrastructure assets to be able to accurate estimate the remaining lifespan of the asset or the asset components and a material passport for structures with a platform to enhance the use of second-hand materials and assure the materials quality information
  - Uncertain aftermaths of circular solutions. This can also cause an attitudinal barrier, such as risk aversion, because of the unawareness of opportunities that circularity can bring. Research and experience with designing circular decreases this barrier.

Circularity in the design process:

There should be a dedicated project team that shares the ambition to execute the project according the circular principles from the start of the project. Besides this, there should be an open and transparent culture between the parties as they need to work together closely to make room for innovative and creative solutions

Initiation phase: The scope, ambitions, urgency, bottlenecks and possible development perspectives are investigated and set. Ambitions to develop circular and sustainable are most effective when determined in the initiation phase of a project as they have the most influence on the design because of the early consideration. The ambition to work circular should be clear from the beginning of the project and works throughout the following phases. The circular design cycle is run trough to explore and set circular possibilities considering the area of the project and possible opportunities.

Exploration phase: The translation is made from ambitions and preconditions for sustainability into alternatives and weighing criteria and the formulation of tangible goals for sustainability in the preferred alternative. This means that the choices in the exploration phase have a major impact on the sustainability and circularity of the final solution. The phase is embodied by the description of the feasibility and necessity of the project and the costs and benefits of the preferred solution. The circular design cycle is run through to explore and set circular possibilities.

Plan phase: The realization of the project Is legally and financially possible. During the plan phase the preferred alternative is elaborated into a detailed design with corresponding estimates. The project team searches for a spatial design with the highest possible environmental value and the lowest possible burden on the environment and surroundings during the construction, use, maintenance and replacement at the end of the service lifespan. In every design consideration the effect on material (re)use is included and becomes an integral part of the assessment framework. The circular design cycle is run through to explore and set circular possibilities for different detail levels.

Circular design cycle:

To include circularity in the integral design process, it is of importance to consider circularity as an integral part. The design cycle guides to do this and can be run trough multiple times in each phase for different detail levels. The cycle works in a cyclic and iterative manner.

Step 1: Analysis question and ambitions

- Integral character: Clearly map out and record all aspects, stages of life and future developments that influence or are influenced by the project. How does circularity and sustainability affect these aspects? Involve specialists and capture the circularity ambitions. For example: Realization, operation, optimal maintenance, end of life phase, environmental aspects, future developments, shipping, area developments ect.
- Consider, for example, CO2 emissions, energy consumption, material use, lifespan ect.

Step 2: Research opportunities while considering the circular design principles. The principles work from top down, from most circular to less circular.

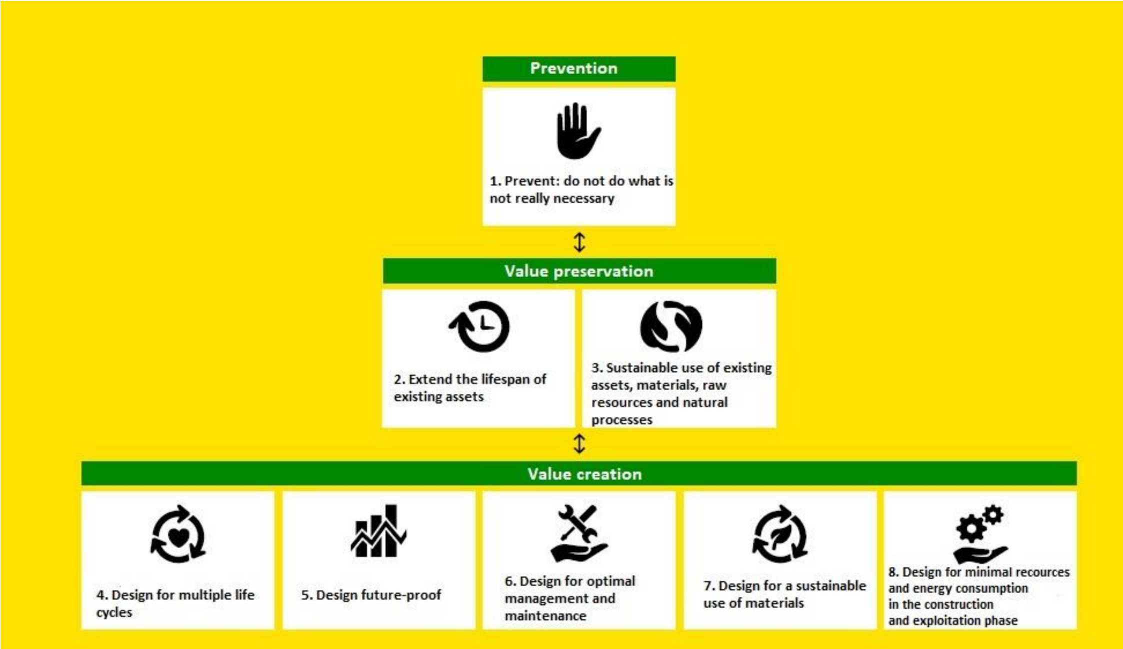


Figure 1: Eight design principles of Circularity (Rijkswaterstaat, 2019a, 2020)

- Prevention: 1. Do not do what is not really necessary
- Value conservation:
  - 2. Extend the lifespan of existing assets or components.
  - 3. Make sustainable use of existing assets, materials, raw resources and natural processes.
- Value creation: How will be dealt with the asset once it reached its end-of-life-stage in a circular way?
  - 4. Design for multiple functional life cycles: The desirable lifespan of an asset depends on the certainty of future developments or when it comes to the realization of a temporary construction. This is the starting point for the design strategy for multiple functional life cycles such as a modular, adaptable or robust design
  - 5. Design future-proof.
  - 6. Design for optimal management and maintenance.
  - 7. Design for sustainable use of materials.
  - 8. Design for minimal raw resources and energy consumption in construction and exploitation phase.

Step 3: Capture ambitions

Step 4: Translate into specifications and design
- Measure the level of circularity for each variant (Dubocalc)

Step 5: Trade-off and assessment
- Include circularity in the trade-off scheme

Step 6: Capture and justify

- Check with the ambitions to create a feedback loop in the design process

The design cycle can be run through multiple times for each phase and for different levels of detail. In this way, circularity is explicitly considered for each design decision.

Contracting/ tender phase: Consider the current and future life cycles of an object when drawing up lifespan requirements. And make a distinction between the lifespan of an entire construction, elements and material. Translate this into a matching contract form and term. Circular solutions must be translated into functional requirements, minimum requirements, and EMAT incentives. When circularity is captured in the EMAT incentives, the incentive must have a substantial bonus to avoid non circular options to win the tender.

- Communicate on an uniform organisational approach and a clear and uniform intention on circularity towards the market to enable them to anticipate.
- Consider involving with the market early in the design process for expertise and innovation
- Include circularity in the tender requirements
- Consider the flexibility of the contract and give room to learn and experiment
- Monitor and validate the circularity ambitions agreed upon throughout the realization and maintenance/exploitation process.

Stroomschema: Implementatie van circulariteit in het ontwerpproces van de publieke opdrachtgever

Circulariteit in het ontwerpproces van de publieke opdrachtgever:

Om circulariteit op te nemen in het ontwerpproces van de publieke opdrachtgever is een stroomschema opgesteld. Dit document is een handleiding voor het gebruik van het stroomschema. Het stroomschema gaat uit van de voorwaarde dat er een integraal ontwerpproces is waarin circulariteit moet worden meegenomen en er voldoende capaciteit is in tijd en budget om de mogelijkheden van een circulair ontwerp te verkennen. Zodra circulariteit is ingebed in de werkwijze van de publieke opdrachtgever, zal deze benodigde capaciteit waarschijnlijk minder substantieel worden.

Voorbereidende aspecten

Om circulariteit op te nemen in het ontwerpproces zijn twee voorafgaande aspecten van belang voor de implementatie:

- Een duidelijke verantwoordelijkheid voor circulariteit. Om de bouwsector ten gunste van circulariteit te organiseren, moet iedereen die bij het project betrokken is, nadenken over hoe bouwafval kan worden verminderd, hergebruikt en upcycled. Er moet een open en transparante cultuur zijn tussen de partijen om kennisdeling mogelijk te maken en ruimte te maken voor een innovatieve en creatieve oplossingen.
    - Rijkswaterstaat heeft als doel om in 2050 alle projecten klimaatneutraal en circulair aan te besteden in combinatie met het versterken van de duurzame leefomgeving. De stappen om dit te bereiken moeten voor de hele bouwsector duidelijk zijn, zodat zij hierop kunnen anticiperen.
    - Organisatie brede aanpak: Richtlijnen voor circulaire keuzes & circulaire ontwerpstrategieën om de projectteams te begeleiden in het maken van circulaire keuzes in het ontwerpproces voor elke fase vanaf de start van het project.
    - Circulariteit opnemen in de projectopdrachten en aanbestedingen in een niet-optionele vorm

- Kennis, begrip en inzicht over circulariteit. Hoe ontwerp je een circulair asset en wat maakt een ontwerp een circulair ontwerp, zijn vragen die helder moeten zijn voor de projectteamleden. Het is belangrijk om kennis, inzicht en mogelijkheden over circulariteit te brengen in de hele keten, van opdrachtgever tot afvalmanagement.
    - Diepgaand inzicht in circulariteit, materialen, hun milieu-impact en hun mogelijke mate van circulariteit is cruciaal voor besluitvorming die circulariteit bevordert.
    - Onderzoek en monitoring naar de bestaande infrastructuur assets om een nauwkeurige inschatting te kunnen maken van de resterende levensduur van een object of diens componenten en een materialenpaspoort voor constructies met een platform om het gebruik van tweedehands materialen te verbeteren en de informatie over de materiaalkwaliteit te borgen.
    - Onzekerheid in de nasleep van circulaire oplossingen. Dit kan ook een houding- en gedragsbarrière veroorzaken, zoals risicomijding, vanwege de onwetendheid van kansen die circulariteit kan brengen. Onderzoek en ervaring met circulair ontwerpen vermindert deze barrière.

Circulariteit in het ontwerpproces:

Er moet een toegewijd projectteam zijn dat de ambitie deelt om vanaf de start van het project volgens de circulaire principes te werken. Daarnaast moet er een open en transparante cultuur zijn tussen de partijen om ruimte te maken voor innovatieve en creatieve oplossingen

Initiatieffase: De scope, ambities, urgentie, knelpunten en mogelijke ontwikkelingsperspectieven worden onderzocht en vastgesteld. Ambities om circulair en duurzaam te ontwikkelen zijn het meest effectief als ze in de initiatieffase van een project worden bepaald, omdat ze door de vroege afweging de meeste invloed hebben op het ontwerp. De ambitie om circulair te werken moet vanaf het begin van het project duidelijk zijn en werkt door in de volgende fasen. De circulaire ontwerpcyclus wordt doorlopen om circulaire mogelijkheden te verkennen en vast te stellen voor het gebied van het project en de mogelijke circulaire kansen.

Verkenningsfase: De vertaalslag wordt gemaakt van ambities en randvoorwaarden voor circulariteit naar alternatieven en afwegingscriteria en het formuleren van concrete doelen voor circulariteit in het voorkeursalternatief. Dit betekent dat de keuzes in de verkenningsfase een grote impact hebben op de duurzaamheid en circulariteit van de uiteindelijke oplossing. De fase wordt belichaamd door de beschrijving van de haalbaarheid en noodzaak van het project en de kosten en baten van de voorkeursoplossing. De circulaire ontwerpcyclus wordt doorlopen om circulaire mogelijkheden te verkennen en vast te stellen.

Planfase: In de planfase wordt het voorkeursalternatief uitgewerkt tot een gedetailleerd ontwerp met bijbehorende ramingen. Het projectteam zoekt naar een ruimtelijk ontwerp met een zo hoog mogelijke milieuwaarde en een zo laag mogelijke milieu belasting tijdens de bouw, gebruik, onderhoud en vervanging aan het einde van de levensduur. In elke ontwerpafweging wordt het effect op materiaal(her)gebruik meegenomen en is dit een integraal onderdeel van het afwegingskader. De circulaire ontwerpcyclus wordt doorlopen om circulaire mogelijkheden voor verschillende detailniveaus te verkennen en vast te stellen.

Circulaire ontwerpcyclus:

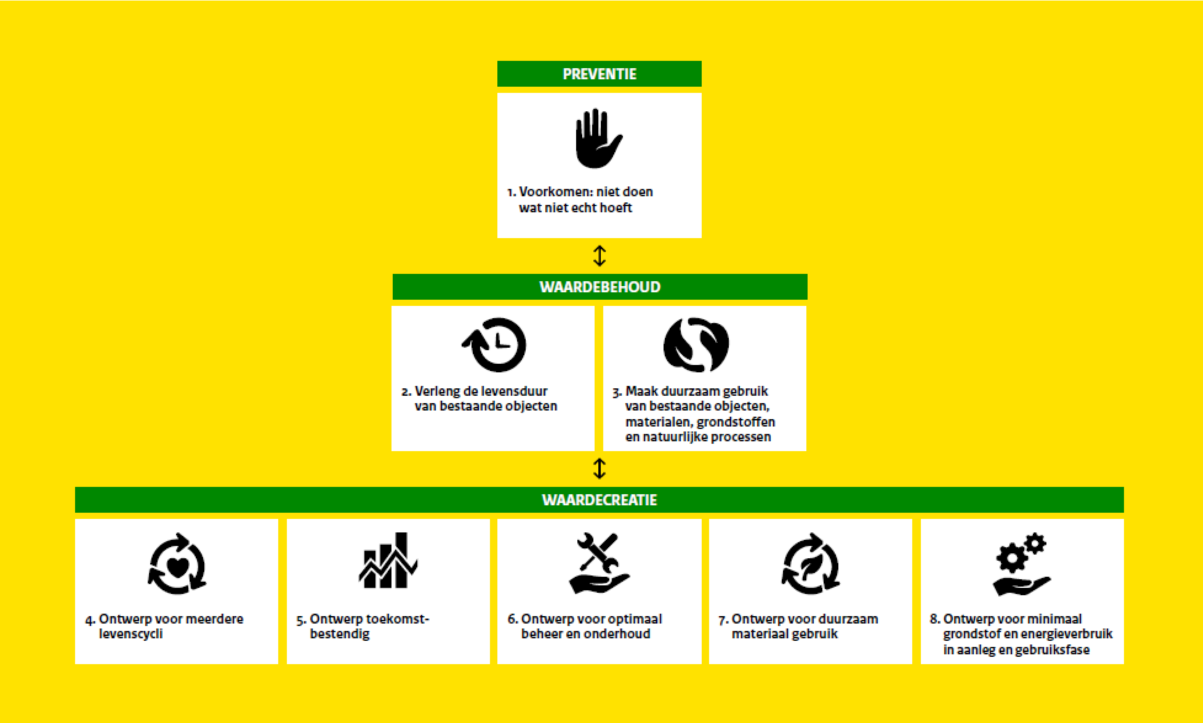
Om circulariteit op te nemen in het integrale ontwerpproces is het van belang om circulariteit als integraal onderdeel te beschouwen. De ontwerpcyclus begeleidt hierbij en kan in elke fase meerdere malen doorlopen worden voor verschillende detailniveaus. De cyclus werkt op een cyclische en iteratieve wijze.

<u>Stap 1:</u> Analyse vraag en ambities

- Breng alle aspecten, levensfasen en toekomstige ontwikkelingen die van invloed zijn of beïnvloed worden door het project helder in kaart en leg deze vast. Wat is de invloed van circulariteit en duurzaamheid op deze aspecten? Betrek de specialisten voor circulaire keuzes en uitgangspunten en leg de circulariteitsambities vast. Bijvoorbeeld: Realisatie, exploitatie, optimaal onderhoud, end of life fase, milieuaspecten, toekomstige ontwikkelingen, scheepvaart, gebiedsontwikkelingen ect.

- Denk bijvoorbeeld aan CO2-uitstoot, energieverbruik, materiaalgebruik, levensduur ect.

<u>Stap 2:</u> Onderzoek mogelijkheden en kansen met begeleiding van de circulaire ontwerpprincipes. De principes werken van boven naar beneden, van meest circulair naar minder circulair.



Figuur 1: Acht circulaire ontwerpprincipes (Rijkswaterstaat, 2019a, 2020)

- Preventie: 1. Doe niet wat niet echt nodig is
- Waardebehoud:
  - 2. Verleng de levensduur van bestaande objecten en componenten.
  - 3. Maak duurzaam gebruik van bestaande objecten, materialen, grondstoffen en natuurlijke processen.
- Waardecreatie: Hoe wordt er circulair omgegaan met het object als het zijn end-of-life-stage heeft bereikt?
  - 4. Ontwerp voor meerdere functionele levenscycli: De wenselijke levensduur van een object is afhankelijk van de zekerheid van toekomstige ontwikkelingen of wanneer het gaat om de realisatie van een tijdelijke constructie. Dit is het uitgangspunt voor de ontwerpstrategie voor meervoudige functionele levenscycli, zoals een modulair, aanpasbaar of robuust ontwerp.
  - 5. Ontwerp toekomstbestendig.
  - 6. Ontwerp voor optimaal beheer en onderhoud.
  - 7. Ontwerp voor duurzaam gebruik van materialen.
  - 8. Ontwerp voor minimaal grondstoffen- en energiegebruik in aanleg- en gebruiksfase.

<u>Stap 3:</u> Ambities vastleggen

Stap 4: Vertaalslag naar specificaties en ontwerp
- Meet de mate van circulariteit voor elke variant (Dubocalc)

Stap 5: Afweging en toetsen
- Neem circulariteit op in het afwegingsschema

Stap 6: Vastleggen en verantwoorden
- Toets het voorkeursalternatief aan de ambities om een feedbackloop in het ontwerpproces te creëren

De ontwerpcyclus kan voor elke fase en voor verschillende detailniveaus meerdere keren doorlopen worden. Op deze manier wordt circulariteit expliciet meegenomen bij elke ontwerpbeslissing.

Contract-/aanbestedingsfase: Houd bij het opstellen van levensduureisen rekening met de huidige en toekomstige levenscyclus van een object en maak onderscheid tussen de levensduur van een gehele constructie, elementen en materiaal. Vertaal dit in een bijpassende contractvorm en -termijn. Circulaire oplossingen worden vertaald in functionele eisen, minimumeisen en BPKV-prikkels. Wanneer circulariteit is gevat in de BPKV eisen, moet dit gepaard gaan met een substantiële bonus op de inschrijfprijs om te voorkomen dat niet circulaire opties de aanbesteding winnen.
- Communiceer over een uniforme organisatorische aanpak en een duidelijk en uniform voornemen over circulariteit richting de markt, zodat zij hierop kunnen anticiperen.
- Overweeg om de markt vroeg in het ontwerpproces te betrekken voor expertise en innovatie
- Neem circulariteit op in de aanbestedingseisen
- Denk aan flexibiliteit in het contract en ruimte om te leren en te experimenteren
- Monitor en valideer de afgesproken circulariteitsambities gedurende het realisatie- en onderhoud/exploitatieproces.