Explorative case study to gain insight on the consequences of circular infrastructural construction projects

Investigating the effects of circularity in construction projects on project process and construction costs

Master Thesis
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December 2022

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By

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To obtain the degree of Master of Science
at the Delft University of Technology,
to be defended publicly on Thursday December 8, 2022 at 1.00 PM.

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Preface

Before you lies the research report titled ‘’Explorative case study to gain insight on the consequences of circular infrastructural construction projects’’. This research tried to identify the effects of circularity on the project process and costs of infrastructural construction projects. The last 9 months I’ve dedicated my life to investigating circularity in the construction sector and the effects of it. This research has been written to obtain a Master degree in Construction Management and Engineering. When I started studying in 2013 at a university of applied sciences, in whole different field of knowledge, I would have never guessed I ended up with a Master degree of the TU Delft. During the writing process of my graduation thesis I experienced many ups, but unfortunately also several downs. I experienced difficulty in putting my ideas on paper, and finding my way through the graduation process, often making rookie mistakes. This influenced and stretched my initial planning for the graduation thesis as well. But after all there is this saying ‘’Plannings are made to be adapted’’. Even though there were the unfortunate setbacks and the late nights studying, I’ve never felt alone during the process and I had help from many people.

First of all I would like to thank Hans for being the chair of the graduation committee. From the start of the research you have awarded my practical approach towards this research topic. This provided me with the motivation to continue on researching this topic in a way it would be accessible for practice. Additionally, your critical view on formulations, methodology and use of sources strengthened this research.

Then I would like to thank Daan. You were the first of my graduation committee I contacted. The courses you have provided during the master program were interesting and engaging, which was strengthened by your own enthusiasm. This has led me to asking you to join my graduation committee. Thank you for your constant help during my research process, from putting my vague ideas into an executable research to improving my research methodology. I really appreciate the time you took for helping me in my research, even when we were on a study trip or when I scheduled a last-minute meeting. Your criticism and guidance helped me to constantly improve my work.

Next, I wish to thank Francesco. As second supervisor you complemented Hans and Daan perfectly. At the start of the research I was very focused on the input of circular materials, while this is just a part of circularity. During the meeting you constantly pointed out the importance of taking the output also in account, which I ultimately did. This improved my research massively. Thank you for your practical criticism and extending my view on circularity.

Subsequently, I would like to thank Erik and Niels from Dura Vermeer for guiding me throughout this process, granting me access to project documents and bringing me into contact with other professionals. You both were very welcoming and supportive from the start, allowing me the ultimate freedom in executing my research whilst providing me with practical feedback in our regular meetings.

Lastly, I would like to thank my friends, family, roommates, and especially Robin for their constant support throughout an intense period. Their fun distractions made it possible for me to complete this graduation thesis successfully.

Mark Kanters

Delft, November 29, 2022

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Executive summary

Climate change, decreasing biodiversity, pollution and resource depletion are just a few of the many negative consequences of our current way of living and exploiting the resources of the planet earth. The construction sector is a major contributor to climate change, the rising CO2-levels causing this change, and the total amount of waste generated. Additionally, the construction sector is also a major consumer of the earths' primary resources, functioning according to the ''take-make-waste'' principle. Thus, change is necessary to keep our planet inhabitable for future generations.

Implementation of the circular economy is one of the solutions to tackle the current linear ''take-make-waste'' economy, especially in the construction sector. There is however still a lot of uncertainty about the implementation of the circularity and the circular economy in the construction sector, caused by cultural and technological barriers in the process towards constructing the project and the market barrier related to financing the overall project. The lack of knowledge about circularity feeds these barriers and make parties hesitant in applying circularity in construction projects. Circular business cases are seen as the most important enabler for destructing the barriers towards circularity in the construction sector, since business cases showcase practical examples of circularity and its implementation, generating practical knowledge. This resulted in the research objective to identify and capture the differences in costs and project process between a circular infrastructural construction project and a regular infrastructural construction project. To reach the objective of this study, the following research question has been formulated to be answered in this study:

What are the effects of the implementation of circularity on the project process and costs in infrastructural construction projects?

A qualitative research has been designed in order to answer this research question, starting with a literature study. The literature study resulted in the identification of the major construction project process components and the circular practices to be executed in each individual component. These process components are: Initiative, design, procurement, construction, and operation & maintenance. Additionally, a circular infrastructural construction project has been defined by the literature study as: *A circular infrastructural construction project is a construction project in which a certain physical infrastructure is constructed which complies to the CE design principles (Design for prevention, design for reducing lifecycle impact, design for future-proofness, design with reused objects, design with secondary resources, and design with renewable resources).*

The research has been performed by the execution of multiple case study on two cases, a circular infrastructural construction project and a regular infrastructural construction projects. The case study focused on three main topics: Circularity, project process, and construction costs. The data was collected by performing semi-structured interviews with involved parties of both case projects and by analysis of project documents. Both case projects have already been delivered to the client, making it possible to analyze both projects from start to finish. Once the data was collected per project, a circularity measurement was executed, together with the identification of the project process and the incurred construction costs. Subsequently, the data on both projects was internally coupled to generate an

integrated overview of the individual case projects. Lastly a cross-case analysis was executed to compare the regular case project to the circular case project, in order to show the differences these two cases. The results show that both case projects experienced a different project process from what is usual. The regular case project included a design competition, while circular case project was missing the procurement procedure. In addition, the project participants of the circular case project indicated during the interviews that one of the major activities was the collection of reusable materials. Hence, Gathering materials was introduced as a new project process component for circular projects. This new component was constantly interchanging with the design of the project, since the available materials determined the design, resulting in redesigning the structure quite often. The circularity measurement showed, as expected, a higher circularity score for the circular project in comparison with the regular case project. Regarding the direct construction costs, the results show for a major part of the cost items higher costs per cost item in the circular case project when compared to the regular case project. This is mainly due to extra activities that need to be executed before a reusable material can be applied. However, in the majority of the purchasing costs was a price reduction found. Reusable materials were often less expensive than new materials. This was the only cost-reducing effect found when applying reusable materials. The indirect construction costs of the circular case project were lower than those of the regular case project. However, these were still high in comparison to the average indirect costs. This increase in costs is most likely the result of the application of an extra material storage on the construction site and the increased coordination and cooperation to establish a circular project, which in turn resulted in more manhours incurred. Mapping of the costs over the project process showed a difference in the distribution of the construction costs between the two case projects. In the regular case project, the costs were mainly incurred in the construction component. In the circular case project, the main share of costs was still allocated to the construction component, however, large portions moved closer to the start of the project. More specifically, to the process components Gathering materials and (Re)Design.

From the findings of the multiple case study and the cross-case analysis, a conclusion can be drawn. The effects of the implementation of circularity are visible in both the construction costs and the project process. The direct construction costs increased as a result of implemented circularity. Applying reusable materials often go hand in hand with introducing new activities to prepare the materials for appliance, which increases the price of the cost item and hence the construction costs. Implemented circularity affected the project process by the introduction of the project process component Gathering materials, and its constant interchange with the (Re)Design component. The introduction of a new process component and the necessary extra activities also leads to an increased project duration. Lastly, a shift of the construction costs among the project components is noticed, leading to the costs distributed more to the front of the project.

Based on the conclusions drawn from this study, a few recommendations can be made. First, the recommendations for the construction sector are made, for whom it is advised to initiate more circular projects. This will create more understanding and support towards circularity. Secondly, when initiating a circular project, take into account that its construction is more expensive than when executed without circular ambitions. Also, make sure that all involved parties are motivated at the start to realize the circular ambitions. Most ideally, the client should immediately start searching for materials once the project is initiated. To make this possible, materials madastres need to be actively used, both at the start of a project and at the end of the lifecycle of a structure. For future research it is recommended to further investigate the effects of circularity on construction costs and project process. This can be done by using the method from this study and applying it on a larger set of case studies, so its results can be generalized and made more reliable. Furthermore it is suggested to investigate other infrastructural structures than bridges as well. Lastly, while this research focused on the construction costs, it could be interesting to investigate the effects of circularity on the transactional costs of a construction project.

Samenvatting

Klimaatverandering, afnemende biodiversiteit, vervuiling en uitputting van de bronnen die de aarde te bieden heeft zijn slechts enkele van de vele negatieve gevolgen van onze huidige manier van leven en het exploiteren van onze aarde. De bouwsector is voor een groot deel verantwoordelijk voor de klimaatverandering, de stijgende CO2-niveaus en de totale hoeveelheid geproduceerd afval. Daarnaast is de bouwsector ook een grootverbruiker van de hulpbronnen van de aarde. Deze sector werkt momenteel nog volgens het lineaire principe ‘take-make-waste’, het gebruik maken van materialen om producten te produceren die na gebruik weggegooid worden. Om onze planeet voor toekomstige generaties leefbaar te houden is er een verandering nodig.

Om de huidige lineaire ‘take-make-waste’-economie aan te pakken in de bouwsector is de implementatie van de circulaire economie een van de oplossingen. Er is echter nog veel onzekerheid over de implementatie van de circulariteit en de circulaire economie in de bouwsector, veroorzaakt door culturele en technologische barrières in het proces naar, en de bouw zelf van het project en de marktbarrière die betrekking heeft op marktcompetitie en de financiering van het totale project. Het gebrek aan kennis over circulariteit voedt deze barrières en zorgt ervoor dat partijen huiverig zijn om circulariteit in bouwprojecten toe te passen. Circulaire businesscases worden hierin gezien als de belangrijkste methode voor het doorbreken van de barrières voor circulariteit in de bouwsector. Dit komt doordat businesscases praktijkvoorbeelden van circulariteit en de implementatie ervan laten zien op een toegepaste manier, waarmee er dus praktische kennis gegenereerd wordt. Dit resulteerde in de onderzoeksdoelstelling om de verschillen in kosten en projectproces tussen een circulair infrastructureel bouwproject en een regulier infrastructureel bouwproject te identificeren en vast te leggen. Om dit doel te bereiken, is de volgende onderzoeksvraag geformuleerd die in dit onderzoek beantwoord wordt:

Wat zijn de effecten van de implementatie van circulariteit op het projectproces en kosten van een infrastructurele bouwproject?

Om deze onderzoeksvraag te beantwoorden is een kwalitatief onderzoek opgezet, startende met een literatuuronderzoek. De literatuurstudie heeft geleid tot de identificatie van de belangrijkste procescomponenten van een bouwproject en de circulaire praktijken die in elk afzonderlijk component uitgevoerd kunnen worden. Deze procescomponenten zijn: Initiatief, ontwerp, aanbesteding, bouw en de exploitatie & onderhoud. Daarnaast heeft de literatuurstudie geleidt tot de volgende definitie van een circulair infrastructureel bouwproject: *Een circulair infrastructureel bouwproject is een bouwproject waarbij een bepaalde fysieke infrastructuur wordt aangelegd die voldoet aan de CE-ontwerpprincipes (Ontwerpen voor preventie, ontwerpen voor reductie van levenscyclusimpact, ontwerpen voor toekomstbestendigheid, ontwerpen met hergebruikte objecten, ontwerpen met secundaire grondstoffen en ontwerpen met hernieuwbare grondstoffen).*

Het onderzoek is uitgevoerd door middel van een meervoudige case study waarbij twee project casussen zijn behandeld, een circulair infrastructureel bouwproject en een regulier infrastructureel bouwproject. De case study zelf richtte zich op drie hoofdonderwerpen: Circulariteit, projectproces en bouwkosten. De specifieke projectgegevens zijn verzameld door het uitvoeren van semigestructureerde interviews

met betrokkenen van de casusprojecten en door middel van een analyse van de projectdocumenten. Beide casusprojecten zijn reeds opgeleverd, waardoor het mogelijk is om beide projecten van begin tot eind te analyseren. Na afronding van de dataverzameling is er per project een circulariteitsmeting, een identificatie van het projectproces en een identificatie van de gemaakte bouwkosten uitgevoerd. Vervolgens zijn de gegevens van beide projecten intern gekoppeld om een geïntegreerd overzicht van de individuele casusprojecten te genereren. Ten slotte is een vergelijkingsanalyse uitgevoerd om het reguliere casusproject te vergelijken met het circulaire casusproject, met als doel het laten zien van de verschillen, en de mogelijke verklaringen ervoor, tussen deze twee casussen.

De resultaten laten zien dat beide casusprojecten een ander projectproces doormaakten dan wat gebruikelijk is. Het reguliere casusproject bevatte een ontwerpwedstrijd, terwijl in het circulaire casusproject de aanbestedingsprocedure ontbrak. Daarnaast gaven de projectbetrokkene van het circulaire casusproject tijdens de interviews aan dat het inzamelen van herbruikbaar materiaal een van de belangrijkste activiteiten was. Daarom is Verzamelen van materialen geïntroduceerd als een nieuw component van het projectproces voor circulaire projecten. Dit nieuwe component wisselde voortdurend af met het ontwerp van het project omdat de beschikbare materialen een enorme invloed hadden op het ontwerp, waardoor het project vaak opnieuw ontworpen moest worden. Zoals verwacht liet de circulariteitsmeting zien dat het circulaire casusproject een hogere circulariteitsscore had vergeleken met het reguliere casusproject. Wat betreft de directe bouwkosten blijkt uit de resultaten dat het circulaire casusproject hogere kosten heeft per kostenpost in vergelijking met het reguliere casusproject. Dit komt vooral door extra werkzaamheden die moeten worden uitgevoerd voordat een herbruikbaar materiaal kan worden toegepast. In het merendeel van de inkoopkosten van materialen werd echter een prijsverlaging gevonden, herbruikbare materialen waren vaak goedkoper dan nieuwe materialen. Dit was het enige kostenbesparende effect dat werd gevonden als gevolg van het toepassen van herbruikbare materialen. De indirecte bouwkosten van het circulaire casusproject waren lager dan die van het reguliere casusproject. Deze waren echter nog steeds hoog in vergelijking met de gemiddelde indirecte kosten van een bouwproject. Deze kostenstijging is hoogstwaarschijnlijk het gevolg van het toepassen van een extra materiaalopslag op de bouwplaats en de toegenomen coördinatie en samenwerking tussen partijen om een circulair project tot stand te brengen, waardoor er meer manuren zijn gemaakt. Het in kaart brengen van de kosten verdeeld over het projectproces liet een verschil zien in de verdeling van de bouwkosten tussen de twee casusprojecten. In het reguliere casusproject werden de kosten vooral gemaakt in het bouwcomponent. In het circulaire casusproject werd het grootste deel van de kosten nog steeds gemaakt in de bouwcomponent, maar grote delen van kosten kwamen ook verder naar voren in het project proces. Met name werden er veel kosten gemaakt in de componenten Verzamelen van materialen en (Her)Ontwerp.

De bevindingen van de meervoudige case study en de vergelijkingsanalyse hebben geleidt tot een conclusie. De effecten van de implementatie van circulariteit zijn zichtbaar in zowel de bouwkosten als het projectproces. De directe bouwkosten stegen als gevolg van de doorgevoerde circulariteit in het project. Het toepassen van herbruikbare materialen gaat vaak gepaard met het uitvoeren van werkzaamheden om de materialen gebruiksklaar te maken, waardoor de kostprijs van de kostenpost en daarmee de bouwkosten stijgt. Circulariteit beïnvloedde het projectproces door de introductie van het project procescomponent Verzamelen van materialen en de constante wisselwerking met het (Her)Ontwerp-component. De introductie van een nieuwe procescomponent en de nodige extra activiteiten leidde ook tot een langere projectduur. Tenslotte wordt een verschuiving van de bouwkosten tussen de projectcomponenten opgemerkt, waarin de kosten meer naar de voorkant van het project proces zijn verschoven.

Op basis van de conclusies uit dit onderzoek kunnen er enkele aanbevelingen worden gedaan. Eerst worden er aanbevelingen gegeven voor de bouwsector. Ten eerste wordt er geadviseerd wordt om meer circulaire projecten te initiëren en bouwen. Zo ontstaat er meer begrip en draagvlak voor circulariteit. Vervolgens, houd er bij het initiëren van een circulair project rekening mee dat de bouw duurder is dan de bouw van een project zonder circulaire ambities. Zorg er ook voor dat alle betrokken partijen bij de start gemotiveerd zijn om de circulaire ambities te realiseren. Daarnaast zou de opdrachtgever idealiter onmiddellijk moeten beginnen met het zoeken naar materialen zodra het project is gestart. Om dit mogelijk te maken, moeten materialen madasters actief worden gebruikt, zowel aan het begin van een project als aan het einde van de levenscyclus van een constructie. Voor toekomstig onderzoek wordt aanbevolen om de effecten van circulariteit op bouwkosten en projectproces nader te onderzoeken. Dit kan worden gedaan door de methode uit deze studie te gebruiken en toe te passen op een groter aantal casussen, zodat de resultaten kunnen worden gegeneraliseerd en betrouwbaarder worden gemaakt. Verder wordt voorgesteld om ook andere infrastructurele constructies dan bruggen te onderzoeken. Tenslotte, terwijl dit onderzoek zich richtte op de bouwkosten, zou het ook interessant kunnen zijn om de effecten van circulariteit op de transactiekosten van een bouwproject te onderzoeken.

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List of abbreviations

CE	Circular Economy
CPP	Circular Public Procurement
D&C	Design & Construct
DBFM	Design, Build, Finance & Maintain
DBFMO	Design, Build, Finance, Maintain & Operate
DBM	Design, Build & Maintain
DBMO	Design, Build, Maintain & Operate
E&C	Engineering & Engineering
ECI	Environmental Cost Indicator
EU	European Union
GPP	Green Public Procurement
KPI	Key Performance Indicator
MCC	Metacom Cost Control
MCI	Material Circularity Indicator
MEAT	Most Economically Advantageous Tender
MKI	Milieukostenindicator
RSA	Royal Society of Arts
SDG	Sustainable Development Goals
SPP	Sustainabile Public Procurement
UN	United Nations
UTA	Uitvoerend Technisch Administratief (Executive, Technical and Administrative)

1

Introduction

This chapter serves as an introduction to the subject of this research. First, the background of the research is provided in section 1.1, elaborating on the rapidly occurring climate change, resource depletion and the circular economy as a possible solution to these challenges. Subsequently in section 1.2, the literature on these topics have been explored for difficulties and challenges when implementing the circular economy in construction projects. This has led to the problem statement of this research. Base on the problem statement, a research objective has been determined in section 1.3. The research objective forms the foundation for the main research question that has been determined in section 1.4. In order to answer the main research question, four sub questions have been formulated. The relevance of this research is explained in section 1.5. Section 1.6 clarifies the focus and boundaries of this research. Afterwards, the strategy of conducting the research activities and generating valuable results is explained in section 1.7. Ultimately, in section 1.8, an outline of the research structure and steps is given.

1.1 Background

Our current way of living and exploiting the planet Earth is destroying our living environment (Whitmee et al., 2015). Climate change, pollution, resource depletion, and decreasing biodiversity are just a few of the many negative consequences we face as a result of our own behavior (IPCC, 2021; Rockström et al., 2009; Rands et al., 2010). The construction sector is a significant contributor to climate change and the rising CO2-levels causing this change (Zhong et al., 2021). In addition, the construction sector has been labelled as one of the major consumers of the primary resources in The Netherlands with a staggering 40% and it is also responsible for 40% of the total amount of waste generated (ABN AMRO, 2017). The construction sector is an example of a 'take-make-waste' economy, or a linear economy wherein we extract raw materials, produce these into goods to be exploited and to ultimately discard them (Ness, 2008). We consider our worldwide economy as a linear economy. It is expected that the current global use of Earths' natural resources will be doubled in 2060 (Hanemaaijer et al., 2021). Continuing with this worldwide linear economy without change will ultimately lead to the downfall of humankind (Whitmee et al., 2015). Thus change is necessary.

The urgency of our degrading world led the United Nations (UN) in 2015 to officially formulating and promoting seventeen global sustainable development goals (SDGs) as global goals of sustainable development for the period 2015-2030 (United Nations, 2015). These SDGs serve as a call for action to end poverty, reduce inequality, stimulate economic growth, tackle climate change and to preserve forests and oceans (United Nations, 2015). The UN SDGs have formed the foundation for what is regarded as the future economic system of the world wherein environmental protection, economic growth and security of raw material supply are embedded, this is the circular economy (CE). The CE is receiving increasing attention all over the world during the last number of years. Yet the gaining attention did not led to a reached consensus in literature about the definition of CE as it still has been captured in a great number of different definitions (Kirchherr et al., 2017b; Murray et al., 2017). In order to create and maintain unity in this research, the definition of CE will be clarified. Prieto-Sandoval et al. (2018) studied the different definitions in current literature concerning CE and formulated the comprehensive definition of CE as an ‘’*economic system that represents a change of paradigm in the way that human society is interrelated with nature and aims to prevent the depletion of resources, close energy and materials loops, and facilitate sustainable development through its implementation at the micro (enterprises and consumers), meso (economic agents integrated in symbiosis) and macro (city, regions and governments) levels*’’. In this research, the definition of CE formulated by Prieto-Sandoval et al. (2018) will be used as a basic principle for CE. Hence, this definition is in line with the definition of CE that is adhered to by the Dutch government and the European commission.

In the next 30 years we will be transitioning from our current linear economy towards a CE. The European commission has set the goal for member states of the European Union (EU) to achieve climate neutrality in 2050 by implementation of the CE (European Commission, 2020a). The European policy on CE saw its first light in 2015, and is the result of the combination of environmental policy and policy on raw materials (European commission, 2015). According to the European commission, a general policy and course regarding the CE summarizes both these topics into one. Furthermore, environmental protection, economic growth and security of supply are considered by the European commission to be the main drivers for the CE. Later, in 2020, the European commission published a new plan for the implementation of CE wherein the goals of 2030 and 2050 were determined (European Commission, 2020a). The foundation of the climate neutrality goals and the CE policy of the European commission lies at the seventeen UN SDGs (Rodríguez-Antón et al., 2022), which is also formulated as a goal for the EU. In addition, the EU has set the goal to reach full climate neutrality by 2050 and a decoupling of the economic growth from resource use (European Commission, 2020a). To fulfill these goals, a CE is aimed for by the EU (European Commission, 2020a).

Both the UN SDGs and the goal of the European commission serves as a baseline for Dutch government policy concerning the deployment of its own sustainability goals. The Dutch government has the goal to achieve a reduction of 50% in usage of the Earth’s primary resources in 2030 and aims to establish a full CE in 2050 (Rijksoverheid, n.d.). Figure 1.1 shows an overview of the hierarchy of CE policies.

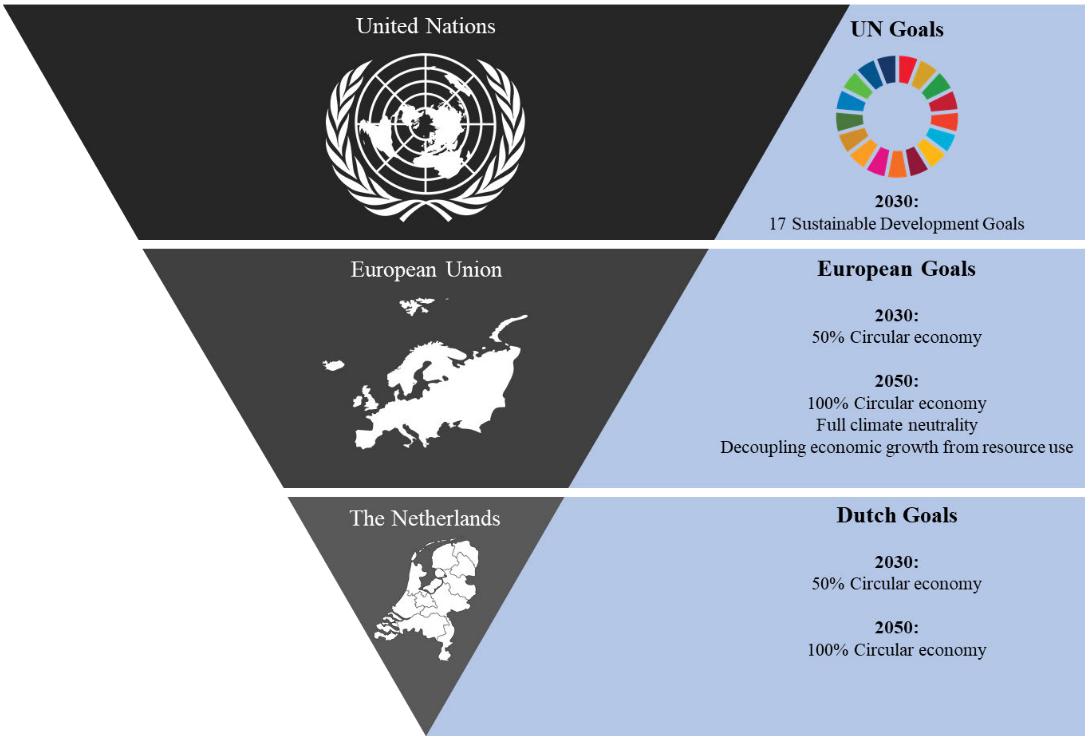

Figure 1.1: Hierarchy of CE-policies (own image).

1.2 Problem statement

The CE functions as a strategy for all industries in reaching a sustainable society and world. Back in 2008, the first steps were made by the EU towards sustainability in the construction sector with the introduction of the Green Public Procurement (GPP) directives, which were used to stimulate sustainability and the decrease of CO_2 emissions (European Commission, n.d.a). In these GPP directives, a relatively new sustainable solution was introduced, which was the CE. The CE, as formulated by the European Commission (2017), is an economic system wherein products and materials are kept in the value chain for a longer period of time, in sequence to recovering raw materials from the products after its lifetime without the loss of any material. It is regarded that the implementation of the CE will provide a possible solution to the current problematic consequences of the construction sector by reducing its carbon footprint, the use of material resources and by protecting scarce materials (Adams et al., 2017).

Over the years, sustainable or Green Public Procurement (GPP) is becoming a more and more important method of procurement in the Dutch construction sector, as it is a way to achieve sustainable infrastructure development (Lenferink et al., 2013). GPP criterion are formulated by mandatory environmental requirements alongside price, technique and organization (Varnäs et al, 2009). There has even been a infrastructural pilot project executed in which CO_2 was used as criterion of the procurement (Anthonissen et al., 2015). As Ershadi et al. (2021) also mentioned, more solutions should be researched and suggested in order to improve the sustainability practice of construction projects in the private sector. Within the GPP there is a new trend which incorporates the idea of a CE, namely Circular Public Procurement (CP). The addition of circular requirements, such as requirements for the extension of product life spans, efficiency and/or intensity of use, efficient cycling of biological or technical materials, as well as for the securing of clean and non-risky cycles, in the procurement phase are to stimulate circularity in construction projects (Alholla et al., 2019). It can be concluded that circularity is slowly becoming a standard within construction projects.

However, in practice, there is still a lot of uncertainty about the implementation of circularity in the construction sector. These uncertainties for the construction sector were summarized by Adams et al. (2017), consisting of a lack of incentive for designing for an end-of-life phase and the lack of economic stimulation for circularity in projects. Kirchherr et al. (2017b) showed that there is even uncertainty about the definition of a Circular Economy in general. In businesses however, there are already several so-called R-models applied to assess the different levels of circularity. In the literature we found the 6R-model (Potting et al., 2018), the 9R-model (Cramer, 2014) and the 10R-model (Reike et al., 2018). Each of these models convey in essence the same levels of circularity, but divided into more or less steps. This already led to the development of two circularity measurement tools: the Material Circularity Indicator (MCI) developed by the Ellen MacArthur Foundation (2019), and the method of measuring circularity developed by Platform CB'23 (2020).

Even though there are circularity measurement tools, the implementation of the CE remains facing delay. Kirchherr et al. (2017a) identified four categories of barriers towards implementing the CE: the cultural, technological, market and regulatory barrier. Whereas the cultural barrier is lacking the awareness or willingness to engage with the CE, the technological barrier is lacking the technologies to implement the CE, the market barrier is lacking the economic viability of CE business models, and the regulatory barrier is lacking the policies that support a CE transition. The presence of the cultural barrier is substantiated by the findings of Saidini et al. (2017) who found that the lack of understanding circularity among industrial practitioners leads to limiting the implementation of circularity in their businesses. Presence of the technological barrier is also substantiated by Tura et al. (2019), who summarized the technological barrier from previous research as a lack of information, knowledge, technologies and technical skills about circularity. On the other hand, the regulatory barrier is a barrier that is currently slowly being deconstructed by the Dutch government by the implementation of new regulations, in line with the nationwide goals of 50% CE in 2030 and a full CE in 2050 (Rijksoverheid, n.d.). Ultimately, there is the CE market barrier, which is affirmed by the difficulties of funding within CE business models (Ellen MacArthur Foundation, 2013), the high costs and the lack of tools and methods to measure benefits of CE projects (Tura et al., 2019). Hence, the cultural, technological and market barrier remain.

It can be noticed that past research is mainly focused on the barriers of the CE, whilst the possible solutions to these barriers seem more important. Especially lifting the cultural, technological and market barriers, since these have not yet been addressed by Dutch government. These three barriers all come together in the execution of a construction project, and are closely connected to one another (Grafström & Aasma, 2021). More specifically, cultural and technological barriers in the process towards constructing the project, and the market barrier in the project overall for financing, with the notion that the initial construction costs remain the deciding cost factor in awarding construction projects (Alshamrani et al., 2015). There appears to be an underlying common cause for the currently present barriers towards implementing circularity, which is a lack of knowledge (Adams et al., 2017). This lack of knowledge causes parties to experience the beforementioned barriers and makes them hesitant in applying circularity into practice. Subsequently, this results in a very limited amount of construction projects in The Netherlands which are executed by the circular philosophy, Circulaire Bouweconomie (n.d.b) registered only seven infrastructural construction projects so far.

The presence of the predetermined barriers are thus caused by a lack of knowledge. More specifically, a lack of knowledge on the effects of circularity on project process, the cultural and technological barrier, and the construction costs, the market barrier. As Adams et al. (2017) concluded, a circular business case or project is seen as the most important enabler for destructing the barriers towards circularity in the construction sector. Hence, the execution of pilot projects on circular construction and analyzing these in case studies can reduce this lack of knowledge.

Researching the effects of circularity in a infrastructural construction project on the process and construction costs therefore an interesting topic to address. The relation between circularity in a project, the project process and the financial values of such a project could provide insights for both the scientific community as the contractors, engineering firms and governmental agencies. It is well-known that financial values in a project do not merely exist of the costs and revenues from construction. The processes or activities within a project could influence the costs as well. For this reason, the process of the project will be included in this research as well, alongside the costs.

1.3 Research objective

As discussed earlier in the problem statement, the CE is still experiencing some barriers towards its implementation in practice. As addressed by Adams et al. (2017), research about the implementation of circular practices in projects can guide us towards the success of the CE in the construction sector. Therefore, the objective of this research is to identify and capture the differences in costs and project process between a circular infrastructural construction project and a regular infrastructural construction project. Bearing in mind that the majority of objectives and goals defined in governmental and corporate reports and policies are expressed in economic values, provides the conclusion that indicators based on economical values are better aligned with these policies and goals (Di Maio et al., 2017), thus a key role to the successful implementation of CE. By making the comparison, in basic terms, between a circular and a regular project this objective is expected to be achieved.

1.4 Research question

Resulting from the problem statement and research objective, the main research question has been determined. In order to answer the main research question, four sub questions have been formulated. The sub questions are provided with a brief explanation of the goal of the associated sub question.

Main research question: *What are the effects of the implementation of circularity on the project process and costs in infrastructural construction projects?*

Sub question 1 (SQ1): *How is the circular economy implemented in the construction industry in general and in infrastructural construction projects? (Chapter 2)*

The goal of answering this sub-question is to define the Circular Economy (CE) and its relationship towards infrastructural construction projects. Relevant literature will be gathered in order to answer this question and its answer will serve as a theoretical background of this research. It is important to understand the theory about CE and the influence and impact it has to the construction sector in general, in order to successfully proceed with the research. Furthermore, the direct implications of CE for infrastructural projects will also create input for the subsequential research sub questions. Therefore, this literature review will act as a foundation to this research.

Sub question 2 (SQ2): *How are the differences in process and costs between a circular infrastructural construction project and a regular infrastructural construction project be disclosed? (Chapter 3)*

With the first sub-question answered, a foundation and theoretical background has been created, defining CE for both the construction sector and infrastructural projects. Now the 'what' has been determined, the second sub-question will answer the 'how'. With the gained knowledge kept in mind, the answer to this sub-question will explain the methodology of the research. First, a method for determining the level of circularity in a construction project is described, to be applied further on in the research. Secondly, the requirements for the case study in general are defined, which will lead to the selection of a circular case study project and a regular case study project. Ultimately, the outline of the case study is elaborated upon, consisting of an explanation of both methods for analyzing the project process and the project costs.

Sub question 3 (SQ3): *How do the activities and costs of a circular infrastructural construction project vary from a regular infrastructural construction project? (chapter 4)*

By combining the theoretical background defined in sub-question 1 and the methodology explained in sub-question 2, the case study will be executed. The case study will exist of a previously executed circular infrastructural construction project and a similar non-circular project. Both projects will be described and analyzed on both the costs and project process according to the methodology defined in chapter 3. By conducting this case study and answering this sub- question, it is expected to gain insights in the differences between the two similar projects, executed with two different rationales.

Sub question 4 (SQ4): *What are the implications of the comparison made between the project process and costs of a circular infrastructural construction project and a regular infrastructural construction project? (Chapter 5)*

Eventually, the most important findings from the case study will be determined. The results will lead to implications of the findings. These implications will be discussed based on the relevant literature, resulting in the conclusion of this research.

1.5 Relevance

The relevance of this research is subdivided into three categories: scientific relevance, practical relevance, and societal relevance. This paragraph highlights how this research is relevant for the scientific world, the industry and society.

1.5.1 Scientific relevance

Needless to say, the amount research in the field of CE and its definition is enormous. However, the gap in knowledge was addressed by Cheng et al. (2018) wherein the need for research investigating the link between finances and circularity is recommended. Furthermore, as can be red in the problem statement, the implementation of circularity in practice is delayed by four barriers (Kirchherr et al., 2017a). As identified, three of the still relevant barriers are the cultural, market and technological barriers. Linking the theoretical knowledge to these barriers and performing a practical case study is unique and has not been done before. This research will lower the cultural, market and technological barriers by providing a practical approach to the theoretical knowledge available by making the comparison between a circularity-oriented infrastructural construction project and a regular infrastructural construction project. The insights gained from this research might even spark the incentive for more practically aimed future research of the implementation of CE in construction projects.

1.5.2 Practical relevance

Businesses are looking for ways to implement circularity, but are hampered by barriers (Kirchherr et al., 2017a). These barriers also apply to the construction sector. However, in the construction sector, business cases were found very helpful to visualize the implementation of CE in construction projects (Adams et al., 2017). Executing a case study wherein CE is linked to project costs and process helps to showcase the implementation of circularity to the construction sector. CE will become a more tangible concept and therefore easier and more attractive to apply in practice. Ultimately, the insights provided by this research can be communicated towards clients, contractors and engineering firms with the goals to spread the knowledge and applicability of CE in the construction sector. As Adams et al. (2017) mentioned, a clear business case or case study was ranked by sector itself as important enabler for the implementation of CE.

1.5.3 Societal relevance

As a society we need to transform to a CE as soon as possible. This research serves as just one of the many steps to practically implement CE in our businesses and ultimately in our society as well. For the construction sector being one of the major polluting industries in the world, decreasing its negative impact by CE has a great societal benefit, to which will be contributed in this research. Even though this study is aimed at the infrastructural construction sector, it can showcase that even a conservative sector as the construction sector is actively moving towards a CE. Hence, it can set an example for other industries and sectors.

1.6 Research scope

The circular economy and its implementation in the construction sector is a broad subject to perform research on, therefore boundaries have been determined to focus on the relevant components only. By doing so, the execution of an in-depth mixed approach research is ensured.

1.6.1 Circularity in construction

Platform CB'23 (2021) defines circularity in the construction sector as ''*The development, use and reuse of buildings, areas and infrastructure, without exhausting natural resources, polluting the living environment and putting harm to ecosystems. Constructing in economically responsible manner which contributes to the wellbeing of man and animal, here and there, now and later*'' (p. 17). This definition provided by CB'23 is comprehensive and complete, hence it will be used as definition for circularity practices in construction in this research. In addition, academic literature has been reviewed for defining circular practices in the projects process, more elaboration on this aspect can be found in paragraph 2.4.

1.6.2 Construction projects

Collaboration with the Dutch contractor Dura Vermeer provides the researcher with access to detailed project specific information. Therefore, the research will only focus on the current implementation of circular practices in Dutch construction projects executed by Dura Vermeer. Knowing that the construction sector consists of two main components, the building sector and the infrastructure sector, further narrowing down has been done here as well. Since the building sector is more or less ahead of the infrastructure sector on the basis of number of projects wherein circularity is applied in practice (Circulaire Bouweconomie, n.d.b), the choice has been made to focus solely on infrastructural construction. Within infrastructural construction belongs the construction of roads, railways, bridges, tunnels, waterways and underground grids.

1.6.3 Circularity measurement

In order to assess circular practices, a method for measuring this circularity will be applied. There is wide variety of methods available, but in this research the circularity measurement method developed by CB'23 will be used. The choice for this method of measurement is substantiated by the fact that this method is publicly available and under constant development. This creates the possibility for future improvements in the method of measurement to be applied and included in this study, making it resilient for future use. The CB'23 circularity measurement method focusses on the circularity in material use and application. Paragraph 3.2 will further elaborate on this method.

1.6.4 Project costs

The costs of a construction project can roughly be divided into two types of costs: a). transaction costs, and b). construction costs. The financial aspect of constructing circular infrastructure will be focused on merely the costs of the construction itself, consisting of engineering costs, materials, machinery and labor. Including transactional costs into this research will result into guesswork, since there is no information available on the process and its costs within circular construction projects. Therefore, the choice has been made to exclude the transactional costs from this research. In turn, the construction costs can be subdivided into: a). direct costs, which are the costs to actually construct the object, and b).

indirect costs, which are the non-recurring costs, overhead costs, construction site costs, execution costs, timebound costs, and profit and risks. Paragraph 3.4 elaborates further on the project costs.

1.6.5 Project process

The project process will be assessed by analysis of the basic components of a construction project. These basic components are present in each construction project and defines a project from its initiation until its operation and maintenance. Further elaboration on the project process is provided in paragraph 2.3.

1.7 Research strategy

The strategy for a research is formed by its research activities and actions. This paragraph elaborates upon the main steps and actions that will be executed with the goal of performing a proper research and gathering valuable results. By holding on to these actions, the research objective will be reached and the main research question will be answered. The explorative nature of this research aligns with the strategy that will be adhered to in this research.

1.7.1 Literature study

This research strategy starts with the execution of the literature study, with the goal of formulating a background of information on the topic of CE in the infrastructural construction sector. The sources for the literature providing this information will be Scopus, TU Delft repository, Google Scholar and Worldcat. To maintain overview of the literature, Mendely will be used to simultaneously track the consulted literature. Topics related to 'circular economy', 'circularity in the construction sector', 'infrastructure projects', and 'construction processes' are represented in this literature. Since the CE is a subject which is vibrant and constantly developing, it is essential for the authenticity and actuality of this research to focus primarily on the use of recent sources of information only.

1.7.2 Case study: mixed approach

This research will consist of both quantitative research and qualitative research. The mixed approach will contribute positively to the explorative nature of this study by identifying and analyzing project data of two case studies, a case study of a circular construction project and a case study of a non-circular construction project. The qualitative part of this research will focus on the influence of circularity on the process of a project. The quantitative part focusses on the influence of circularity on the construction costs. A further elaboration on both types of research and its implementation in this study will be given in chapter 3.

1.7.3 Case selection

The circular construction project case which will be analyzed in the case study has already been determined, because of the limited available projects and its novelty. For comparative purposes, a non-circular project case will be chosen which is the most similar to the circular case project. From the case selection strategies described by Seawright & Gerring (2008), the most similar case selection strategy is regarded to be the most suitable, since this research aims to compare cases based on similarity in its characteristics. By first identifying available cases and determining the key variables, the available projects will be analyzed for similarities with the circular project case. The project with the most similarities on the key variables will be included in the case study.

1.7.4 Cross case comparison

Both the qualitative and quantitative aspects of both cases will be compared to one another in a cross case analysis. The qualitative aspect of the project cases, the construction process, will be analyzed and compared based on a traditional project processes according to literature and the experiences of professionals, which is gathered with help of interviews. The construction costs, as the quantitative part of this study, will be further specified and broken down into materials and activities. The comparison is made by analyzing the differences in the costs of these specified components and identifying the 'gaps' in activities and materials between both projects.

1.7.5 Research validation

The results of this study need to be validated in order for the research to be interpreted as reliable and accurate. The validity of the results will be checked by consulting and comparing relevant literature to the results and the conduction of an interview with an experienced professional.

1.8 Thesis outline

This document has been organized and structured by the research sub questions. At first chapter 1, the current chapter, the problem statement, research objective, research question and research strategy are explained. Secondly, chapter 2 provides the literature study, which functions to provide a background of information on the investigated topic in order to ultimately define the necessary information and the framework of the research. The literature study in this research is focused on the implementation of circular economy practices in construction projects in general and during different project components. Thirdly, chapter 3 elaborates upon the methodology that will be used to execute the research, which is both a qualitative and quantitative approach to executing a case study, the case selection procedure, and the setup of the case study in general. Subsequently, these methods will be applied in practice in chapter 4. This chapter presents the results of the case study, the cross-case analysis for comparing purposes, and finally the validation of the results. Chapter 5 discusses the interpretation and implications of the results, and a consists of a reflection on the research process. At last, in chapter 6, the conclusion is defined by answering the main research question. In addition to this, the limitations of this research and recommendations for future research are given as well in this chapter. A brief overview of the thesis outline is provided in figure 1.2 below.

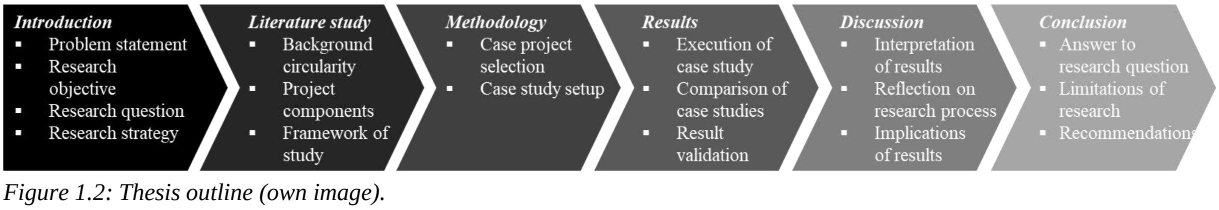

Figure 1.2: Thesis outline (own image).

2

Literature study

The goal of this chapter is to answer the first sub question from this study (SQ1), which is: ''How is the circular economy implemented in the construction industry in general and in infrastructural construction projects?''. The answer to this question will be given with help of a literature study. SQ1 can be divided into five segments which are elaborated in this literature study and can be seen in figure 2.1. The literature study serves as a background and foundation to this research, which provides all the necessary information and elaboration on relevant subjects to construct this research upon. At first, the circular economy in the construction industry is elaborated in paragraph 2.1, creating a general understanding of CE and its relation to the construction industry. Secondly, paragraph 2.2 focusses on the implementation of circularity in construction projects. Thirdly, in paragraph 2.3, literature on construction projects is analyzed to identify its major components. These components are subsequently analyzed upon CE practices in paragraph 2.4, in order to show what activities can be are representative or can be implemented to stimulate circularity in the standard components of an infrastructural construction project. Paragraph 2.5 is dedicated to formulating a definition for circular infrastructural construction projects. Ultimately, paragraph 2.6 summarizes the most important findings of the literature study in a theoretical framework. The paragraphs are arranged accordingly to the five segments of SQ1 as summarized in Figure 2.1.

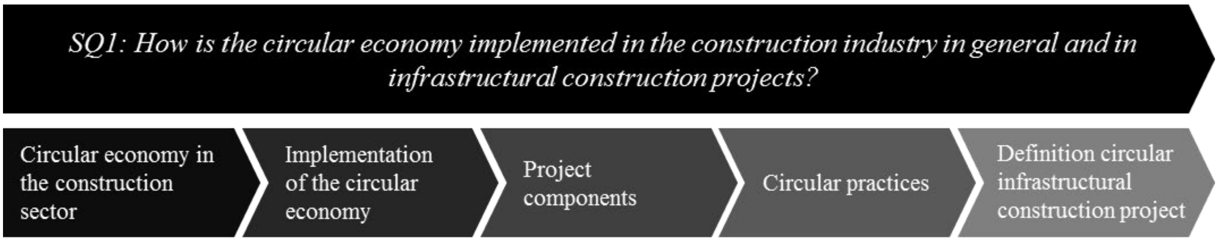

Figure 2.1: SQ1 subdivided into five segments (own image).

2.1 Circular economy in the construction sector

The CE is regarded as the future economic system of the world wherein environmental protection, economic growth and security of raw material supply are embedded. The transition to this new economy also includes the construction sector. Currently, the construction sector is a major raw material consumer and polluter (ABN AMRO, 2017; Zhong et al., 2021). Implementation of the CE in the construction sector could lead to the reduction of these negative effects, which is beneficial to the health of this planet and its people. The application of CE in the construction sector as portrayed in past literature has been investigated by Osobajo et al. (2020) and it was concluded that the majority of research is focused on resource use and waste management. Only limited research on supply chain integration, building designs, policy, energy efficiency, land use, offsite manufacturing, whole life costing & risk, cost reduction, cost management, and health & safety management has been conducted (Osobajo et al., 2020, p. 39). As was concluded by Osobajo et al. (2020), current CE practices fail to facilitate a true circular construction industry, since it does not cover all facets of construction projects. Therefore, it can be argued that the implementation of CE in the construction sector is still in its early stages.

Within the construction industry in general, there is a difference in the progression of CE observed between the building sector and the infrastructure sector. The building sector has already progressed further on the implementation of CE, which is visible in the number of completed circular projects in the Netherlands. At the moment, 7 circular infrastructural construction projects are completed whilst there are 168 circular building projects completed according to the Circulaire Bouweconomie (n.d.b). This is a team of experts which assist the Dutch Government in guiding the transition towards the CE in 2050 in The Netherlands. The maintained definition of circular projects, as determined by the Circulaire Bouweconomie (n.d.a), is a project which satisfies the needs for a structure without exceeding the carrying capacity of the earth in the form of resource depletion, CO_2-emissions, pollution, loss of biodiversity and other environmental damages. The circular infrastructure projects are depicted in figure 2.2.

Figure 2.2: Circular infrastructural projects in the Netherlands. 1. Bicycle lane Hoornbloem, Hoorn; 2. Ritspad, Amsterdam; 3. Gevlebrug, Amsterdam; 4. Demolition Waddenviaduct, Amsterdam; 5. Tweede leven brug, Almere; 6. Circular viaduct, Kampen; 7. 3D-printed bridge, Nijmegen (Own image, adapted from Circulaire Bouweconomie, n.d.b; Floriade, 2021).

2.2 Implementation of circularity in construction projects

The implementation of CE in the construction sector is mainly focused on maximizing the reuse and recycling of materials, components and products, thus supporting further and more sustainable consumption and production cycles (Andrews, 2015). The potential methods of processing materials, components and products in support of implementing the CE are widely described and investigated in literature. The methods have been categorized and listed into a hierarchy, providing a clear and insightful overview. This hierarchy of CE practices is known as the R-model. The academic world is divided opinion about the most versatile R-model, and presents a wide range of R-models, ranging from a 3R-model to 10R-model (Jawahir et al., 2006; Yoshida et al., 2007; Rusjanto et al., 2011; Kazerooni Sadi et al., 2012; Sihvonen & Ritola, 2015; Reike et al., 2018; Xing et al., 2019; Vlajic et al., 2021). All these different R-models show overlap with other R-models, some more disaggregated than others, see figure 2.3.

Yoshida et al., 2007 **R3**	Kazerooni Sadi et al., 2012 **R4**	Rusjanto et al., 2011 **R5**	Jawahir et al., 2006 **R6**	Xing et al., 2019 **R7**	Vlajic et al., 2021 **R8**	Sihvonen & Ritola, 2015 **R9**	Reike et al., 2018 **R10**
			Redesign	Rethink Resillient Regulate	Rethink Redesign		Refuse
Reduce	Reduce	Reduce	Reduce	Reduce	Reduce	Reduce	Reduce
Reuse	Reuse	Reuse	Reuse	Reuse	Reuse	Reuse	Reuse
					Replace	Repair	Repair
						Refurbish	Refurbish
			Remanufacture			Remanufacture	Remanufacture
					Repurpose	Repurpose Resynthesize	Repurpose
Recycle	Recycle	Recycle	Recycle	Recycle	Recycle	Recycle	Recycle
	Recover	Recover	Recover	Recover	Recover	Recover	Recover
		Disposal					Remine

Figure 2.3: Overlap between R-models (own image).

As can be seen in figure 2.3, when summarized, the R-models all contain the three principles reduce, reuse and recycle, which could therefore be seen as the three basic principles, or 3R-model. Further specifications in addition to these basic principles makes the application of CE and its different methods more comprehensible to apply in practice. In addition, the 3R-model is not sufficient and extensive enough to mitigate the environmental impacts of construction and demolition waste and cannot ensure the adaptation of environmental innovation in the whole life cycle of a construction project (Esa et al., 2017). The 10R-model is therefore selected to serve as a foundation for CE-practices in this research. Furthermore, the study from Reike et al. (2018), in which 69 papers were analyzed on the applied R-models, also concludes that the 10R-model is the best applicable R-model for CE-practices and thus substantiated the choice for the 10R-model as foundation for this research. The 10R-model consists of: Refuse, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover, remine. A brief description of the R's in 10R-model according to Reike et al. (2018) is displayed in table 2.1 below:

Table 2.1: 10R-model description (Reike et al., 2018).

R	**R-term**	**Definition**
1R	Refuse	New or second hand materials will be refused to be applied in a project. By doing so, the project will be rethinked, and other solutions or designs are considered.
2R	Reduce	Less new or second hand materials will be applied. The used materials will be used longer and will thus have an increased life span. Less materials will be applied in a more efficient way.
3R	Reuse	Second hand materials, that have been harvested from decommissioned projects, will be applied in a project by making only small adjustments to newly applied material. To create an oversight of the available materials, a material library, like madaster, and stockpile with second hand materials needs to be created. Used girders for example, with a long life cycle, can be applied in a new project.
4R	Repair	Objects are repaired or small parts are replaced, making the object and structure operational again. Instead of replacing an entire component, the component will be repaired.
5R	Refurbish	Small components of objects are repaired or replaced while the overall structure remains intact. This results in an upgraded object, still serving the same use.
6R	Remanufacture	The entire structure of the object is disassembled, checked, cleaned and components are replaced or repaired when necessary. The object is brought back to its former glory, still serving the same use.
7R	Repurpose	Discarded components of an object are adapted and reused for another function. This will create a new object for a new use and thus a new life cycle.
8R	Recycle	An object is discarded and processed into raw materials, creating input for new products or objects. The materials are salvaged to the highest possible value.
9R	Recover	Components or materials from a demolished object are used as biomass or incinerated with the goal to produce energy.
10R	Remine	Components or materials from a demolished object are dumped on land and used as landfill.

2.3 Construction project components

Just like the current take-make-dispose economy, the process of a traditional construction project can be regarded as linear. However, for the CE to succeed, construction projects, as well as the entire economy, must move from a linear process to a circular process. There is currently little knowledge available on the process of circular construction projects. However, it is known that nearly every construction project consists of a set of standard components, which combined result in a successful project delivery (Kagioglou et al., 2000; Keoki Sears, 2015; Lenferink et al., 2013; The Chartered Institute of Building, 2022).

Among the academic literature, there is a disunity about these standard components. Keoki Sears (2015) identifies the major construction project components as: Planning & definition, Design, and Procurement & construction. On the other hand, Kagioglou et al. (2000) defines ten major project components, to be subdivided into the four broad components: Preproject, Preconstruction, Construction, and Post-construction. Like Keoki Sears, Lenferink et al. (2013) is already a bit more elaborate then Kagioglou et al. in defining the standard project components by including the construction project component which encompasses after the construction of the project, resulting in the components: Design & procurement, Construction, and Maintenance & operation. Cornick & Mather (1999) and Grit (2022) determined similar construction components which are: Initiation, Design, Definition, Tender, Construction, and Operation & Maintenance. The most extensive summary of standard project components has been formulated by The Chartered Institute of Building (CIOB, 2022), who identifies: Inception, Feasibility, Strategy, Preconstruction, Construction, Engineering services, Completion & handover, and Post-completion. For the purpose of this research, it is necessary to determine an uniform set of project components. To do so, the different sets of project components have been put into a table, see figure 2.4. By listing the components alongside one another and comparing these, it is possible to group them into major project components. This led to the identification of the following major components of a construction project: Initiative, Design, Procurement, Construction, and Operation & maintenance. For validation purposes, these components have been proposed to two professionals at Dura Vermeer, who both agreed to the five major components.`

<table>
<tr><td>CIOB, 2022:</td><td>Inception</td><td>Feasibility</td><td>Strategy</td><td colspan="3">Preconstruction</td><td>Constructi on</td><td>Engineerin g services</td><td>Completion & handover</td><td>Post-completion review</td></tr>
<tr><td>Cornick & Mather, 1999; Grit, 2022:</td><td colspan="2">Initiation</td><td colspan="2">Design</td><td>Definition</td><td>Tender</td><td colspan="2">Construction</td><td colspan="2">Operation & maintenance</td></tr>
<tr><td>Lenferink et al., 2013:</td><td colspan="2"></td><td colspan="4">Design & procurement</td><td colspan="2">Construction</td><td colspan="2">Maintenance & Operation</td></tr>
<tr><td>Kagioglou et al., 2000:</td><td colspan="2">Preproject</td><td colspan="4">Preconstruction</td><td colspan="2">Construction</td><td colspan="2">Post construction</td></tr>
<tr><td>Keoki Sears, 2015:</td><td colspan="2">Planning & definition</td><td colspan="2">Design</td><td colspan="4">Procurement & construction</td><td colspan="2"></td></tr>
<tr><td></td><td colspan="2">Initiative</td><td colspan="2">Design</td><td colspan="2">Procurement</td><td colspan="2">Construction</td><td colspan="2">Operation & maintenance</td></tr>
</table>

Figure 2.4: Project components according to literature (own image).

2.4 Circular practices

In traditional construction projects, the five major components occur according to the sequence: Initiative, design, procurement, construction, operation & maintenance. It could however occur that this sequence does not apply to circular construction projects. In the next subparagraphs will zoom in on the individual components itself, to find out what the component encompasses and how circular practices could be applied in the specific project component.

2.4.1 Initiative

For a construction project to start, an initiative must be taken to execute it. This initiative for a project might be the result of arising problems or new demands. During the initiation of the project, the client expresses its wishes and ideas for an object to be constructed in the public space. To a great extent, the project requirements are already identified (Cornick & Mather, 1999). In addition, the client determines and reserves funds for the project (Kagioglou et al., 2000) and establishes a feasible time schedule (CIOB, 2022).

The first circular practices can be made towards constructing a circular construction project when initiating the project. As addressed by Gerding (2019), the initiation of a project should be the starting point of implementing circularity into projects. The essential precondition for achieving circularity in a project during the initiation, is the commitment of all related actors (D'coutho, 2020; Kozminska, 2019; Gorgolewski & Morettin, 2009). The commitment of all parties to actively contribute to a circular project can be captured in the contract in which every party engages. Moreover, in 2030 this will become a standard as circular tendering will be obliged by the Dutch government in nearly all construction projects (Rijkswaterstaat, n.d.).

During the initiation of the project, the client will decide upon the type of contract to use to market the project and find suitable contractors or engineering firms for executing the project. There are eight frequently used contractypes to be distinguished in the Netherlands (PIANOo Expertisecentrum Aanbesteden, n.d.e):

- **RAW**
  Traditional contract type in which the contractor is responsible for constructing the intended structure. Design and engineering of the intended structure is provided by the client (PIANOo Expertisecentrum Aanbesteden, n.d.f);

- **Design & Construct (D&C)**
  Integrated contract type in which the contractor is responsible for designing and constructing the intended structure. Designing often includes the engineering of the structure as well. After completion of the construction, the contractor hands the structure over to the client (PIANOo Expertisecentrum Aanbesteden, n.d.c);

- **Engineering & Construct (E&C)**
  Integrated contract type in which the contractor is responsible for engineering a provided design and constructing the intended structure. After completion of the construction, the contractor hands the structure over to the client (PIANOo Expertisecentrum Aanbesteden, n.d.d);

- **Design, Build & Maintain (DBM)**
  Integrated contract type in which the contractor is responsible for designing, constructing and maintaining the intended structure. After completion of the construction, the contractor hands the structure over to the client to operate it. However, the contractor is still responsible for the maintenance of the structure during the agreed contract period (PIANOo Expertisecentrum Aanbesteden, n.d.a);

- **Design, Build, Maintain & Operate (DBMO)**
  Integrated contract type in which the contractor is responsible for designing, constructing, operating and maintaining the intended structure. After completion of the construction, the contractor is responsible for the operation and the maintenance of the structure during the agreed contract period (PIANOo Expertisecentrum Aanbesteden, n.d.a).

- **Design, Build, Finance & Maintain (DBFM)**
  Integrated contract type in which the contractor is responsible for financing, designing, constructing and maintaining the intended structure. After completion of the construction, the contractor hands the structure over to the client to operate it. However, the contractor is both responsible for financing the project itself and execution of the maintenance of the structure during the agreed contract period. The client reimburses the contractor with recurring payments (PIANOo Expertisecentrum Aanbesteden, n.d.b);

- **Design, Build, Finance, Maintain & Operate (DBFMO)**
  Integrated contract type in which the contractor is responsible for financing, designing, constructing, operating and maintaining the intended structure. After completion of the construction, the contractor is responsible for the operation and the maintenance of the structure during the agreed contract period. In addition, the contractor is also responsible for financing the project. The client reimburses the contractor with recurring payments (PIANOo Expertisecentrum Aanbesteden, n.d.b);

- **Bouwteam Design & Build**
  Integrated contract type in which the project consists of two main phases and hence two procurement procedures. During the first phase, the project is procured resulting in a collaboration between the contractor and client to design the intended structure. Secondly, during the second phase, the project is once again being procured for the construction of the designed structure (Bouwend Nederland, n.d.).

From the eight most used construction contract types seven are of an integrated nature, wherein the contractor is responsible for multiple tasks. As concluded by Lenferink et al. (2013), integrated contracts contribute to the development of sustainable infrastructure, hence circularity in construction projects. In summary, circularity in this project component can be achieved when all parties within the project are assessed as motivated to produce a circular project and are actively contributing to enabling this in the initiation of the project. As for the selected contract type, circular practices can benefit from applying an integrated contract, leaving more room for innovation.

2.4.2 Design

The design component encompasses the process of shaping the project from both an architectural and engineering perspective (Keoki Sears, 2015). All possible design solutions are proposed, discussed and agreed upon. Furthermore, the design component also includes the specification of the production and technical requirements for the designs (Cornick & Mather, 1999).
The design of a project or object to be constructed can play a large role in implementing circular practices into projects. Back in 2013, the Royal Society of Arts (RSA) already addressed the importance of rethinking design in order to achieve the CE. Aimed at the design of manufactured products, the RSA (2013) defined four basic models for designing for circularity, which are:

1. **Design for longevity**
   Promote a long life and reliable product that can easily be dismantled for upgrade or repair by user;

2. **Design for service/leasing**
   Changes the product ownership into a product as a service business model. As the product and, therefore, the material ownership stays with the producer or manufacturer, the designed products are durable and long lasting in order to maximize efficiency;

3. **Design for re-use in manufacture**
   Aims at the return of old products or their components back to manufacturers for an upgrade on faulty or obsolete parts replacement, to be subsequently resold;

4. **Design for material recovery**
   Recaptures materials and products to be reprocessed and recycled into new materials. This involves components that cannot be repaired or upgraded.

In succession and addition to these four circular product design models, the Ellen MacArthur Foundation (2017) defined the process of implementing circularity in design into four stages: Understand, define, make, release. These circular design steps are rather general and also aimed at product design, but convey the first principle of the CE and circular design: ''*Design out waste and pollution*'' (Ellen MacArthur Foundation, 2017). This basic principle is recognized in all four circular design models developed by the RSA. Not only in product design, but also in the construction sector, the design phase can make a great impact on the implementation of circularity in projects. In building projects it is even regarded as the most important phase to achieve circularity (Van den Berghe & Vos, 2019). Also for infrastructural construction projects, the design phase can guide towards circularity (Dijcker et al., 2018).

Circularity in the design phase of an infrastructural construction project can be achieved in multiple ways. Platform CB'23, a Dutch collaborative organization between different parties in the construction sector and researchers, developed a document in which the need for implementing circularity in the design phase of construction projects is addressed (Platform CB'23, 2021). This document serves as a mutual agreement within the parties in the construction sector on the actions to achieve a CE in the construction sector. Platform CB'23 (2021) developed the following six circular design strategies to be implemented in the design phase:

1. **Design for prevention**
   This strategy aims at preventing the use of products, materials or elements. This can be done by simply dispensing the construction, combining different functions or by developing an entirely different solution (Platform CB'23, 2021);

2. **Design for reducing lifecycle impact**
   This strategy aims at analyzing different design alternatives and their environmental impact, a lifecycle analysis can be utilized for this. From these design alternatives, the design which has the least negative impact on the environment will be implemented (Platform CB'23, 2021);

3. **Design for future-proofness**
   This strategy aims at designing an future-proof object. This is done by creating a design in which room is offered to accommodate the possibility to make adaptations to the object in order to satisfy and suit future needs (Platform CB'23, 2021);

4. **Design with reused objects**
   This strategy comprises of creating a design in which reused components or elements are applied. The components and elements are supplied by demolished objects (Platform CB'23, 2021);

5. **Design with secondary resources**
   This strategy comprises of designing with raw materials or residual streams that have been used before. These materials will replace the use of applying new raw materials (Platform CB'23, 2021);

6. **Design with renewable resources**
   This strategy consists of designing with renewable construction materials which are extracted from renewable sources. Renewable sources are sources which are grown, naturally supplemented or naturally cleaned on a human timescale (Platform CB'23, 2021).

These design strategies define the application of circularity practices in the design phase of a construction project. Since the strategies have been developed by an umbrella organization representing the construction sector, there is a consensus about these strategies. This makes the strategies fit to use as an index for circularity in the design phase.

Shaping the design also means to determine the technical specifications of the design, leading to more concrete objects to be constructed. Hence, the specifications have a certain level of influence on the level of circularity implemented in the project. It is however important for circularity purposes to prevent a high degree of specifications prior to the procurement or tender of the project, since it could cause a segregation between design and construction, leading to decreased innovation (Dubois & Gadde, 2002; Pietroforte, 1997) and thus the implementation of circularity. Furthermore, formulating and determining inflexible project specifications has similar negative consequences. Inflexibility in specifications can both be addressed to a high degree of specifications or the descriptive nature of the specification. To promote innovation (and therefore also circularity) it is attractive to formulate performance-based specifications. Performance-based specifications ‘’*allocates contractors' responsibility to develop and apply the means and methods of construction of their choice provided the end results meet the acceptance of the owner*‘’ (Rose & Manley, 2012). This provides the contractor with the flexibility to apply different solutions and emphasizes the use of innovations in their design and construction (Rose & Manley, 2012). Therefore, it is argued that innovation and foremost CE can be successfully implemented in the design when the specifications either have a flexible attribute and are non-descriptive or they are performance based. Complying with these properties leaves room for the contractor and creates incentives to innovate and thus e.g. introduce new elements of CE into a project.

2.4.3 Procurement

The procurement component is regarded as one of the most important components for contractors, as this component decides which contractor will execute the project. For the procurement of the project, the contractors writes a tender. This tender contains detailed designs, a project execution plan for the construction of the contracted object, and a price offer for the execution (Cornick & Mather, 1999). Once agreed upon by all parties, remuneration of the project is ensured since the tender also functions as a contract. Often contractors compete with one another for the awarding of the project, leading to competitive bidding. Depending on the type of issued procurement procedure or contract type, the contractor is expected to produce a financing scheme, more detailed design, usage plan, and a maintenance plan (Lenferink et al., 2013; PIANOo Expertisecentrum Aanbesteden, n.d.e).

As concluded by Eriksson (2017) and Tawiah et al. (2008), the tender, procurement and contracting strategies of the client are essential in facilitating innovation and sustainable development. Hence, implementing CE can be boosted by using the proper procurement strategy. With the goal of promoting sustainability in projects, the European Commission introduced directives for Green Public Procurement (GPP) (European Commission, 2006) and Sustainable Public Procurement (SPP) (European Commission, n.d.b). The published directives from the European Commission for SPP and GPP focused on including sustainability goals for public procurement, making it possible for contractors to earn a fictitious discount on the tender amount. Especially aimed at the CE and in line with SPP and GPP, the European Commission introduced Circular Public Procurement (CPP) in order to promote circular practices and award contractors who do so (European Commission, 2017). The European Commission defines circular public procurement as: "*The process by which public authorities purchase works, goods or services that seek to contribute to closed energy and material loops within supply chains, whilst minimizing, and in the best case avoiding, negative environmental impacts and waste creation across their whole life-cycle*" (European Commission, 2017). Hence, CPP addresses the need for a circular ambition wherein services and products are produced with an extended life span and value retention (Sönnichsen, & Clement, 2020; Alholla et al., 2019). Tools like performance based procurement, life cycle approach, life cycle costing and reuse/recycle criteria as elements of CPP can promote circularity in the project (Allholla et al., 2019).

2.4.4 Construction

During the construction phase, the object is being constructed, according to the plans and contract agreed upon in the procurement component. (Cornick & Mather, 1999; Lenferink et al., 2013). The actors involved in this phase are: Client, designer, construction advisor, contractor and possible subcontractors

(Cornick & Mather, 1999). All activities and materials prescribed are brought to execution in the construction component. Project data consists mainly of contract documents, e.g. cost estimations, work plans and drawings. This data provides an overview of the amount of materials used and the activities executed. The construction component is also the component in which the circularity, material wise, is put into practice according to elements of the R-model. Hence circular practices in the construction could be refusal of materials, reduced amount of materials, reuse of materials, repair of materials, refurbishment of materials, remanufacturing of materials, repurposing of materials, recycling of materials, material recovering, and remining of materials (Reike et al., 2018). However, in order to execute circular practices in the construction component, all other components should put their effort in facilitating these practices.
At the moment of writing, there are three methods of measuring circularity which are accessible by the researcher, which are Dura Vermeer's KPI method, the circularity measurement method from the Ellen MacArthur Foundation, and the Platform CB'23 circularity measurement method (Dura Vermeer, 2020a; Ellen MacArthur Foundation, 2019; Platform CB'23). All of these circularity measurement methods are determined by linking the mass of materials and the duration of activities to predetermined values for each individual material or activity. Further elaboration and substantiation on the targeted method can be found in paragraph 3.4.

2.4.5 Operation & maintenance

The final construction project component is the operation & maintenance of the project. This component comes into play once the project has been constructed and its operations, and regular maintenance, can start, ensuring a successful lifecycle (Cornick & Mather, 1999; Kagioglou et al., 2000).

Once the project is completed and the handover has taken place, the contractor loses its main responsibility of the project, unless the issued contract is a DBM, DBMO, DBFM, DBFMO, or Bouwteam type of contract (PIANOo Expertisecentrum Aanbesteden, n.d.e). In projects which issued these types of contracts, the contractor is held responsible for the maintenance and operation of the object during the time span of the contract. These contracts could therefore create an incentive for the contractor to construct a good, solid object which can serve an extended life-cycle due to frequent maintenance (Lenferink et al., 2013). The client and contractor can even agree upon a CE-type of contract wherein the contractor is also held responsible for the deconstruction of the object after its service-life, which could be beneficial for re-using object components. However, since the issued contract type is chosen at the very start of a construction project, the contract-type cannot be attributed as a circular practice of this project component.

In the ultimate CE, the project process is not linear and hence the last component in line is connected to the first component, safeguarding the circular process. In essence, when applied to construction projects, the output (or materials) of the last component forms the input for the first component of the same or a different project to be processed further. Once again, the R-model for circularity comes into play. Different R's determine the level of how an obsolete object should be processed or handled in order to enter into a new (circular) lifecycle. By smart disassembly of the object, most materials can be harvested from the object to be used in a new construction project, thus closing the loop of the CE (Ghaffar et al., 2020). Harvesting materials from objects which have reached their end-of-service-life is regarded as a circular practice in the demolition of a project. Therefore, the end-of-service-life is interesting to address as well in this project component. However, these components are part of the construction of a project, not the demolition of it. But this component could already serve as a preparation for its materials in a new lifecycle, by adding the materials to a madastre and constantly tracking these. Addition of a harvested Material passport is essential for a paradigm shift towards a functioning circular construction industry (Heisel & Rau-Oberhuber, 2020). This provides an overview of the stock of available reusable materials. Controlled operations and regular maintenance can ensure the quality of the materials, hence enhancing future possibilities of using the materials, and ultimately closing the CE-loop (Sassi, 2008).

2.5 Circular construction project

Succeeding the background information on CE in the construction sector and the circular practices per project component, more elaboration on the definition of a circular construction project is given. Due to its novelty and the increasing pressure as a result of government policy, CE is becoming more and more popular. On one hand, this is positive, since more attention creates an incentive for more direct action to be taken. On the other hand however, the popularity may cause projects and objects to be labeled and marketed as circular to respond to the trend, even though circularity is only applied to a limited proportion of the object or project. To ensure uniformity, a definition of a circular infrastructural construction project will be decided upon and maintained throughout this study.

Platform CB'23 (2021) uses the following definition for a circular structure: ''*A structure that has been designed and executed according to circular design principles and/or is constructed using circular products, elements and materials*''. This description of a circular project is rather broad, therefore it will be further specified. To decide whether a project is a circular project, is done with help of the 10R-model for circularity and the ''Leidraad Meten van circulariteit 3.0'' from Platform CB'23 (2022). As noted before, the 10R-model consists of 10 circular principles, ranked from a high to a low level of circularity: Refuse, Reduce, Re-use, Repair, Refurbish, Remanufacture, Re-purpose, Recycle, Recover and Re-mine (Reike et al., 2018). Using the definition of circular construction projects by CB'23, which is partly formed upon the 10R-model, a circular construction project can be identified. For the project to be considered as circular and thus to be selected as the circular case study, it must comply in a positive manner with the CE design principles as elaborated in section 2.4.2, which are: Design for prevention, design for reducing lifecycle impact, design for future-proofness, design with reused objects, design with secondary resources, and design with renewable resources. A construction project must aspire these principles upfront in order to be labeled as circular. The last couple of years, a number of methods have been developed to measure the level of circularity in a project after completion. Section 3.4 will provide a more elaborate explanation about the level of circularity in the project and how to measure this.

2.6 Framework literature study

With the completion of the literature study, the first research sub question can be answered: ‘’*How is the circular economy implemented in the construction industry in general and in infrastructural construction projects?*’’ By combining the major findings of the literature study in a framework, the sub question can be answered. Figure 2.5 summarizes the major findings per segment of SQ1 as determined in the introduction of this chapter and in figure 2.1. However, more in-depth information on the major findings can be found in the related paragraphs of the literature study.

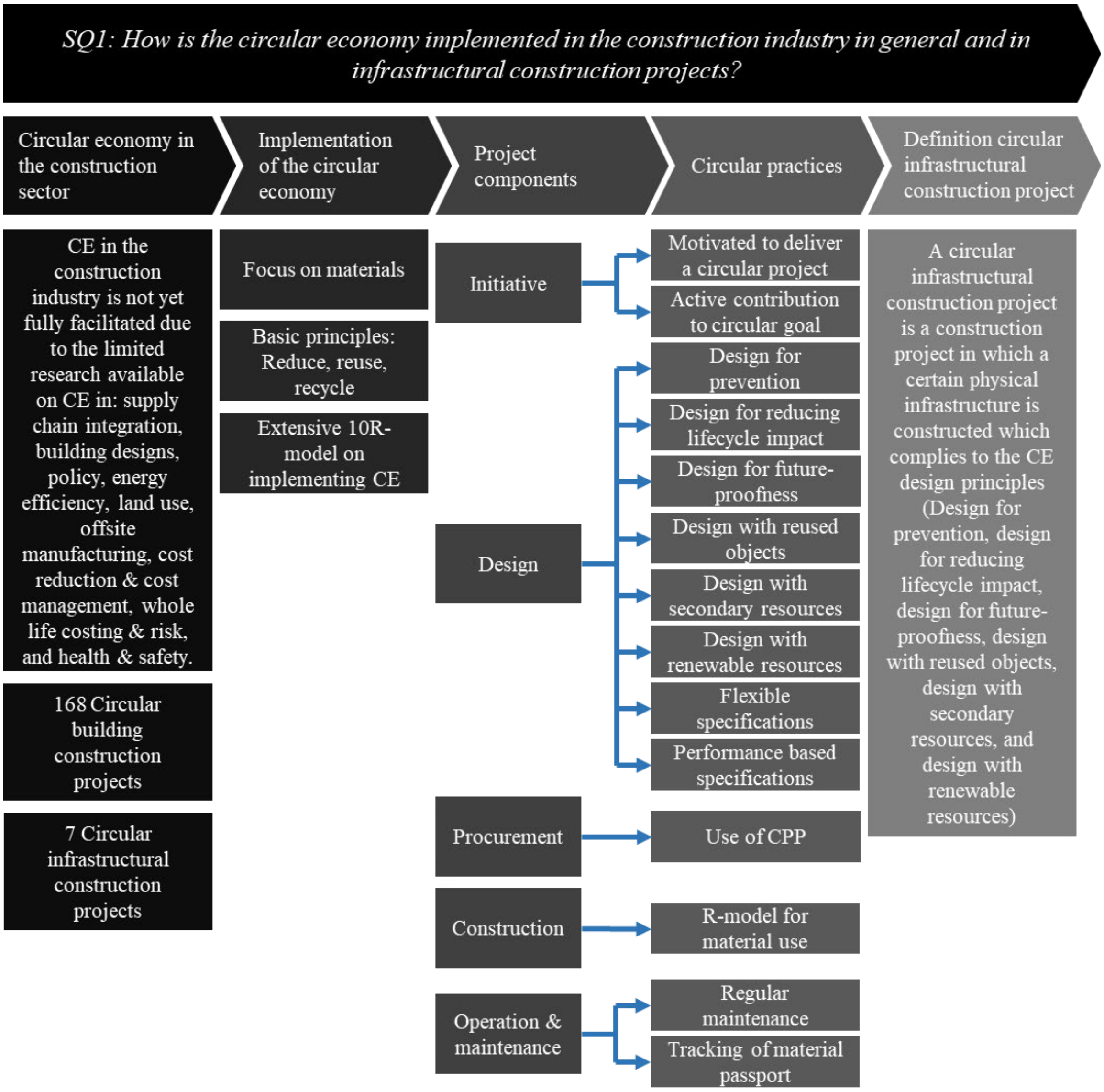

Figure 2.5: Literature study framework (own image).

The literature study findings functions both as a background of this research and a starting point for the methodology of this study. The identified project components will serve as basic knowledge on which the process of a project can be identified. Subsequently, this can coupled with knowledge on the activities and construction costs, identifying what circular practices have been applied in circular infrastructural construction project. Having formulated the definition of such a project provides the use of genuine circular projects and thus prevents project containing greenwashing. Further elaboration on the exact application of the information found in the literature study will be given in the next chapter.

3

Methodology

This research is set out to provide an answer to the main research question, which is formulated as: ''What are the effects of the implementation of circularity on the activities and costs in infrastructural construction projects?''. To do so, a research method needs to be designed to answer this question, which led to the formulation of research sub-question 2 (SQ2): ''How can the differences in process and costs between a circular infrastructural construction project and a regular infrastructural construction project be disclosed?''. This chapter will answer this question and illustrate a clear path for the research to follow. Paragraph 3.1 will focus on the selection procedure of projects to be included in the case study. Once these projects have been identified, the data can be gathered from these projects by execution of the case study. Methods of gathering data will be further elaborated per main pillar, as concluded by the literature research in chapter 2. First, paragraph 3.2 focusses on the method to calculate the level of circularity of the projects in the case study. Secondly, paragraph 3.3 will elaborate upon an approach to analyze the project process. Thirdly, the approach to determine the construction costs will be explained in paragraph 3.4. Paragraph 3.5 elaborates upon the method to analyze, compare and process the data as a result of the case study, which is the cross-case analysis. Finally, paragraph 3.6 summarizes the methods and approaches applied in this research in a conclusion of this chapter.

In order to generate a substantiated and comprehensive answer to the main research question, qualitative research will be performed, resulting in an in-depth and detailed understanding of a subject and its effects (Knafl & Howard, 1984). Due to the practical nature of the research question, a qualitative research approach will be performed by means of a multiple case study, consisting of two cases. Through thorough analysis of the individual cases, information and data will be collected. The choice for the analysis of two cases is substantiated by Yin (2003), arguing that results and conclusions drawn from one case study are less powerful than those from more than one case study. Furthermore, selecting only one case study could cause uncertainty about the case, considering the uniqueness or conditions of the case, leading to skepticism of the case study. The use of two cases will reduce or eliminate the skepticism that could arise (Yin, 2003). Selecting the cases to include in the multiple case study is also bound to certain requirements, validating its credibility. The cases from the multiple case study should be selected with the prerequisite that for each case similar results are predicted or that, for predictable reasons, contrasting results are expected (Gustafsson, 2017). Understanding the similarities and differences between each case generates important influences to the literature, which is the ultimate goal of a properly executed multiple case study (Gustafsson, 2017). To gather this data in the case study, a wide variety of approaches and methods are available, such as archival data gathering, questionnaires, interviews, and observations (Fellows & Liu, 2015). This case study is no exception and will also consist of a combined approach of different methods for gathering data about the cases. Execution of a case study is in line with what Adams et al. (2017) suggested to be beneficial in deconstructing the barriers towards implementing circularity in the construction sector

3.1 Case selection

The case study will consist of two cases. One case will be a circular infrastructural construction project, while the other case will be a regular or traditional infrastructural construction project. Selecting both cases for the case study will be done in two different manners. The circular case will serve as the base case for the case study and is chosen first. Secondly, the regular case project is chosen. The circular projects' characteristics determine the selection requirements for the regular project.

3.1.1 Circular infrastructural construction case project

Circular infrastructural construction projects are relatively new to be constructed, and are therefore scarce. Only a handful of these projects have been completed in the Netherlands, see section 2.1, making the circular case project pool limited in size to select a suitable project from. Large circular projects, above the €5.382.000 threshold for European procurement, have not yet even been constructed in the Netherlands. From the small pool of available projects, a choice needs to be made for a circular project case. For this circular project case, the definition of a circular construction project will be used as defined in the literature study in section 2.5.

As concluded in the literature study, the description of a circular infrastructural construction project is: *A circular infrastructural construction project is a construction project in which a certain physical infrastructure is constructed which complies to the CE design principles (Design for prevention, design for reducing lifecycle impact, design for future-proofness, design with reused objects, design with secondary resources, and design with renewable resources)*. This description will be used to select a suitable circular infrastructural construction project to be included into the case study.

There are other requirements which need to be met in order to select a circular case study. As a prior requirement for the projects to be included in the selection, it needs to be addressed as innovative, due to the niche or innovative nature of circularity in construction projects. In addition, it is desirable that the project has been executed by Dura Vermeer due to the availability and access of inside project information. Furthermore, the project needs to be of infrastructural nature and it has to be completed within the last 2 years to guarantee its actuality. Preferably, the circular case project is a bridge that has been constructed, since these objects are most fit for circular practices. This is due to the fact that most bridges are demolished before they reach their projected service life, resulting in many reusable components which are structurally still in good condition (Coenen et al., 2020). According to Rijkswaterstaat (2020) 80% of the targeted bridges and viaducts for demolition in 2020 were still in such good condition that they could serve elsewhere as bridges or viaducts for another service life.

Searching for and identifying innovative and circular infrastructural construction projects executed by Dura Vermeer, led to the project Tweede leven brug, which was completed in 2021. This is an infrastructural construction project for the construction of a pedestrian and bicycle bridge which has been entirely constructed from reused materials. The bridge is located on the site of the International Horticultural Exhibition Floriade in Almere. After the event, this site will be transformed into a new residential area wherein the Tweede leven brug will remain to be a part of its vital infrastructure. This project will be chosen as the circular case project to be included in the case study.

3.1.2 Regular infrastructural construction case project

In contrast to the selection of the circular case project, the non-circular or regular case project can be chosen from a large pool of available projects. Regular infrastructural construction projects do not have a circularity goal or a circular ambition, making these more common and hence a wider range of available case projects. This section will elaborate on how a suitable regular case project has been selected to be included into the case study.

As a first preliminary requirement, the projects selected for the case study must already have been executed and will not be older than five years, calculated from the starting date of the tender. The requirement that the project has already been executed allows for a thorough case study research of the project results after its completion. The five year border guarantees the actuality and accuracy of the project data on its processes, components and costs. An additional prerequisite requirement is that the constructed object of the case project must also be a bridge, for equal comparison. The combination of these projects' recency and the age of transition we are currently living in makes it possible that we are, unknowingly perhaps, already creating opportunities in projects for sustainable ideas, knowing that one of the methods or tools to reach sustainability is circularity. It can therefore not be assumed that regular or traditional projects are fully traditional, meaning that it is very likely that projects of this size still contain a small sustainable part, hence the project not being fully traditional. Therefore, the term 'regular project' is selected over 'traditional project'. Concluding, this regular infrastructural construction project has no direct goal to be a sustainable or circular construction project, but it could consist of small sustainable elements which have become ''standard'' over the years. To further analyze the available projects and to select a suitable regular case project, selection metrics have been defined. Subsequently, the best comparable regular case project will be chosen with help of the determined metrics.

3.1.2.1 Case selection metrics

The most suitable case project should have similarities or comparable properties with the circular project case, the project Tweede leven brug. There is a total of ten different projects which comply to the preliminary case project requirements and are thus eligible of being selected as the regular case project. In order to find the best comparable case project, the following metrics have been determined:

Project size

The second metric is the project size, which is subdivided in the length and the width of the constructed object and the ratio between the length and width. The dimensions of the object could have influence on the processes, constructability, complexity, costs, schedule and quality of the overall project. Since it is very likely that there is no project available with the exact same dimensions, the ratio length to width has been added to this metric. On project size it is desirable that the regular case projects roughly has the same ratio as the circular project case.

Materials

The applied materials are included in the selection procedure as metric, since the used materials in a construction project can influence the construction process, design and costs greatly. This is due to different production processes, different material properties and differing purchase prices Therefore, the materials of which the object has been constructed need to be similar. Similar material use makes both projects comparable to one another and contributes to the scientific foundation of the case study.

Complexity

Complexity is a project characteristic which can have great influence on the process itself, related costs and project schedule. A higher project complexity may pose an influence on construction costs, project schedule, project quality and project safety (San Cristóbal, 2017). It is therefore an important metric to include in the selection procedure. Geraldi et al. (2011) discovered five dimensions on which a project could be regarded as complex, these are: structural, uncertainty, dynamics, pace, and socio-political.

As determined by Geraldi et al. (2011), the five dimensions of complexity can be identified by different attributes of a construction project. Attributes for structural complexity are a large project size, much variety in the project, or many interdependencies between elements of the project. Causes for uncertainty complexity are the application of a novelty in the project, lack of experience with project elements, and the lack of availability of information. Dynamics complexity is caused by changes that appear in the project on specifications, management team, suppliers, or in the environmental context. Pace complexity can be identified by the pace of the project or the rate at which projects are delivered. A high pace of projects leads to pace complexity. Lastly, the causes for socio-political complexity are importance of the project, the support towards the project from project participants and stakeholders, the alignment of opinions, interests and requirements, and lastly, the transparency of hidden agendas. A project which is of high importance, lacking support from project participant or stakeholders, missing alignment of opinions, or missing transparency among its participants can lead to socio-political complexity in a project. To assess the complexity of the available construction projects, five degrees of complexity will be maintained: Not complex, slightly complex, moderately complex, very complex, and extremely complex. The available projects will awarded a certain degree of complexity, according to the five characteristics of complex projects defined by Geraldi et al. (2011), see table 3.1 below:

Table 3.1: Different types of complexity within projects (table adapted from Geraldi et al. (2011)).

Type of complexity	***Attributes of complexity***
Structural	• Project size; • Variety; • Interdependencies.
Uncertainty	• Novelty; • Experience; • Availability of information.
Dynamics	• Changes in project.
Pace	• Pace of the project.
Socio-political	• Importance of the project; • Support to (project) or from (stakeholders); • Alignment of opinions, interests and requirements; • Transparency

The attributes mentioned in table 3.1 are indicators of a specific type of complexity in a construction project. It is therefore also possible for projects to experience multiple types of complexity. To quantify and measure the complexity of a project, a scale has been determined, see table 3.2. Based on this scale, the projects in the gap analysis will be awarded a certain degree of complexity for comparison purposes.

Table 3.2: Project complexity scale.

Number of types of complexity present in project	***Project complexity***
0-1	Not complex
2	Slightly complex
3	Moderately complex
4	Very complex
5	Extremely complex

Contract type

The type of procurement and issued contract roughly determines the process the involved parties will be proceeding when developing the project. As was concluded in the literature study in paragraph 2.3, different type of contract may cause different sequences of project components. Because of the possible differences in the projects' process and phasing, it is necessary that the projects are issuing the same type of contract to make a fair comparison.

Project duration

The completion date is included in the gap analysis as well to showcase the recency of the projects. As noted mentioned before, there is a prerequisite requirement that the projects starting dates should be no more than five years ago. The minimum requirement for the starting year of the projects in the gap analysis is 2017. The costs of a project are greatly influenced by the year in which a certain object has been constructed due to the fluctuating price level of both materials and labor. Thus, the closer the dates are together, the better comparable the projects are.

Construction costs

The construction costs are part of the project characteristics, but merely functions as an informational source. Since the construction costs are one of the more interesting aspects of this case study and a difference is expected between the costs of different case projects, there is no need for using construction costs as a metric. It is necessary to ensure that the construction costs are included in this gap analysis and not the total project costs, considering that the transactional costs are included in the total project costs as well. More elaboration on the construction costs is provided in paragraph 3.5.

Location

The location of the construction project is a metric which is included in the selection procedure as well. The location of the project can affect the accessibility of the project and hence also the costs of the project. Given the fact that differences in the Netherlands are relatively small between project locations, the choice for a comparable project case will not be heavily influenced by the project's location.

3.1.2.2 Selection regular infrastructural construction project

From the list of possible case projects, a suitable regular case project is chosen. This has been done by comparing the characteristics, or metrics, of the circular case project to those of the regular project. The characteristics of the projects are all combined in table 3.3, including the circular case project, providing an overview of the metrics. The goal is to find to best comparable case project to the base case. Table 3.3 is used to select the best comparable case project to the circular case project mentioned at the top of the table. More detailed information on the case projects is provided in Appendix A.

Table 3.3 : Overview case selection.

	Name project	Type object	Size			Materials	Location	Complexity	Contract type	Year finished	Price offer
			Width	Length	Ratio						
1	Tweede leven brug	Bicycle and pedestrian bridge	5m	80m	1 : 16	Concrete, steel, wood	Almere	Very complex	Design & construct	2021	€ 817 700,00
2	Prins Clausbrug	Bicycle and pedestrian bridge	14m	137 m	1 : 10	Concrete, steel	Dordrecht	Very complex	Design & construct	2021	€ 11 667 000,00
3	Jan Linzelviaduct	Bicycle and pedestrian bridge	6,50 m	335 m	1 : 51,50	Concrete, steel	Den Haag	Moderately complex	Design & construct	2020	€ 9 377 000,00
4	Plaspoelhaven brug	Bicycle and pedestrian bridge	3,90 m	22,85 m	1 : 6	Composite	Leidschendam	Not complex	Design & construct	2018	€ 157 038,99
5	Enkele Wiericke fietsbrug	Bicycle and pedestrian bridge	2,50 m	21,50 m	1 : 9	Concrete	Nieuwerbrug	Not complex	Design & construct	2022	€ 262 957,29
6	Enkele Wiericke verkeersbrug	Traffic bridge	7 m	17 m	1 : 2,50	Concrete	Nieuwerbrug	Not complex	Design & construct	2022	€ 333 401,88
7	Schiebroeksepolder brug	Bicycle and pedestrian bridge	4,80 m	17,50 m	1 : 3,50	Concrete	Schieveen	Not complex	Design & construct	2019	€ 122 137,13
8	Wisenniabrug	Bicycle and pedestrian bridge	2 m	30 m	1 : 15	Concrete, steel	Leiden	Very complex	Design & construct	2020	€ 535 056,59
9	Rhijngeest	Bicycle and pedestrian bridge	5 m	17,80 m	1 : 3,50	Steel, composite	Oegstgeest	Not complex	Design & construct	2020	€ 215 000,00
10	Kraanvogelbrug	Bicycle and pedestrian bridge	4,75 m	34,5 m	1 : 7,50	Steel	Spijkenisse	Slightly complex	Bouwteam	2017	€ 1 990 000,00
11	Kickersbloem	Traffic bridge, including bicycle and pedestrian lanes	25,15 m	46,55 m	1 : 2	Concrete, steel	Hellevoetssluis	Slightly complex	Design & construct	2020	€ 2 504 324,40

The Wisenniabrug in Leiden has been selected as the regular case study since this project is the best comparable to the circular case project. The Wisenniabrug might be a smaller project, but the ratio width to length is nearly the same as that of the Tweede leven brug. All remaining projects have ratios which differ more from the circular case. The function of the Wisenniabrug being a bicycle and pedestrian bridge corresponds with the function of the Tweede leven brug. In addition, both bridges are constructed in an urban environment. Lastly, both projects are regarded as projects with a similar level of complexity. Concluding, the Wisenniabrug is the best comparable case project in regard to the Tweede leven brug.

3.2 Circularity assessment

There are currently three methods available for assessing circularity in construction projects. These are the Material Circularity Indicator (MCI) developed by the Ellen MacArthur Foundation (2019), the method of measuring circularity developed by Platform CB'23 (2022), and lastly the in-house company KPI-method developed by Dura Vermeer. These three methods will be first be elaborated and a method will be chosen to use in this study. Secondly, the chosen method will further explained, including the necessary calculations and formulas.

3.2.1 Circularity measurement method selection

The Ellen MacArthur Foundation MCI method is aimed at companies in all sectors and industries. The MCI provides these companies with an indication of their progress from an linear to a circular model, both on product level and on business level (Ellen MacArthur Foundation, 2015). Due to the general nature of this method however, it is not specifically aimed the construction sector. Therefore it could lack in specific applicability to the construction sector.

The KPI method from Dura Vermeer is specifically aimed at construction projects, and seems therefore suitable to apply in this study. This method determines the level of circularity in a project based upon three Key Performance Indicators (KPI's); percentage input of secondary or biobased materials, percentage output of high-quality reusable materials, and the percentage output of design of objects for future reuse (Dura Vermeer, 2020a). The downside to this method however, is that it is an in-house company method which is only accessible by Dura Vermeer. This results in that measurements on circularity made in this research are not publicly traceable, hence verifiable.

The circularity measurement method from CB'23 is, like the Dura Vermeer KPI method, aimed at the construction sector specifically. The measurement method from CB'23 has been developed collaboratively government agencies, companies and institutions in the construction sector, and is regarded as a consensus upon circularity in the Dutch construction sector (Platform CB'23, 2022). This method focusses on six main indicators which includes all aspects related to both circularity in material use and in application. In contrast to the KPI method, the CB'23 method is publicly accessible and under constant development. This creates the possibility for future improvements of this method to be applied and included in this research, making it resilient for future use. Therefore, the choice has been made to use the CB'23 circularity measurement method in this study to measure the level of circularity of the case projects.

3.2.2 Measuring circularity

To provide guidance to companies in measuring the level of circularity in construction projects, Platform CB'23 set up a guide to do so, which is actively being developed. The guide ''Leidraad Meten van circulariteit 3.0'' replaced ''Leidraad Meten van circulariteit 2.0'', both from Platform CB'23 (2022), recently. This most recent method described from Platform CB'23 for measuring the level of circularity in construction projects is based upon six indicators, which are the following as formulated by Platform CB'23 (2022):

1. **Quantity of primary and secondary, scarce or non-scarce, materials used;**
   This indicator resembles the quantity of input material necessary for the project or object to be constructed. The input materials can be divided into two dimensions: Primary (new) or secondary materials, and scarce or non-scarce materials. Primary materials could either be produced from renewable or non-renewable resources, while secondary materials could either come from reusing or recycling. The scarcity of a material can be subdivided into physical scarcity and socio-economic scarcity, an overlap in these types of scarcity is also a possibility. The renewable primary materials can even be further divided into sustainably produced material and non-sustainably produced material.

2. **Quantity of material available for the next cycle;**
   This indicator features the quantity of output that is generated by the project which is available for the next cycle. This output could either be recycled or, even better, be reused.

3. **Quantity of materials lost;**
   This indicator covers the quantity of materials that are lost after the service life of the constructed object. These materials will then be used for energy-recovery or landfill.

4. **Environmental impact;**
   Every material used in a project has a certain impact on the environment as a result of material extraction, material processing and transport. It is therefore important to take these environmental impacts into account whenever a project is assessed on circularity, since circularity is eventually one of the methods to reduce the negative impact on the environment.

5. **Quantity of functional value at the end of the lifecycle;**
   This indicator focusses merely on the end of the lifecycle, and covers the amount of functional value that is left of a component. It does so by including and assessing the functional quality, technical quality, degradation of the component, and the re-use potential.

6. **Quantity of economic value at the end of the lifecycle;**
   As similar with indicator 5, this indicator only focusses on the end of the lifecycle. The components are assessed on their economic value that they have left. Costs including disassembly, transport, processing, and disposal are subtracted from the leftover economic value.

3.2.2.1 Exceptions from the circularity measurement method

The circularity measurement method is based on the six indicators mentioned in the previous section. However, in this study, not all indicators will be used to measure the circularity in the case projects.

Indicator 4 features the environmental impact of the project in financial terms. The environmental impact in financial terms of materials can be determined by calculating the ECI (environmental cost indicator) or Milieukostenindicator (MKI) in Dutch (Stichting Bouwkwaliteit, 2019). This ECI-score is currently applied in nearly every large tender (PIANOo Expertisecentrum Aanbesteden, 2019). With the ECI it is possible to calculate the total environmental costs during the entire lifespan of a structure of all used materials (Stichting Bouwkwaliteit, 2019). The ECI is calculated by first estimating, in the tender, the total amount of materials that will be used in the construction. Secondly, these amounts will be multiplied by the shadow costs of these materials. The shadow costs are the costs that arise as a result of the impact of the material on the environment. Once completed for every component, the ECI can be determined. The ECI-score only indicates the environmental costs of the project. When applied in projects, it is often one of the deciding factors in MEAT (Most Economically Advantageous Tender) procurement procedures, to generate a fictional discount on a tender. When procurement procedure has ended, there is no further use of the ECI-score. In practice however, the ECI-score on concludes about sustainability only, circularity is not regarded. It is often even just used for the procurement only, to decide upon which tender has won (C. Reit, personal communication, October 13, 2022). Additionally, there is confusion among the experts about calculating the ECI-scores, more specifically, when to take into account the shadow costs of reused materials (I. Spierings, personal communication, September 22, 2022). Since the ECI-score has no bearing on circularity, and due to the divided opinions about how to calculate ECI-scores for circular projects, the choice has been made to exclude indicator 4 from the circularit measurement method.

Whilst the 10R-model summarizes circular strategies, the above mentioned indicators measure the circular impact a project has (Platform CB'23, 2020). However, there is still uncertainty present about value retention at the end of the lifecycle, which is represented by indicators 5 and 6 (Platform CB'23, 2022). The lifecycle of a certain civil structure often ends several decades into the future. This makes it difficult to formulate a prediction, based on present day knowledge, for the remaining value of a certain component after its lifecycle. There is no accurate knowledge available about the events, dangers and other circumstances the structure will encounter during its lifecycle, since we simply cannot foresee the future. Merely a prediction can be made of the value of the components. Introducing predictions leads to uncertainty, which needs to be prevented in order to reach accurate results from this research. Hence, indicators 5 and 6 will be excluded. Summarizing, the decision has been made to exclude indicators 4, 5 and 6 from the circularity measurement method, in order to assess the level of circularity of the case study projects. Uncertainty is governing in all three indicators, leading to this decision.

3.2.3 Calculating circularity

The four included indicators in this study for measuring circularity are adapted from the circularity measurement method of Platform CB'23. These indicators are based upon the used materials, their origin and its expected future potential. Each indicator is subdivided into several components of the respective indicator, resulting in a specific formula for every individual component. Figure 3.1 shows the included indicators and its subdivision of components. Next up, the subdivisions of indicators are described. The circularity measurement formulas related to the indicators are provided in Appendix B.

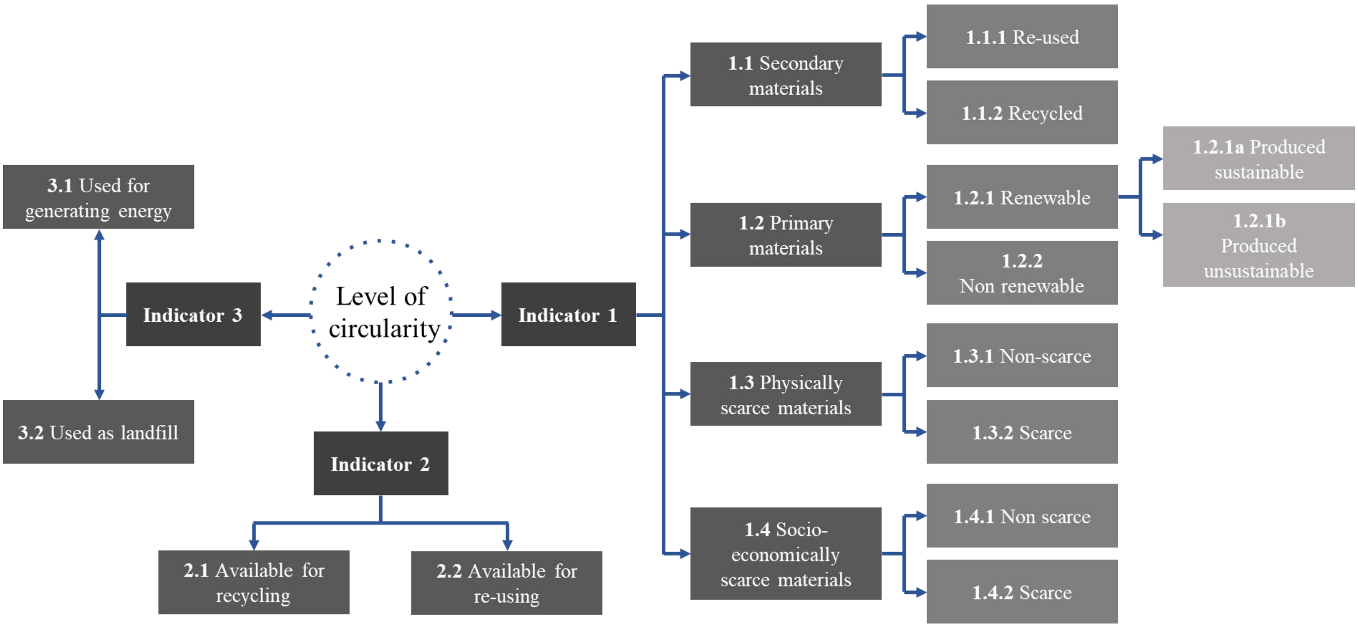

Figure 3.1: Overview included CB'23 circularity measurement indicators and its subdivisions (own image, adapted from CB'23, 2022).

3.2.3.1 Indicator 1

Indicator 1 resembles the amount of input materials to construct or repair the object and is divided into primary, secondary, physically scarce, and socio-economically scarce materials. These input material flows are even further subdivided into more specific flows, showing the proportion of material in relation to the entire object.

Indicator 1.1 resembles the secondary materials, which is the amount of materials that has already served one or more lifecycles before being applied in the current project. These secondary materials are subdivided into re-used secondary materials and recycled secondary materials. The reused secondary materials are materials or components which have required little adaptations to be applied in the current project. The recycled secondary materials are materials which originate from recycling, meaning that the original component after its lifecycle was divided into raw materials, which is subsequently being applied in the current project. A high amount of applied secondary materials is beneficial to the circularity score of the project.

Indicator 1.2 consists of the primary materials, which are the materials that are being applied for the first time, directly originating from the natural resources. These materials are further subdivided into renewable and non-renewable primary materials. Renewable primary materials are the newly applied materials originating from renewable raw materials, non-renewable primary materials are not originating from renewable raw materials. A renewable raw material is originating from a resource which is grown or replenished on a human timescale (Platform CB'23, 2022). The renewable materials are further subdivided into materials produced sustainable and materials produced unsustainable, according to the NIBE-report ''Hernieuwbare grondstoffen'' (2021). Additionally, the sustainability of sustainably produced primary materials has been approved by internationally acknowledged certification or other product data. A high amount of applied primary materials is not beneficial to the circularity of a project. Whenever primary materials should be applied, sustainably produced renewable primary materials contribute the most to circularity.

Indicator 1.3 resembles the physically scarce materials applied in the project. However, the physically scarce material indicator has not been developed yet. Currently, CB'23 is investigating the usage of abiotic depletion potential for determining physically scarce materials (Platform CB'23, 2022).

Indicator 1.4 defines the amount of socio-economically scarce and non-scarce materials applied in the project. Whether a material is regarded as socio-economically scarce or not, is determined according to the list of critical raw materials for the EU (European commission, 2020b). A low amount of socio economically scarce materials is beneficial to the circularity score.

3.2.3.2 Indicator 2

Indicator 2 resembles the amount of output materials which are likely to serve another use in a lifecycle after ending the current lifecycle. This could either be done by re-using or recycling the components or materials. Indicator 2.1 summarizes the amount of materials available for reuse in the next lifecycle, while indicator 2.2 sums up the amount of materials available for recycling. The expected future use of the applied materials will be determined by gathering input from project participants by interviews. Both a high amount of reusable and recyclable output material is beneficial to the level of circularity. However, since reuse is higher on the R-model than recycle, re-use is more beneficial to the circularity score.

3.2.3.3 Indicator 3

Indicator 3 resembles the amount of output materials which are likely to not be applied once again in a lifecycle by re-use or recycle. The material amounts are most likely discarded by either incineration and energy generation, indicator 3.1, or used as landfill, indicator 3.2. The expected future use of the applied materials will be determined by gathering input from project participants by interviews. Both of these future purposes for the materials are not beneficial to the circularity score. Hence, a lower amount of materials appointed to indicator 3.1 or 3.2 is better for the circularity in a project.

3.2.3.4 Indicator 4

Indicator 4 features the environmental impact of the project in financial terms. The environmental impact in financial terms of materials can be determined by calculating the ECI (environmental cost indicator) or Milieukostenindicator (MKI) in Dutch (Stichting Bouwkwaliteit, 2019). This ECI-score is currently applied in nearly every large tender (PIANOo Expertisecentrum Aanbesteden, 2019). With the ECI it is possible to calculate the total environmental costs during the entire lifespan of a structure of all used materials (Stichting Bouwkwaliteit, 2019). The ECI is calculated by first estimating, in the tender, the total amount of materials that will be used in the construction. Secondly, these amounts will be multiplied by the shadow costs of these materials. The shadow costs are the costs that arise as a result of the impact of the material on the environment. Once completed for every component, the ECI has been determined. In practice, the ECI is applied during the specification phase and tender phase. The client determines two ECI-scores in its project requirements: The reference score, which is a minimum prerequisite, and the target score, which is the best achievable score (N. Hop, personal communication, May 31, 2022). Mind that the lower the ECI-score is, the better the party’s tender is. In MEAT (Most Economically Advantageous Tender) procurement procedures the party with the lowest ECI-score can earn the highest fictional discount on their tender bid, thus resulting in a more competitive bid.

3.2.3.5 Circularity score

The aforementioned indicators result in different percentages of materials in both flows of input or output. Per case study project, the calculated values of the indicators will be presented in a table. Table 3.14 shows an overview of what the (sub)indicators describe with the calculated values. The circularity assessment of both cases will result in a similar table, showing a clear overview of the values of the circularity indicators.

Table 3.4. Overview of indicators for circularity measurement.

Indicator	Symbol	Description
1.1	S_x	Percentage secondary input material of total object or sub-object
1.1.1	H_x	Percentage re-used input material of total object or sub-object
1.1.2	R_x	Percentage recycled input material of total object or sub-object
1.2	V_x	Percentage primary input material of total object or sub-object
1.2.1	H_x	Percentage renewable primary input material of total object or sub-object
1.2.1a	N_x	Percentage sustainably produced renewable primary input material of total object or sub-object
1.2.1b	VN_x	Percentage unsustainably produced renewable primary input material of total object or sub-object
1.2.2	NH_x	Percentage non-renewable primary input material of total object or sub-object
1.3.1	n/a	In development
1.3.2	n/a	In development
1.4.1	NK_x	Percentage socio-economically non-scarce material of total object or sub-object
1.4.2	K_x	Percentage socio-economically scarce material of total object or sub-object
2.1	H_g	Percentage realistic re-usable output material of total object or sub-object
2.2	R_e	Percentage realistic recyclable output material of total object or sub-object
3.1	R_{ew}	Percentage output material used for energy generation
3.2	R_{st}	Percentage output material used as landfill
4	ECI	Environmental impact of the project in financial terms

Unfortunately, the CB'23 circularity measurement method 3.0 is still lacking a formula or technique for determining the combined total score of circularity in a construction project based on the (sub)indicators (CB'23, 2022). CB'23 regards this as a future goal of this measurement method. However, the values of the individual indicators are known, which could, even though there is no combined scoring mechanism available yet, provide information on the level of circularity per indicator. Based on the differences of values of the indicators and what these resemble, the comparison will be made between the two case projects. Based on the description of the indicator, one could argue which value is regarded as more circular then the other.

3.3 Project process

The project process of construction project is a collection of internal workings and activities in a project in order to deliver the contracted object. However, this project process can differ per project. This paragraph describes the method of how the project process is being analyzed in this study. First the project process in general will be examined and a suitable method for analysis will be described in section 3.3.1. Secondly, in section 3.3.2, the described method of analysis is further elaborated in more detail.

3.3.1 Project process analysis

In the literature study five major components which are present in each infrastructural construction project were identified: Initiative, design, procurement, construction, and operation & maintenance. Together, these components make up the project process. For a successful project delivery, the project must go through each of these components. This applies to every infrastructural construction project. For non-circular projects, the order in which the components are usually being executed is: Initiative, design, procurement, construction, and operation & maintenance. Depending on the type of issued contract, several components can be combined into one, for example in DBM, DBMO, DBFM, DBFMO, D&C, and E&C contracts. The sequence of in which the components are being executed may also differ per contract type. Figure 3.2 illustrates the eight most frequently used construction contracts and their project process. One can see that these projects follow a linear process, and that the issued contract type influences the sequence and combination of components greatly.

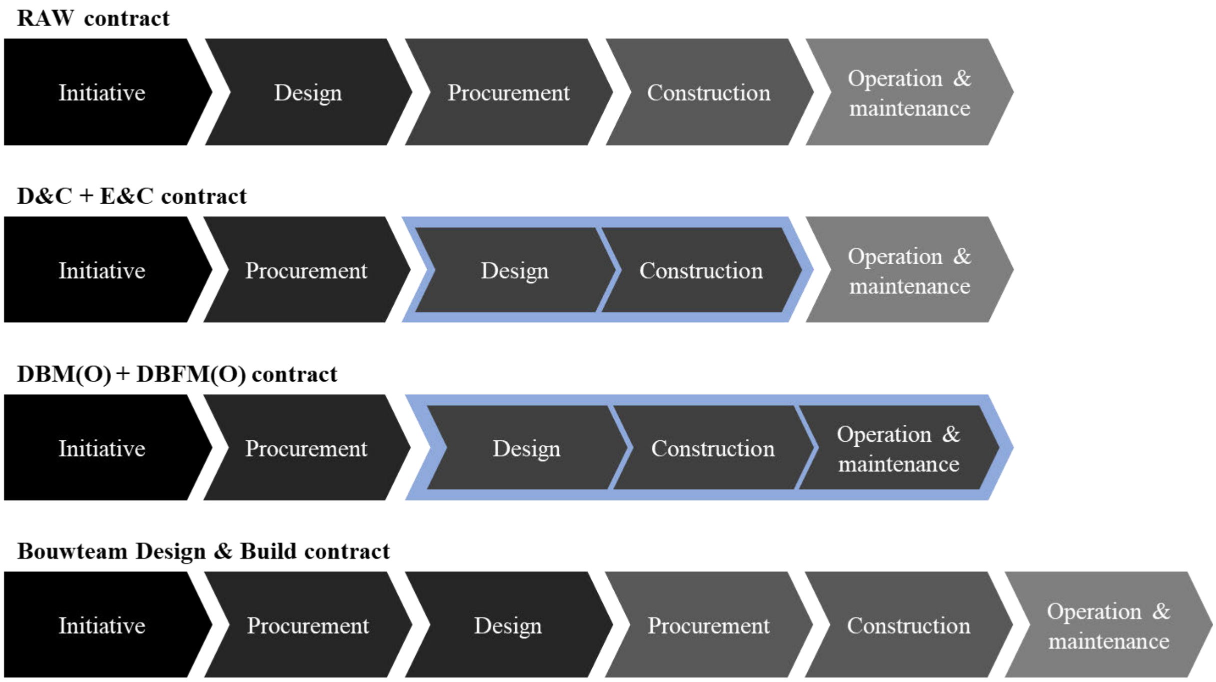

Figure 3.2: Component sequences in different Dutch construction contract types. Shaded in blue are the project components which are lumped together from the contractors perspective (own image).

But what does the project process of a circular infrastructural construction project look like? The gap in knowledge about the project process of circular projects will be addressed in this study by analyzing the process of an already executed circular infrastructural construction project. Information on the process will be gathered by conducting interviews with those directly involved in the case project. Both the stakeholders involved in the circular as the non-circular project will be interviewed. The execution of interviews is a common approach that is used when doing case study research, since it can provide more in-depth information on a case (Fellow & Liu, 2015). The goal of these interviews is to gather information on how the project process has proceeded per project. Based on the five project components it will be possible to construct a project process diagram after the first round of interviews, to illustrate the sequence of activities. To validate these project process diagrams, involved stakeholder will be asked to verify or decline the diagram after these have been presented to them. Verification of the diagram validates the correct interpretation of the interviewee by the interviewer. In the event of rejection, feedback is gathered on the incorrect information and an adaptation on the diagram is made in consultation with the other relevant interviewees. The next paragraph will go into more detail about conducting the interviews.

3.3.2 Method of interview

There are a variety of approaches available in which an interview can be conducted. According to the academic literature, three different interview methods in qualitative research can be distinguished (Qu & Dumay, 2011). These methods are summed up and elaborated upon in table 3.15 down below.

Table 3.5: Overview of different interview methods for qualitative research (Qu & Dumay, 2011).

Interview method	***Description***
Structured interview	A structured interview is an interview where the interviewer asks the participant a number of pre-established questions, wherein only a limited number of response categories are allowed. In addition, all participants are asked the same questions and the interviewer will deviate as little as possible from the pre-established script.
Semi-structured interview	The method of conducting a semi-structured interview lies between the method of a structured and an unstructured interview. In a semi-structured interview, the interviewer prepares and asks questions in a systematic manner in order to cover a broad series of themes around the main topic of the research. During the interview, the interviewer will ask questions and continue further on certain answers to generate a full understanding of the topic.
Unstructured interview	An unstructured interview is an open process which shapes the situation and context of the interviewer and participant. Beforehand, the interviewer does not know the necessary questions to be asked. The interviewer will have to develop, adapt and generate follow-up questions during the interview, in light of the research topic.

The purpose of this research in general is to gain a full understanding of circularity practices in infrastructural construction projects and its consequences on the construction costs and project process. To fuel this purpose and to generate input for this research, interviews will be conducted. Thus, in line with the purpose of this research, interviews are used to gather an amount of comprehensive information on the process of both a circular and a non-circular infrastructural construction project. From the interview methods mentioned above, the semi-structured interview provides the best fit with the goal we aim to achieve from the interviews. Due to the properties of a semi-structured interview, such as covering a broad series of themes, which could be linked to the major project components, and generating a full understanding of these themes, this method corresponds with the desired goal of the interview. Conducting structured interviews is not desirable, since the rigid answer possibilities may limit the gathering of in-depth information. The disadvantage of the unstructured interview is the high flexibility, causing a risk to drift off on the topic and not gathering the necessary input from the participants. Hence, the semi-structured interview is the best method to apply in this research.

3.3.2.1 Participant selection

Participants for the semi-structured interview will be selected based on the selected projects resulting from the gap analysis which act as cases in the case study. These candidates need to be selected with care as they will have a great influence on the outcome of the research. In order to choose the right participants, a list of requirements has been composed. Participants for the interview will need to comply with the following requirements:

- The participant has 5 or more years of working experience in the construction industry.
- The participant is working at a party which contributed to the case project.
- The participant has been involved in the case project.
- The participant was involved during the entire lifespan of the case project
- The participant can provide information to the interviewer on the case project.
- The participant agrees to the confidentiality agreement of the interview, providing consent to use their input in conducting this research.

Adhering to these requirements, participants can provide the interviewer with the relevant input to process in the case study. The results of the gap-analysis in combination with the abovementioned requirements led to a total of 11 interviews that have been conducted. The participants name has been anonymized by a letter and the company's name they represent has been anonymized by the type of company. This was told to the participants at the start of every interview. Anonymization of the names leads to participants who speak more freely about a topic and thus providing unbiased information. Table 3.16 provides an overview of the interviewed participants.

Table 3.6: List of interviewed participants

Project case	***Participant***	***Type of organization***	***Role in organization***
Circular	A	Designer	Architect
	B	Advisor	Programmanager
	C	Advisor	Structural advisor
	D	Contractor	Manager
	E	Subcontractor	Director
	F	Subcontractor	Project leader
Regular	G	Client	Projectmanager
	H	Designer	Architect and partner
	I	Contractor	Manager
	J	Advisor	Advisor
	K	Subcontractor	Project leader

3.3.2.2 Interview protocol

Since a semi-structured interview will be conducted, the questions have been determined beforehand. The questions have been determined and formulated by the results of the literature study, more specifically, the definition of the project components and their circular practices. The questions in the interview have been formulated in such a manner that the response of the participant will not be steered in any direction. The predetermined questions are listed in the interview protocol, which is organized by topic and functions as a script for the interview. By doing so, the consistency in interviews is maintained. The interview protocol can be found in appendix D. The interview consists of both open and closed questions. The open questions are meant for gathering in-depth information about certain topics, while the closed questions serve the goal of collecting input for the case study. The interview data is triangulated by conducting interviews with multiple participants on the same topics, creating multiple data sources (Thurmond, 2001).

The interview is divided into five sections. The first section is of an introductory and general nature wherein both the interviewer and participant introduce themselves. Secondly, the participant will be asked open questions about the circular economy in general. The third section focusses on the implementation of circularity in the related case project and is subdivided into the five major project components as determined in the literature study: Initiative, design, procurement, construction, operation & maintenance. The fourth section consists of open questions about the case project itself, with the goal to gain in-depth information about the project. Finally, in the fifth section, the interview will be closed by some final questions about the future of circularity in the construction sector.

The interviews will be conducted in person preferably, however, digital video-meetings are also a suitable method for interviewing participants. Given the fact that the participants are all native Dutch-speaking, the interview will be conducted in Dutch. Doing so, ensures unambiguous information and eliminates language barriers. For the sake of acquiring comprehensive information, the interviews will be recorded and transcribed. After creating a summary of the interview, a copy will be sent to the participant for verification. Once verified by the participant, the acquired information will be processed and analyzed in the case study, leading to a project process diagram. To verify this project process diagram, the interviewees will be asked to check the diagram. This way, the correct interpretation of the interviews can be confirmed. Figure 3.3 illustrates the process of conducting the interviews.

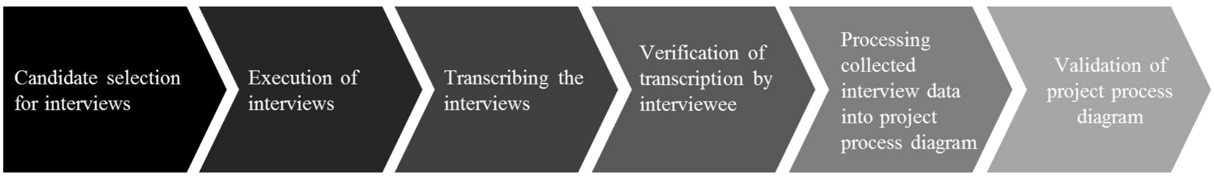

Figure 3.3: Flow diagram illustrating the execution and processing of the interviews (own image).

3.4 Construction costs

To find a link between the costs and circularity in construction projects, it is necessary to include the costs into the case study. This will show a practical real-life example on how circularity could affect the costs of a construction project. This paragraph explains the construction project costs and the method used in this research to include and analyze these costs.

3.4.1 Construction project costs breakdown

The costs of a construction project are comprised of two main components: Transaction costs and construction costs. Transaction costs are the necessary costs for initiating and completing a transaction. In construction projects, these costs include making estimations and executing preparatory work for a tender bid, setting up and managing contracts, and other activities as a result from deviations from the original contract conditions (Li et al., 2013). Transaction costs vary extremely between different projects and are largely dependent on external or environmental factors (Winch, 1989). These costs are project-specific, and are therefore difficult to estimate. In addition, there is no data on these costs available since it is not actively being tracked. Hence, an approximation of the transaction costs is likely to be unreliable due to the many variations on which it is dependent. The construction costs on the hand are the necessary costs for constructing the contracted object itself and are monitored. These costs include, among others, engineering as well as production costs. The scope of the costs is limited to the construction costs only, which means that only the costs that arise from constructing the project are taken into account.

The construction costs are further subdivided into direct costs and indirect costs. The direct construction costs reflect the costs directly needed for the physical production of the object, which comprises of labor, materials, equipment use and machinery. The indirect construction costs are of a more general nature and include the construction site costs, non-recurring costs, operating costs, overhead costs, profit and risks, and the time bound costs. Figure 3.4 illustrates the breakdown structure of the project costs.

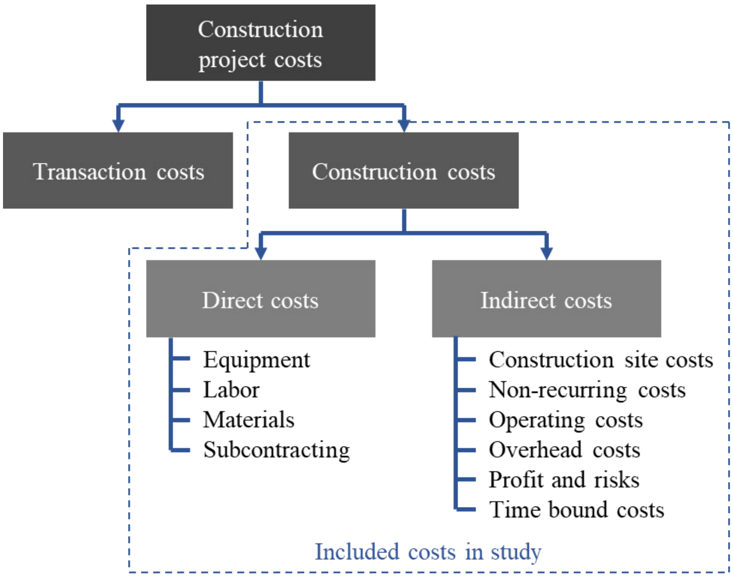

Figure 3.4: Breakdown structure of construction project costs (own image).

3.4.2 Determining the costs

The construction costs of both case projects are known, since these have already been executed. To gain understanding of the construction costs, project documents containing the actual costs incurred will be analyzed. This data is accessible through data summarized in Dura Vermeer's cost control program Metacom Cost Control (MCC). MCC tracks the incurred costs of a construction project in order to monitor, regulate and control the expenses of a project. Given the fact that the costs summarized in MCC are the actual incurred costs, provides this research with factual financial data of the case projects. This contributes to the authenticity of the project costs, and hence the scientific value of this research.

The direct construction costs are identified and analyzed by specifying the project activities and dividing these into labor, materials, equipment and subcontracting. This specification is made according to the Dutch RAW standard contract document system. The RAW system provides a standard method to divide construction projects into smaller components and activities. Subsequently, these are even further subdivided into equipment, labor and materials according to standardized units of measurement. The standardized RAW system includes the direct as well as the indirect construction costs. The direct costs are expressed in units of measurement like per piece, per m, per m², per m³, or per hour, dependent on the material or activity. Handling an uniform method or units for measurement ensures the objective comparability of the two project cases. The indirect costs are usually expressed in percentages of the contract sum. The height of the percentage differs per type of indirect costs is often determined when issuing the contract. Both the direct and indirect costs will be analyzed per cost item. For the direct costs this will be the relevant unit of measurement combined with labor and materials, whilst for the indirect cost it will be merely the percentages. By making the choice to compare the costs per item, one can immediately identify what the source is of a deviating price between the projects. By consideration of the five major project components, the costs for operation and maintenance are also taken into account in the analysis of costs. Often, the contractor these costs are determined by the contractor to provide the client with an indication of what the structures' maintenance would cost.

3.5 Cross-case analysis

The interviews and access to the project documents have resulted in a collection of data on the project processes and construction costs of both case projects. This data has been further processed by comparing the project processes and the construction costs of both case projects to one another. By doing so, the differences or gaps between the data have been identified, calling this the gap analysis The project processes of the Wisenniabrug and the Tweede leven brug have first been analyzed and compared separately from the project process, as will be elaborated in section 3.5.1. Subsequently, an analysis and comparison of the construction costs of both projects has been made by the method described in section 3.5.2. Ultimately in section 3.5.3, the method is described on how results are gathered by identifying the link between the construction costs and the project process.

3.5.1 Cross-case analysis project process

The method on how data has been gathered on the project process has already elaborated in paragraph 3.3. With this data on both case projects, the comparison between processes can been made. From input gathered by the interviews, a process diagram for each case project on how the project process was constructed has been made and verified by the interviewees. Differences in process will be directly visible from these process diagrams. Observation of the major components and the order in which these have occurred in the project showcase where the differences are in the process. Using the detailed information gathered from the interview, the reasoning behind the course of both processes will be sought on an individual project case level, resulting in an extensive analysis of the project process. Once completed, the elaboration of both projects courses of process will be compared one last time in order to check for links between the two case projects.

3.5.2 Cross-case analysis project costs

As explained in paragraph 3.4, the data upon construction costs is obtained by analysis of project documents like costs estimations and the cost control program. Since the projects have already been finished, the registered costs are the actual incurred costs, not just a quotation. As with the gap analysis of the project process, the differences between both projects are the most interesting and need to be fitted with a proper explanation. The specifications of the costs make it possible to investigate the potential sources of differentiations between the costs of both projects. These gaps between the projects can then be concluded upon.

3.5.3 Coupling of process and costs

Once the processes and costs have been investigated separately, the costs and processes are coupled for a final round of investigations. Doing so, is whether to check if the process influences the costs or vice versa, or there is no link to be found whatsoever. It can be seen as investigating the interactions between the process and the costs. The possible pinpointing of costs to certain project components could provide the industry with points to pay attention to in future projects.

3.5.4 Validation

The results from the comparisons made and the executed gap analysis in the case study will be validated in order to ensure its accuracy and quality. This data validation is done by presenting the results of the case study to two professionals in the construction industry. The results will be discussed and assessed on authenticity and likelihood of being plausible results. The professionals need to agree unanimously on the presented results in order for the data to be validated.

3.6 Conclusion methodology

Results in this study are gathered by executing a case study in which a circular infrastructural construction project, Tweede leven brug, and a regular infrastructural construction project, Wisenniabrug, are being analyzed. The first analysis in the case study is calculating the level of circularity of both projects, which validates the circular pledges of the circular case project and the lack of circularity in the regular case project. Secondly, the processes of both projects are analyzed on its major components and the comparison is made between the projects, resulting in argumentation on the influence of circularity on the process. Thirdly, the construction costs of both projects are compared to one another based on the individual items of which the structure is constructed. Subsequently, the comparison between the two projects is made in the cross-case analysis. The differences between the projects are analyzed and an explanation is formulated. During this analysis, the links between the project process and the construction costs is also investigated. Ultimately, the gathered data and results will be validated by presenting the findings to two professionals in the construction industry. Together, the results are discussed and will be assessed on plausibility. Concluding, figure 3.5 illustrates the research methods used in this study to show the differences in process and costs between the two case projects. Hence, this figure also serves as an answer to SQ 2: *''How can the differences in process and costs between a circular infrastructural construction project and a regular infrastructural construction project be disclosed?''*.

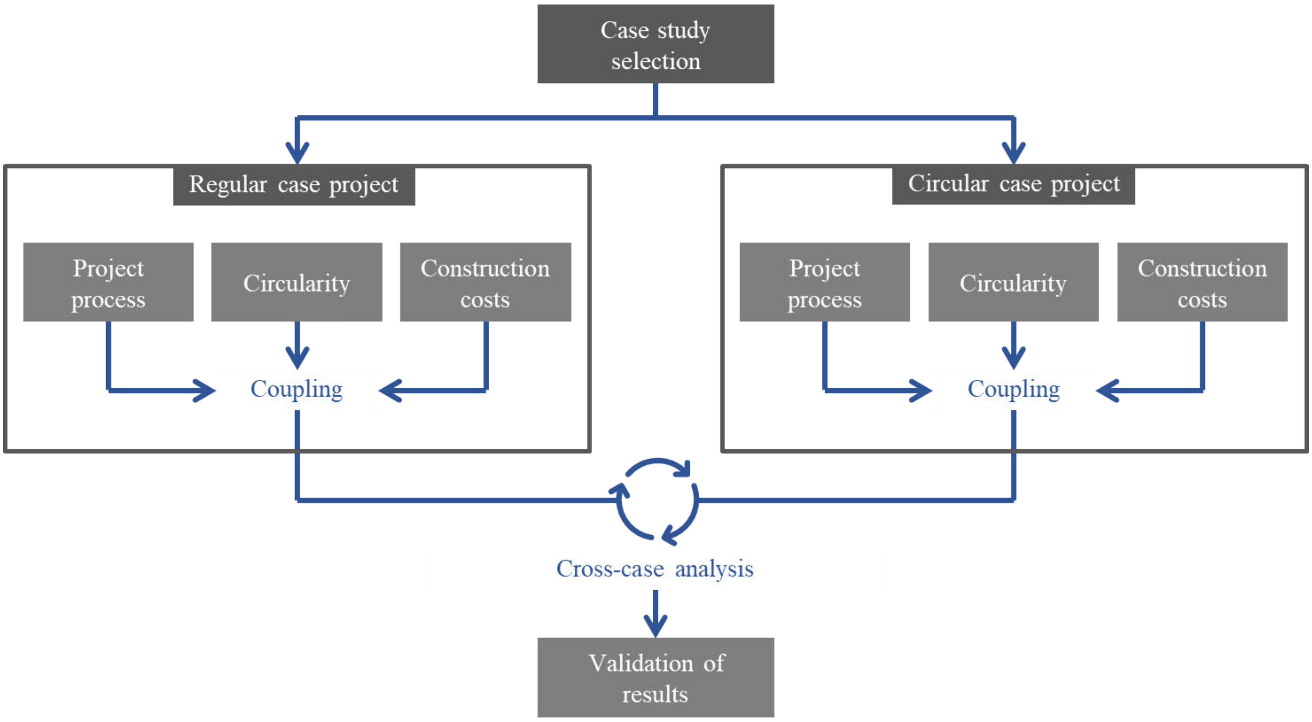

Figure 3.5: Overview of the research method used in this study (own image).

4

Results

This chapter will elaborate upon the results of both case studies. By doing so, an answer will be provided to the third research sub question (SQ 3), which is: How do the activities and costs of a circular infrastructural construction project vary from a regular infrastructural construction project? The presented data has been gathered from analyzing project specific data and collecting insights and experiences retrieved from interviews. The two case studies of this research have been individually analyzed in paragraph 4.1 and 4.2. Both paragraphs follow the same structure: First, the executed circularity assessments are explained, followed by the observed process of the projects, by its directly involved project member. Thirdly, the construction costs are presented. Afterwards, in paragraph 4.3, both case studies will be compared to one another on the results from the circularity assessment, the project process, and the construction costs. Subsequently, this will lead to an integrated comparison in paragraph 4.4, elaborating upon the observed differences between both case studies. The results will ultimately be validated in a discussion with experts which is described in paragraph 4.5.

Using the circularity measurement method of Platform CB'23, the values for the indicators of circularity have been determined. These values have been calculated using the input gathered from project documents, which is summarized in the overview of applied materials for the circular case project in Appendix H. For the determination of the weight and amounts of materials applied in this case project, several assumptions have been made. Assembly materials, such as nuts, bolts, etc. have not been included in the estimation of the total weight of the project. This category of materials has been excluded from the overview since there is no documentation available on the amount of applied assembly materials. In addition, the total weight of these materials is insignificant compared to the massive total weight of the entire structure. Applied materials and their amounts or quantities are usually not provided in unit of weight, this is however necessary to calculate the indicators of circularity. To transform the applied materials to unit of weight, the dimensions of the materials are multiplied with the specific gravity of the material. Further details and an overview of the applied materials are provided in Appendix H for the circular case project and in Appendix I for the regular case project. The detailed calculations of the circularity indicators are elaborated in Appendix J for the circular case project and Appendix K for the regular case project. One may notice from the circularity indicators that indicator 1.3.1 and 1.3.2 have been excluded. This is due to the fact that these indicators are still in development. Indicator 4, the ECI-score, has also been excluded from the circularity calculations. When generating the results of this case study and consultation with experts on ECI-scores, it became clear that there is uncertainty about how to apply the ECI-score to circular projects or project with reused components. The ECI-score is based upon the amount of materials applied, the shadow costs the material generates and other related costs for applying it in a project. The uncertainty arises when the shadow costs are allocated for reused materials. Does a reused element carry the same shadow costs as a new material? Are the shadow costs of a reused component already encountered for in a previous project? Different experts on ECI may interpret these questions on how to encounter reused materials in their calculations differently. The ECI-score is simply not yet ready to include circular practices in its calculations. Therefore, the choice has been made to exclude the ECI-score and hence indicator 4 from the circularity measurement.

To gain insights on the general process of both case projects, directly involved project participants from different organizations were interviewed according to the interview protocol in Appendix C. Guided by the predefined project components from paragraph 2.3, participants gave a detailed description about the process of the case project and their experiences with the project and circularity. The interviews have been individually summarized in Appendix D for the circular case project and in Appendix E for the regular case project. To analyze the interview data, all input gathered from the regular project interviews has been collected and summarized in a table in Appendix G. This table summarizes the input gathered from interviewees categorized per question asked, a collection of the extra activities which influenced the process according to the interviewees, and the most important remarks that were made on the process.

The construction costs of both case projects has been retrieved from project specific documents, such as contract documents, cost estimations, and cost control documents. To analyze the project costs in a structured manner, the collected data has been summarized in a cost overview in Appendix L for the circular case project and Appendix M for the regular case project. Whenever possible, the construction costs have been subdivided to element level wherein the costs are further specified into labor, materials, equipment and subcontracting. Combining the available cost documents made it possible to approximate the incurred construction costs accurately.

4.1 Circular case: Tweede leven brug

The Tweede leven brug is regarded as the circular case project in this case study. This project was first initiated in 2019 and was completed in 2021. The bridge was part of a larger development project of Dura Vermeer, the Floriade, which is a world horticultural exhibition. The prestigious nature of this exhibition facilitated the perfect conditions to initiate an experimental project, the Tweede Leven brug, literally translated, the Second life bridge. The main aim of this project for the contractor was to experiment with creating a circular bridge which consisted entirely of reused materials, hence being considered the circular case project in this study. By execution of this case study, the project has been analyzed on circularity, project process and construction costs.

4.1.1 Circularity assessment

The values of the determined circularity indicators have been calculated for the Tweede leven brug in table 4.1. Besides the scores for the circularity indicators, table 4.1 also describes how the calculations were made. Further detailed calculations of these values for the circular case project have been added to Appendix J.

Table 4.1: Calculated values of the indicators of circularity for the Tweede leven brug based on the methods developed by Platform CB'23 (2022).

Indicator	***Symbol***	***Description***	***Score***
1.1	S_x	Percentage secondary input material of total object or sub-object. Calculated by dividing the total weight of the structure by the weight of the secondary materials, which is the sum of the reused and recycled materials.	**69.74%**
1.1.1	H_x	Percentage re-used input material of total object or sub-object. Calculated by dividing the total weight of the structure by the weight of all reused materials, which is the sum of a large part of the applied steel, all wood, and the concrete girders.	**68.10%**
1.1.2	R_x	Percentage recycled input material of total object or sub-object. Calculated by dividing the total weight of the structure by the weight of all recycled materials, which is roughly 40% of all new steel applied according to Björkman & Samuelsson (2014).	**1.64%**
1.2	V_x	Percentage primary input material of total object or sub-object. Calculated by dividing the total weight of the structure by the weight of all new materials, which is 60% of the new steel, concrete grouting, and concrete baffle plates.	**30.26%**
1.2.1	H_x	Percentage renewable primary input material of total object or sub-object. Calculated by dividing the total weight of the structure by the weight of all new renewable materials. There are however no new renewable materials present in this structure.	**0.00%**
1.2.1a	N_x	Percentage sustainably produced renewable primary input material of total object or sub-object. Calculated by dividing the total weight of the structure by the weight of all sustainably produced new renewable materials. There are however no new renewable materials present in this structure.	**0.00%**
1.2.1b	VN_x	Percentage unsustainably produced renewable primary input material of total object or sub-object. Calculated by dividing the total weight of the structure by the weight of all unsustainably produced new renewable materials. There are however no new renewable materials present in this structure.	**0.00%**
1.2.2	NH_x	Percentage non-renewable primary input material of total object or sub-object. Calculated by dividing the total weight of the structure by the sum of the weight of all new materials, which is 60% of the new steel, concrete grouting, and concrete baffle plates.	**30.26%**
1.4.1	NK_x	Percentage socio-economically non-scarce material of total object or sub-object. Calculated by dividing the total weight of the structure by the sum of the weight of all socio-economically non-scarce materials according to the EU list of critical raw materials (European commission, 2020b), which is all materials except the steel and the girder pads.	**74.70%**
1.4.2	K_x	Percentage socio-economically scarce material of total object or sub-object. Calculated by dividing the total weight of the structure by the sum of the weight of all socio-economically non-scarce materials according to the EU list of critical raw materials (European commission, 2020b), which is the steel (due to the use of Fluorite and Cokes) and the girder pads (due to the use of natural rubber).	**25.30%**

2.1	H_g	Percentage realistic re-usable output material of total object or sub-object. Calculated by dividing the total weight of the structure by the sum of the weight of realistically reusable materials after the lifecycle of the structure. Based on the conducted interviews, the concrete girders and baffle plates are deemed reusable.	**42.19%**
2.2	R_e	Percentage realistic recyclable output material of total object or sub-object. Calculated by dividing the total weight of the structure by the sum of the weight of realistically reusable materials after the lifecycle of the structure. Based on the conducted interviews, the applied steel and concrete grouting are deemed recyclable.	**48.56%**
3.1	R_{ew}	Percentage output material used for energy generation. Calculated by dividing the total weight of the structure by the sum of the weight of realistically reusable materials after the lifecycle of the structure. Based on the conducted interviews, the applied wood is likely to be burned for energy generation.	**9.23%**
3.2	R_{st}	Percentage output material used as landfill. Calculated by dividing the total weight of the structure by the sum of the weight of realistically reusable materials after the lifecycle of the structure. Based on the conducted interviews, the applied girder pads are likely to be used as landfill.	**0.02%**

The indicators of circularity are clear and generate an elaborate picture of the level of circularity that has been achieved in this project. It can be noticed from the indicators that the project was steered on applying reused materials, since the highest percentages were achieved on the secondary materials indicators. This is strengthened by the relatively low percentage of primary materials. The percentage of secondary materials however is lower than expected. Especially when taking into account that this project was launched as being completely constructed from reused materials. The focus on reusing materials is to be seen in percentage of reused secondary materials, which is almost equal to the percentage of secondary input materials, meaning that the vast majority of secondary materials is originating from reuse instead of recycling. The primary applied materials in the project are made up completely of non-renewable materials. The source of materials is mainly the newly applied steel, concrete and girder pads, which are non-renewable materials. In addition, the girder pads and steel are even regarded as socio-economic scarce material due to presence of natural rubber in the girder pads and cokes and fluorite in the steel. This socio-economically scarce label to steel applies to all the used steel in this project, including the reused steel. When considering the end of this object, about half of the mass of applied materials is deemed as reusable after the lifecycle of this bridge. Since the future cannot be predicted, assumptions for future use were made. The assumptions for materials being reusable for future structures, recyclable, used for energy generation or landfill have been made upon input gathered from the interviews.

During the interviews conducted to understand the project process, the participants were also asked several questions about the circular economy in relation to the construction sector. Unanimously, the participants of the circular case project were supportive towards the circular economy and understood its importance. Each participant had their own ideas on circularity and its implementation in construction projects, as listed below:

- When initiating a circular project, participants should already focus on the end of service life of the structure;

- As experienced in this project, the process was centered around the materials. This focus on materials needs to be accounted for in future circular projects;
- Collaboration between different organizations in the project is key to creating a successful circular project;
- The initiation of the project is very important to achieve circularity in projects. Support and dedication towards circularity is created during the initiation of a project. Once each project participant is motivated toward a common goal, it will be easier to achieve this goal;
- Materials which are available for reuse need to be certified and registered, in order to make the materials traceable. If the reusable materials are traceable and certified it will be easier to apply these in construction projects. This will take some time however;
- The client initiating the project should be responsible for providing the contractor with reusable materials when a circular project is initiated;
- The main challenge for circular construction projects will be arranging the logistics of reusable materials between a new project and an obsolete structure fit for harvesting. Ideally, a structure will be constructed from components that are harvested from another project which is simultaneously being deconstructed.

4.1.2 Project process

The Tweede leven brug is a project within the development assignment of the Floriade, a world horticultural exhibition. The client formulated the general idea of a bridge and provided the contractor with a designated location. However, at the start, the client wanted a different bridge than the one that was ultimately constructed. Due to the flexibility of the set requirements of the bridge and the motivation of both the architect and contractor, the client was persuaded into constructing a circular bridge made from reused components, the Tweede leven brug. Hence, the architect and contractor can be regarded as the initiators of this bridge. Because the bridge was already part of the overarching development project, there was no procurement procedure for this bridge particularly. Thus, after receiving the approval of this bridge, the contractor and architect started working on this bridge. The majority of the participants addressed the activity of searching for materials as extra activity that had to be executed. This took place prior to the design and construction components. The construction was initiated after the final design was completed. There was a dynamic process taking place between the gathering of materials and the design of the bridge, in which there was a constant switching between material gathering and (re)designing. It can be concluded that gathering of materials was a major component influencing the process, it occurred often that the structure had to be redesigned when the intended material seemed unfit or was not available. Therefore it would be beneficial to introduce this new component ‘’Gathering materials’’ as a standard project component especially for circular projects. Usually, the purchasing of materials is done in the construction component, but from the interviews it seemed that gathering materials greatly influences the process. This component does not merely exist of collecting the materials. Assessment of the materials for reuse is also included into this new component, since it is a prerequisite before a material can be applied. Preparation and modification of the materials can be assigned to the construction component, since these activities encompasses the processing of materials for implementation in the project. The construction itself came with a challenge of its own as well, which was the storage of the reusable materials. Normally, when constructing an object, materials are delivered on the construction site where these can be immediately applied. In this circular project, once the materials were gathered, these needed to be stored somewhere before these could be applied in the construction. Most of the time when reusable materials become available due to the demolition of an obsolete structure, these cannot be immediately used in the new project. There is no timing between availability due to demolition and construction. Hence, the materials need to be stored in this intervening period. Luckily in this project, the client assigned the contractor a storage location near the construction site, which was beneficial for the construction process. After completing the construction, the bridge was handed over to the municipality for its operation & maintenance.

In general, the process of this project was for a major part experienced similar to that of a regular construction project. There were however some differences. Searching and gathering materials, assessing materials on quality and suitability, adapting the design according to the materials, adapting materials for reuse, and an increased amount of communication and coordination were found to be the main differences in the project process. Adding to this is the transport and storage of the reusable materials, but this was not an major issue in this project. By summarizing and analyzing the responses of the interviewees, the project process can be captured in the predetermined project component as depicted in figure 4.1.

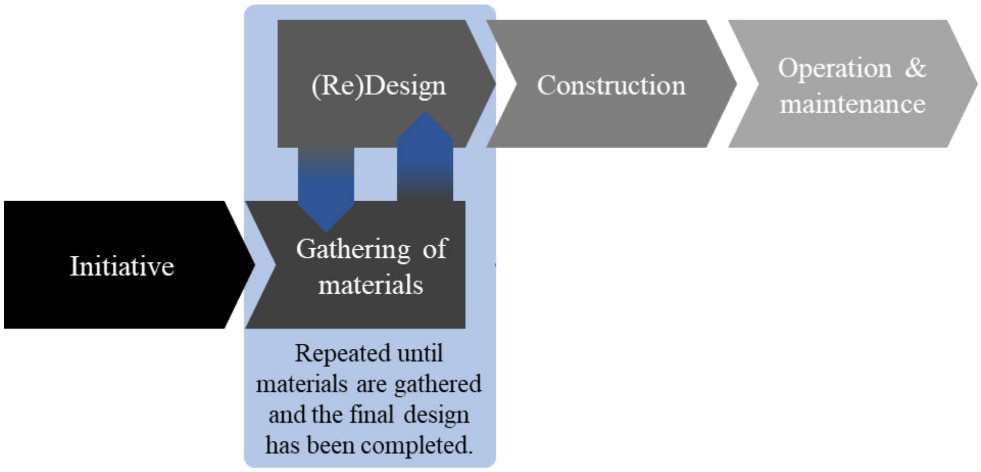

Figure 4.1: Project process of the Tweede leven brug project based on the data gathered in the interviews (own image).

As outlined earlier, the project process of the Tweede leven brug did not include a procurement component. However, the absence of the procurement in this project may have affected the results in this particular case study. Normally, the procurement procedure can be regarded as a competition wherein parties present their tenders to the client in order to win the tender, and thus get to construct the project. The role of competition in a tender often ensures the client with receiving high quality tenders for a competitive price. Hence, the absence of this competitive element in this specific project may have had an influence on the price offered to the client and the quality of the design. The offered price for this project could be less than when there was a procurement, since there is no need to offer a reduced or competitive price. Also, the project quality could be less than a project with procurement for the same reason. However, we should also take into account that this project was initiated as a pilot project to experiment with reused materials. In procurement, there is always this dilemma between focusing on quality or focusing on offering a competitive price. Not being limited by a procurement procedure offered in this project room to experiment. Normally, the procurement component would be included in a project, thus also in a circular construction project. This results in the process scheme illustrated in figure 4.2, which depicts the process of a circular construction project.

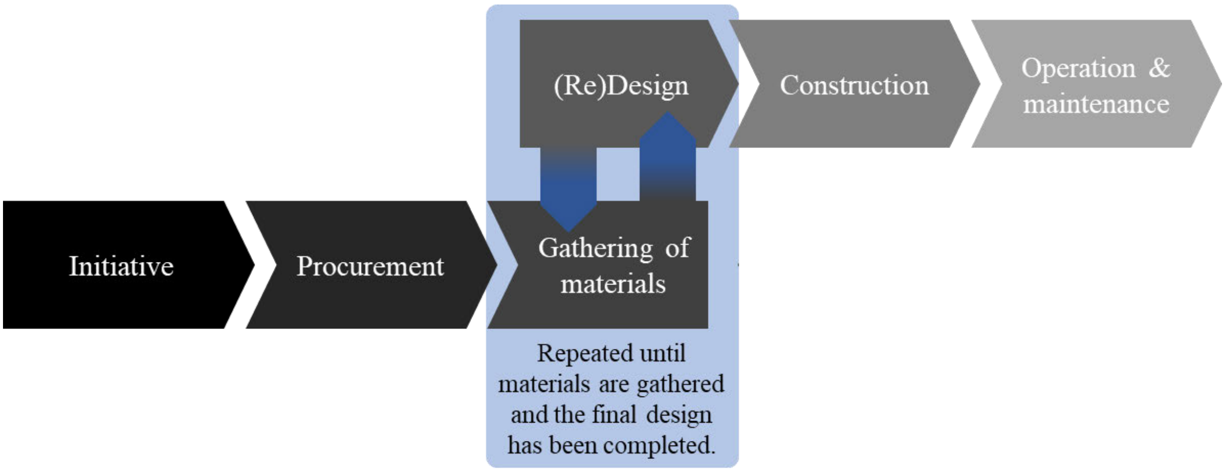

Figure 4.2: Project process of circular infrastructural construction projects, based on the Tweede leven brug project process and the data gathered from the interviews (own image).

4.1.3 Construction costs

The construction costs of the circular case project were retrieved from project specific documents, such as contract documents, cost estimations, and cost control documents. Together, the input of this data has been combined into a cost overview of the actual construction costs. The used documents are listed in the data logbook in Appendix Q. The project was offered to client in 2021 for an amount of € 800,000.00. Thus, the used price level of the cost documents and the cost overview is that of 2021. The price level is subject to material scarcity, bankruptcies, competition and geopolitics, and can greatly influence the calculated and incurred costs. When analyzing the project cost documents, the actual costs were determined as presented in table 4.2. The costs are divided into the major elements of the project. A more detailed cost overview including all cost elements and activities is provided in Appendix L. For this cost overview, several assumptions were made, which are also included in Appendix L.

Table 4.2: Overview of construction costs of the circular case project Tweede leven brug.

Code	Description	Total
	DIRECT CONSTRUCTION COSTS	
1	**ACCESSIBILITY**	
10	**Scaffolding**	**€ 17.954,57**
2	**PILING**	
20	**Piling foundation**	**€ 64.836,00**
3	**BRIDGE STRUCTURE**	
30	**Substructure**	**€ 28.322,30**
31	**Girders**	**€ 70.375,13**
32	**Superstructure**	**€ 113.183,22**
4	**BRIDGE DECK**	
40	**Wooden deck**	**€ 142.862,63**
5	**RAILING**	
50	**Bench**	**€ 35.873,80**
51	**Railing**	**€ 111.778,73**
6	**FINISHING**	
60	**Baffle plates**	**€ 5.496,00**
	TOTAL ESTIMATED DIRECT COSTS =	**€ 590.682,39**
	INDIRECT CONSTRUCTION COSTS	
9	**INDIRECT COSTS**	
90	**Construction site costs**	
900	Construction site	€ 40.873,00
91	**Non-recurring costs**	
910	General costs subcontracting	[redacted]
92	**Operating costs**	
920	Operating personell	[redacted]
93	**Overhead costs**	
930	General costs	€ 81.747,09
	TOTAL INCURRED INDIRECT COSTS =	**€ 349.293,09**
	TOTAL CONSTRUCTION COSTS =	**€ 939.975,48**

As one can see, the actual costs were higher than the initial price offer made to the client. Thus the contractor made a loss on this project. However, we should take into account that this project is perceived as a prestigious project due to its experimental nature. So looking merely at the numbers, this project was a financial loss. But when combining the costs to the entire picture, this project might seem as an investment in the future for being one of the first contractors to construct a bridge with largely reused materials. It could be regarded as a form of marketing.

In addition to the construction costs, the costs for maintenance have also been determined. This data was retrieved by consulting experts with experience in setting up maintenance plans. Normally, maintenance plans function as an informative document to the client on how to maintain the constructed structures. It is important to note these costs are the expected costs for maintenance, determined by experiences of the contractor, even though circular projects are not that common. The maintenance costs are displayed in table 4.3. The costs of large maintenance items are largely dependent on the amount of wear and tear. It is difficult to approximate the abrasion over a period of 10 or more years. In addition, once the large maintenance will be executed, a whole different price level is dominating the expenditures on maintenance. Hence, this price level is also hard to determine.

Tabel 4.3: Maintenance costs Tweede leven brug

Code	Description	Costs per item	Frequency	Costs per year
1	**Inspections**			
10	Functional inspection on bridge, steel structure, and safety	€ 500,00	2x per year	€ 1.000,00
11	Inspection on cleanliness of the bridge	€ 250,00	1x per year	€ 250,00
2	**Large maintenance**			
20	Reapplication of the wear layer of the bridge deck	TBA	1x per 10 years	TBA
21	Planing the wooden railing	TBA	1x per 10 years	TBA
			Total amount of expected maintenance costs per year =	**€ 1.250,00**

4.1.4 Coupling the circular case project

For an integral analysis of the project case, the circularity assessment, construction costs and project process have been coupled. The interrelations between these three pillars have been investigated, resulting in a comprehensive picture of the case project. The construction costs are first coupled to the project process, which is then followed by a coupling of the process to the circularity assessment. Thirdly, the circularity assessment is coupled to the construction costs. In the end, the three main pillars of the case study project are combined in an integral evaluation.

4.1.4.1 Coupling construction costs – project process

The construction costs and its cost items have been analyzed individually, and are allocated to the identified project process components of the Tweede leven brug case project. This resulted in figure 4.3 wherein an overview is presented with the related costs for each individual project component. Appendix N includes a more detailed overview of the construction costs and its structures in each component.

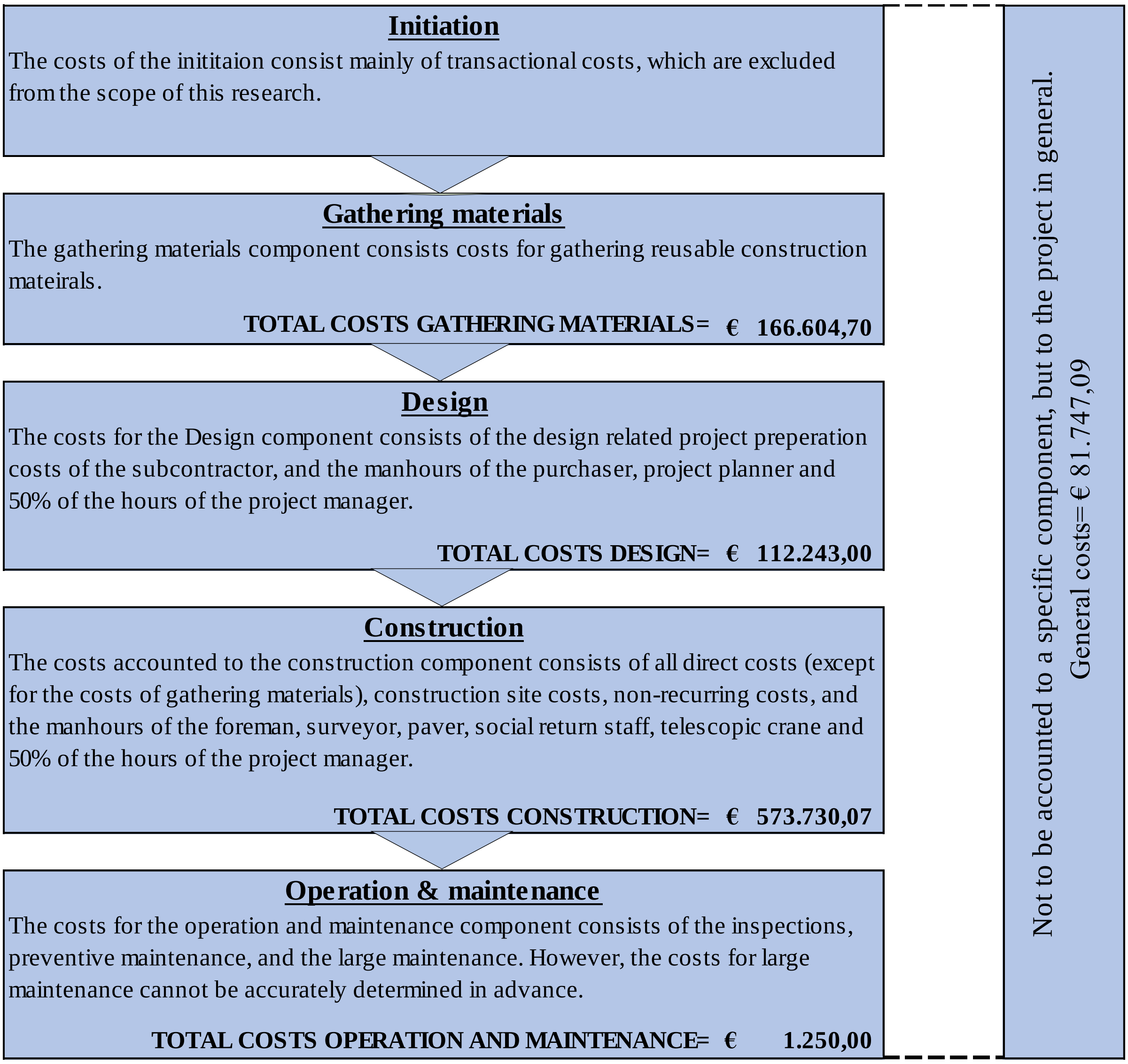

Figure 4.3: Construction costs accounted to the project components of the circular case project (own image).

From figure 4.3 can be seen that the Initiation component does not contain any costs. Even though the contractor is largely responsible for the initiation of this circular case project, especially for the focus on circularity, these costs are labelled as transactional costs and are thus not within the scope of this study. Additionally, these costs have not been tracked, making it difficult to approximate the costs for this component. Following the Initiation component is the Gathering materials component, which has been newly introduced to the project components. Usually in construction projects, the gathering of materials is included as purchasing of new materials in the construction component. A significant amount of the total construction costs can be accounted to this component, proving its importance of being regarded as a project component. Included in this component are the activities for gathering the steel materials, wood, and concrete girders. Steel piling is also included, however, it is unknown what the costs were for gathering the used steel piling since it was subcontracted and no access was granted on the costs specifications. The Material gathering component is followed by the Design component in the figure, however, in real life projects these components interchange constantly until the final design is completed. The costs related to the design component consist of the manhours needed to create the design, necessary work preparation, and the contributions to software and other systems used in preparing the project. Next, the construction component, which consist mostly of the direct construction costs, excluding the material gathering. In addition to the direct construction costs, a large part of the indirect construction costs are included as well. The costs in this component are collectively responsible for financing the physical construction of the object, including the manhours, equipment, subcontracting, but also non-recurring costs. Lastly, the costs are coupled to the Operation and Maintenance component, which contains the yearly expected costs of maintenance.

4.1.4.2 Coupling circularity – project process

When coupling the results from the circularity assessment to the project process, it can be immediately noticed that the high percentage of reused input material has led to the introduction of the Gathering materials component. The circular aspiration of the project resulted in extra activities to be executed of which gathering materials was deemed of high importance by the interviewees of the circular project. The influence of circularity has thus led to the introduction of the new project component for circular construction projects. Besides assessing the input material, the circularity method also addresses the output materials after the lifecycle of the project. There had been no attention paid to this particular aspect of circularity in this case project, the focus was laid on reusing secondhand materials. If this case project would also have focused on the end of its life cycle, it could be called, process-wise, a true circular project since it closed the linear process and makes it circular. A result of this could be introduction of another project component for circular projects, situated between Operation & maintenance and Initiation. This component would cover the demolition of an obsolete structure and the handling of reusable materials for future project. Unfortunately, this research was directed at the reuse of materials and its consequences on costs and project process, hence this process component was not further investigated.

4.1.4.3 Coupling construction costs – circularity

As previously mentioned, the circular ambitions of the project participants of this circular case project resulted in extra project activities to be executed which can be independently accounted to circularity. Activities in projects ultimately lead to costs, hence the coupling of costs and circularity. Table 4.4 summarizes the activities which were executed as a result of circularity. These activities have been identified by comparing the activities of the circular case project to similar activities executed in a project without circular ambitions. The differences in necessary activities to construct a certain element exposed the extra activities that needed to be executed to reach circular ambitions. Additionally, these extra activities due to circularity have been confirmed by two experts, as will be elaborated in paragraph 4.6.

The major extra activity has already been mentioned several times, which was gathering materials. In table 4.4 this activity is present as well, as harvesting wood. It can be seen that this activity is responsible for a considerable portion of the total costs. One could argue that gathering materials is also present in a regular construction project as purchasing of materials. However, it is common practice in the construction sector that the purchasing price of new materials include carriage paid delivery. There is of course some effort needed of the purchaser to order materials, but this is neglectable. Supplementary to activities regarding gathering secondhand materials is processing these gathered materials into reusable materials. Normally, a purchaser would simply order a specific element with specific dimensions from the producer, but secondhand materials need to be first processed into elements that can be used. Of course, processing the materials generates costs, depending on the activities. Table shows an overview of the activities and related costs which are the resulting from the implementation of circularity. This overview has been created based on the cost items noted in the construction cost overview in Appendix L.

Table 4.4: Overview of construction activities due to circularity.

Activities due to circularity	***Costs per item***
Inspection and certification steel piling	€ [redacted]
Steel abutments - supply of steel material	€ [redacted]
Steel abutments - transport to treatment location	€ [redacted]
Steel abutments - preparing steel for treatment	€ [redacted]
Steel abutments - treatment (sawing, composing, welding)	€ [redacted]
Repair of concrete girders	€ [redacted]
Loading and supplying concrete girders	€ [redacted]
Steel beam supports - supply of steel material	€ [redacted]
Steel beam supports - treatment (sawing, composing, welding)	€ [redacted]
Steel crossbeams - supply of steel material	€ [redacted]
Steel crossbeams - disassembly of initial steel material	€ [redacted]
Steel crossbeams - preparing steel for treatment	€ [redacted]
Steel crossbeams - treatment (sawing, composing, welding)	€ [redacted]
Steel support beams - supply of steel material	€ [redacted]
Steel support beams - treatment (sawing, composing, welding)	€ [redacted]
Wooden girders - supply of wood	€ [redacted]
Wooden girders – transport	€ [redacted]
Wooden girders - cleaning the wood	€ [redacted]
Wooden girders - sorting, sawing, shortening, planing	€ [redacted]
Wooden bridge deck – transport	€ [redacted]
Wooden bridge deck - cleaning the wood	€ [redacted]
Wooden bridge deck - sorting, sawing, shortening, planing	€ [redacted]
Wooden bench oak - supply of wood	€ [redacted]
Wooden bench oak – transport	€ [redacted]
Wooden bench oak - cleaning the wood	€ [redacted]
Wooden bench oak - sorting, sawing, shortening, planing	€ [redacted]
Wooden bench oak - check bevels	€ [redacted]
Wooden bench wagon wood - supply of wood	€ [redacted]
Wooden bench wagon wood - transport	€ [redacted]
Wooden bench wagon wood - cleaning the wood	€ [redacted]
Wooden bench wagon wood - sorting, sawing, shortening, planing	€ [redacted]
Wooden bench wagon wood - check bevels	€ [redacted]
Steel railing - supply of steel material	€ [redacted]
Steel railing - treatment (sawing, composing, welding)	€ [redacted]
Wooden railing - supply of wood	€ [redacted]
Wooden railing – transport	€ [redacted]
Wooden railing - cleaning the wood	€ [redacted]
Wooden railing - sorting, sawing, shortening, planing	€ [redacted]
Wooden top railing - supply of wood	€ [redacted]
Wooden top railing – transport	€ [redacted]

Wooden top railing - cleaning the wood	€	[redacted]
Wooden top railing - sorting, sawing, shortening, planning	€	[redacted]
Wooden top railing - chisel costs and setting up machine	€	[redacted]
Harvesting of wood	€	[redacted]
TOTAL	**€**	**375.756,84**

In total, there is an amount of € 375,756.84 of the construction costs to be accounted to circular practices in this case project. It is however important to note that in a vast number of the mentioned cost items the purchasing of materials is included. This is an activity which would occur in regular projects as well. However, in this project the purchased materials are secondhand materials in various shapes and forms, which are likely to be purchased for a different price than new materials. Therefore the choice has been made to include these costs as well in the overview.

4.2 Regular case: Wisenniabrug

The Wisenniabrug is a bridge which was part of a larger project, the Singelparkbruggen, which consisted of the assignment to construct six bridges in the historical city centre of Leiden. This project was first initiated back in 2015 by the municipality of Leiden and was eventually finished in 2020. In the case study, this project has been regarded as the regular case project, resulting from the case selection in paragraph 3.1. As with the circular case project, this project has also been analyzed on circularity, project process and construction costs.

4.2.1 Circularity assessment

The values of the determined circularity indicators have been calculated for the Wisenniabrug in table 4.5. Besides the scores for the circularity indicators, table 4.5 also describes how the calculations were made. Further detailed calculations of these values for the circular case project have been added to Appendix I.

Table 4.5: Calculated values of the indicators of circularity for the Wisenniabrug based on the methods developed by Platform CB'23 (2022).

Indicator	*Symbol*	*Description*	*Score*
1.1	S_x	Percentage secondary input material of total object or sub-object. Calculated by dividing the total weight of the structure by the weight of the secondary materials, which is the sum of the reused and recycled materials.	**13.04%**
1.1.1	H_x	Percentage re-used input material of total object or sub-object. Calculated by dividing the total weight of the structure by the weight of all reused materials. There are however no reused materials present in this structure.	**0.00%**
1.1.2	R_x	Percentage recycled input material of total object or sub-object. Calculated by dividing the total weight of the structure by the weight of all recycled materials, which is roughly 40% of all new steel applied according to Björkman & Samuelsson (2014).	**13.04%**
1.2	V_x	Percentage primary input material of total object or sub-object. Calculated by dividing the total weight of the structure by the weight of 60% of the new steel and all other newly applied materials.	**86.96%**

1.2.1	H_x	Percentage renewable primary input material of total object or sub-object. Calculated by dividing the total weight of the structure by the weight of all new renewable materials, which is the applied wood only.	**3.22%**
1.2.1a	N_x	Percentage sustainably produced renewable primary input material of total object or sub-object. Calculated by dividing the total weight of the structure by the weight of all sustainably produced new renewable materials, which is the applied wood only.	**3.22%**
1.2.1b	VN_x	Percentage unsustainably produced renewable primary input material of total object or sub-object. Calculated by dividing the total weight of the structure by the weight of all unsustainably produced new renewable materials. There are no unsustainably produced new renewable materials present in this structure.	**0.00%**
1.2.2	NH_x	Percentage non-renewable primary input material of total object or sub-object. Calculated by dividing the total weight of the structure by the sum of the weight of all new materials, which is 60% of the new steel and all other newly applied materials, except for the wood.	**83.59%**
1.4.1	NK_x	Percentage socio-economically non-scarce material of total object or sub-object. Calculated by dividing the total weight of the structure by the sum of the weight of all socio-economically non-scarce materials according to the EU list of critical raw materials (European commission, 2020b), which is all materials except the steel (use of cokes and fluorite) and cast iron (use of phosphorus and silicon).	**67.41%**
1.4.2	K_x	Percentage socio-economically scarce material of total object or sub-object. Calculated by dividing the total weight of the structure by the sum of the weight of all socio-economically non-scarce materials according to the EU list of critical raw materials (European commission, 2020b), which is the steel (use of fluorite and cokes) and the cast iron (use of phosphorus and silicon).	**32.59%**
2.1	H_g	Percentage realistic re-usable output material of total object or sub-object. Calculated by dividing the total weight of the structure by the sum of the weight of realistically reusable materials after the lifecycle of the structure. The concrete beams and steel are deemed reusable.	**17.91%**
2.2	R_e	Percentage realistic recyclable output material of total object or sub-object. Calculated by dividing the total weight of the structure by the sum of the weight of realistically reusable materials after the lifecycle of the structure. Based on the conducted interviews, the applied steel and concrete grouting are deemed recyclable.	**78.81%**
3.1	R_{ew}	Percentage output material used for energy generation. Calculated by dividing the total weight of the structure by the sum of the weight of realistically reusable materials after the lifecycle of the structure. Based on the conducted interviews, the applied wood is likely to be burned for energy generation.	**3.22%**
3.2	R_{st}	Percentage output material used as landfill. Calculated by dividing the total weight of the structure by the sum of the weight of realistically reusable materials after the lifecycle of the structure. Based on the conducted interviews, the applied girder pads are likely to be used as landfill.	**0.05%**

The indicators of circularity are clear and generate an elaborate picture of the level of circularity that has been achieved in this project. From the percentages of the indicators calculated, it can be seen that this project has not been created with any intention of achieving circularity. No reused materials have been applied. The secondary materials that have been applied are coming unintentionally from an recycled source. The project largely consists of non-renewable materials which can be declared by the fact that the bridge almost completely consists of steel. This great amount of steel is also responsible for the significant percentage of socio-economically scarce materials. However, this steel can be easily recycled into new steel, as reflected by high percentage of recyclable materials after the life cycle of this bridge. The concrete beams and steel piling could be reused after its current application.

During the interviews conducted to understand the project process, the participants were also asked several questions about the circular economy in relation to the construction sector, even though they were not involved in circular construction project. Unanimously, the participants of the regular case project were supportive towards the circular economy and understood its importance. It was therefore interesting to hear their suggestion for implementing circularity into construction projects:

- Insights about the available materials will provide more information about its possible future function or application. In addition, it provides info on the background and its previous applications, which could possibly influence its future use;
- Innovation projects provides companies with the opportunity to innovate without any severe consequences. Hence, from practice these projects are deemed beneficial for the further development of circularity in practice;
- Initiating larger circular projects will create a larger impact on development of circularity;
- Project requirements should offer room for the contractor to innovate. Currently, project requirements are often limiting the possibilities for innovation, and thus circularity;
- The financial incentive in a procurement procedure should be replaced by an incentive for circularity and sustainability. Many actors in a construction project are still driven by financial incentives. There needs to be a cultural shift towards circular and sustainable incentives, especially within governmental organizations;
- In circular construction projects, the idea and design needs to be determined based on the available materials instead of first creating a design and then searching for materials;
- When initiating a construction project, the project participants should already think about implementing circularity and the end the life cycle of the structure;
- Standardization of structures could promote circularity in structures. Standardization will result in less engineering work to execute, less costs for maintaining a stock of spare parts, and increased opportunities to reuse components.

4.2.2 Project process

The Singelparkbruggen project, of which the Wisenniabrug was part of, was a project in which the municipality of Leiden initiated the project. The municipality hosted a design competition for architects to create designs for six bridges in the park surrounding the historical city centre. The bridges would serve as a connection between the different green areas within the old city canals and should have similarities in design. The design competition was of a participative character, involving the residents of Leiden in selecting and awarding the winning design. After the design had been awarded, the design component is commenced and the architect further developed its design to a definitive version. This design served as the foundation on which the municipality procured the project to execute it by means of a Design & Construct contract. After the project had been awarded to the contractor with the winning bid, the contractor had to transform the definitive design of the architect into a executable design. The architectural definitive design was binding throughout the project. This resulted in the architect fulfilling a consulting role for the contractor in adapting the architectural designs to executable designs. Since this is preparatory work prior to the construction itself, it is regarded as part of the construction component. Once the preparatory work had been completed, the contractor started with the construction of the six bridges, with help of a group of subcontractors. Halfway through the project, the initial subcontractor for the steel structures of the bridges went bankrupt. This caused the introduction of a new subcontractor halfway through the project, which impacted the time schedule. Eventually, when the construction was completed, the project was handed over to the client for the operation & maintenance. Using the predetermined project components from the literature study and paragraph 3.3, the process of this project can be captured as portrayed in figure 4.4.

Figure 4.4: Project process of the Singelparkbruggen/Wisenniabrug project according to the data gathered in the interviews (own image).

An unique feature of the Singelparkbruggen project, and thus the Wisenniabrug, was the design competition hosted after the initiation of the project by the municipality. Throughout the project, the awarded design of the architect was guiding. A design competition however, is uncommon for infrastructural projects. Therefore, the sequence depicted in figure 4.X will not be sufficient for most infrastructural construction projects with no circular intentions. Excluding the design competition component, results in one of the standard sequences previously mentioned in paragraph 3.3.1. This is the sequence of the D&C contract as depicted in figure 4.5, which was also issued to the contractor in this project. Both project processes displayed in figure 4.4 and 4.5 were verified and validated by the interview participants.

Figure 4.5: Project process of regular infrastructural construction projects using a D&C contract (own image).

4.2.3 Construction costs

The project documents of the regular case project were analyzed on construction costs. The input related to costs has been put together into a cost overview of the actual construction costs. The sources from which the input on costs has been gathered are project specific documents which have been listed in Appendix N. The project was first initiated in 2015 by a design competition from the municipality. 2 Years later, in 2017, the contractor offered the construction of the project for sum of € 3,977,000.00. Take into account that this price offer was made to construct all six bridges of the Singelparkbruggen project, not just solely the Wisenniabrug. The specific share for the Wisenniabrug of this price offer was € 535,056.59, determined taking the sum of the direct costs for the Wisenniabrug and the share of the indirect construction costs for the Wisenniabrug, see formula 4.1.

$$Direct\ costs\ Wisenniabrug + \frac{Direct\ costs\ Wisenniabrug}{Total\ direct\ costs} * Total\ indirect\ costs \tag{4.1}$$

The maintained price level for this price offer was that of 2017. Since the price of materials, equipment, labor and subcontractors differs throughout the years, it is important to mention the governing price level. Table 4.6 shows the actual costs incurred of this project, based on project documents and several assumptions. These assumptions included a scaling factor to transform the costs from the entire project to the Wisenniabrug only. The table below only shows the major cost elements. The extended cost overview is added to Appendix M, which also includes the assumptions made.

Table 4.6: Overview of construction costs of the regular case project Wisenniabrug.

Code	Description	Total
	DIRECT CONSTRUCTION COSTS	
1	**ACCESSIBILITY**	
10	**Lighting**	**€ 10.828,25**
2	**PILING**	
20	**Piling foundation**	**€ 18.339,63**
3	**BRIDGE STRUCTURE**	
30	**Substructure**	**€ 66.399,42**
300	Preparatory work abutment Oude Herengracht	€ 13.581,28
301	Abutment Houtmarkt prepratory work	€ 2.958,71
302	Abutment Oude Herengracht	€ 10.144,76
303	Abutment Houtmarkt	€ 29.685,87
304	Pillars	€ 10.028,80
31	**Superstructure**	**€ 163.793,08**
4	**BRIDGE DECK**	
40	**Pavement bridge deck**	**€ 19.545,73**
6	**FINISHING**	
60	**Slackening structure**	**€ 5.929,33**
	TOTAL INCURRED DIRECT COSTS =	**€ 284.835,44**
	INDIRECT CONSTRUCTION COSTS	
9	**INDIRECT COSTS**	
91	**Construction site costs**	**€ 17.301,66**
910	Traffic measures	€ 5.650,30
911	Construction site	€ 11.651,36
92	**Non-recurring costs**	[redacted]
920	Testing costs	€ 1.635,67
921	Tender	[redacted]
922	Legal costs	€ 72,13
921	Provisional sums	€ 1.570,86
93	**Operating costs**	**€ 106.157,68**
94	**Overhead costs**	**€ 53.961,61**
95	**Profit and risk**	[redacted]
96	**Time bound costs**	[redacted]
	TOTAL INCURRED INDIRECT COSTS =	**€ 210.477,10**
	TOTAL CONSTRUCTION COSTS WISENNIABRUG =	**€ 495.312,53**

As one can see, the actual construction costs of the Wisenniabrug were lower than the initial price offer of € 535,056.59 made to the client. Thus the contractor made a profit of [redacted] on this project. This is in line with the result of the Singelparkbruggen project in general, which made a profit of [redacted]. If the actual total profits were to be multiplied by the factor estimated direct costs total project to estimated direct costs Wisenniabrug, a profit share for the Wisenniabrug would be [redacted], which is less than half of the incurred profit.

It is interesting to see that the indirect costs are relatively large and make up for 42.49% of the total construction costs, which is large when compared to other projects. The largest share of these indirect costs is caused by the operating costs, which consists of the incurred manhours by the executive, technical and administrative (UTA) staff of the contractor. This large cost item can be explained by the extra design work the contractor had to execute and the location of the construction site. Due to its location in the city centre, it was necessary to focus more on area management with the goal to keep the local residents and other stakeholders satisfied. This ultimately resulted in the necessary extra manhours of UTA-staff.

To cover the operation and maintenance component for this project, the maintenance costs were determined by the contractor, with the goals to provide the client with an indication of the yearly costs of maintenance. This data has been collected from the maintenance plan created for this bridge. These costs are displayed in table 4.7. Costs of large maintenance items are largely dependent on the amount of wear and tear. It is difficult to approximate the abrasion over a period of 10 or more years. In addition, once the large maintenance will be executed, a whole different price level is dominating the expenditures on maintenance. Hence, this price level is also hard to determine. Therefore, the costs per year for large maintenance has been excluded, but the expected activities have been listed.

Table 4.7: Maintenance costs Wisenniabrug

Code	Description	Costs per item	Frequency	Costs per year
1	**Inspections**			
10	Functional inspection on bridge, steel structure, and safety	€ 500,00	2x per year	€ 1.000,00
11	Inspection on cleanliness of the bridge	€ 250,00	1x per year	€ 250,00
2	**Preventive maintenance**			
20	Polishing stainless steel spheres	€ 500,00	2x per year	€ 1.000,00
3	**Large maintenance**			
30	Reapplication of hydrophobic layer pavement	TBA	1x per 10 years	TBA
31	Replacement of slackening structure	TBA	1x per 25 years	TBA
	Total amount of expected maintenance costs per year =			**€ 2.250,00**

4.2.4 Coupling the regular case project

For an integral analysis of the project case, the circularity assessment, construction costs and project process have been coupled. This way, a complete image is given of the case project, investigating its interrelations. First, the construction costs are coupled to the project process, followed by a coupling of the process to the circularity assessment. Thirdly, the circularity assessment is coupled to the construction costs. Ultimately, the three main pillars of the case study project are combined in an integral evaluation.

4.2.4.1 Coupling construction costs – project process

The construction costs have first been combined with the project process components. By analysis of the costs and its description, the cost items have been allocated to the project component for which the item is relevant. This resulted in figure 4.6, wherein the costs have been assigned to the project components of this case project. Appendix O includes a more detailed overview of the construction costs and its structures in each component.

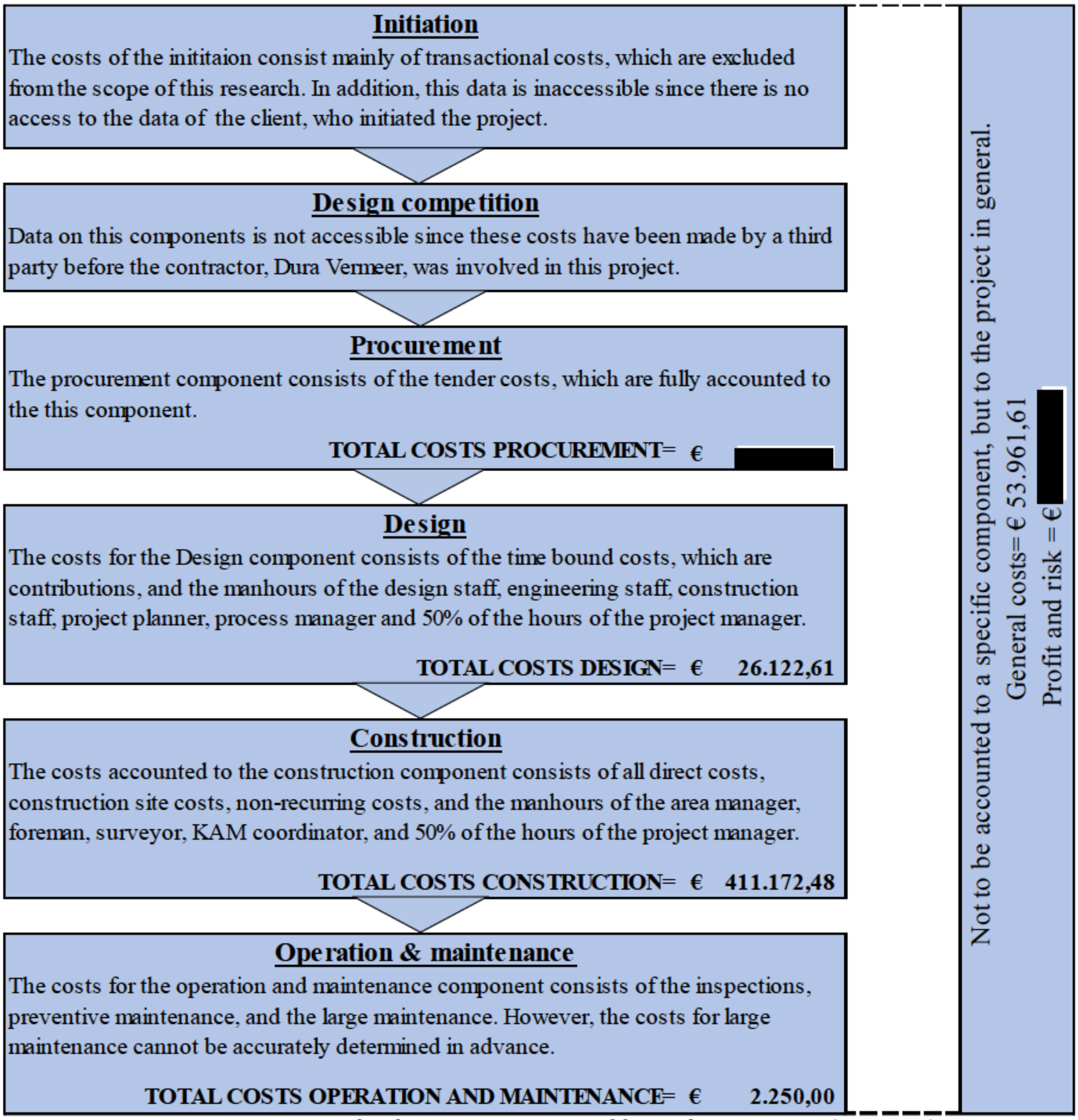

Figure 4.6: Construction costs accounted to the project components of the regular case project (own image).

As can be noted from the figure, the components Initiation and Design competition do not contain any construction costs. The Initiation component has been started before the contractor was involved in this project, hence, there is no access to information on the costs made in this component. The same applies to the Design competition component. Additionally to the Initiation component, the initiation of a project often consists largely of transactional costs, which have been excluded from the scope of this research. The Procurement component consist of the costs made for producing the tender, in order for the contractor to win the procurement procedure. These costs were a single cost time of the indirect construction costs. Since the design resulted from the design competition wasn't immediately executable, the contractor needed execute some design activities on its own. In addition, work preparation has also been included in the Design component. The extra activities and manhours that needed to be invested are reflected in the costs accounted to this component. When coupling the construction costs to the Construction component, it can be noticed that this component consists of both the direct costs and some of the indirect costs. The indirect costs accounted to this component are costs for setting up the construction site, non-recurring costs, manhours directly involved in the construction and half of the hours of the project manager, since this person has to share its attention to both the Design and Construction components. Eventually, the Operation and Maintenance component only consist of the expected maintenance costs. Overall, there are two cost items which could not be accounted to any specific project component. These are the general costs and the risk and profit.

4.2.4.2 Coupling circularity – project process

Circularity was not one of the goals the client wished for in this project, hence it had no influence on the project process. This is accompanied by the results of the circularity assessment of this case project in section 4.2.1. When discussing the process of this project with the stakeholders, no circular activities were identified, meaning that the process could not have been influenced by circularity. Only activities after the lifecycle of the bridge are related to circularity, when the bridge ends its life cycle and materials are released to be reused or recycled. This process step is however excluded from the scope of this study.

4.2.4.3 Coupling construction costs – circularity

As with the project process, circularity has not been actively implemented and is not represented in cost items of both the direct and indirect costs. Therefore, the absence of circularity in this case project automatically results in the lack of an interrelation between costs and circularity.

4.4 Cross-case comparison

The circular case project and the regular case project have been compared to each other. The results of this comparison are presented in this paragraph. First, the circularity assessments are compared, followed by the project process and the construction costs. The differences in results have been substantiated with possible explanation of what might have caused these differences.

4.4.1 Circularity comparison

The circular and regular case projects have been compared to one another on circularity score, based upon the calculated indicators of circularity, as determined in paragraph 4.1.1 and 4.2.1. Table 4.8 summarizes the scores of the circularity indicators of both case projects.

Table 4.8: Comparison circularity assessments case projects

Indicator	***Symbol***	***Description***	***Score Circular case project***	***Score Regular case project***
1.1	S_x	Secondary input material *(Higher percentage is more circular)*	**69.74%**	**13.04%**
1.1.1	H_x	Reused input material *(Higher percentage is more circular)*	**68.10%**	**0.00%**
1.1.2	R_x	Recycled input material *(Higher percentage is more circular)*	**1.64%**	**13.04%**
1.2	V_x	Primary input material *(Lower percentage is more circular)*	**30.26%**	**86.96%**
1.2.1	H_x	Renewable primary input material *(Higher percentage is more circular)*	**0.00%**	**3.22%**
1.2.1a	N_x	Sustainably produced renewable primary input material *(Higher percentage is more circular)*	**0.00%**	**3.22%**
1.2.1b	VN_x	Unsustainably produced renewable primary input material *(Lower percentage is more circular)*	**0.00%**	**0.00%**
1.2.2	NH_x	Percentage non-renewable primary input material *(Lower percentage is more circular)*	**30.26%**	**83.59%**
1.4.1	NK_x	Socio-economically non-scarce material of object *(Higher percentage is more circular)*	**74.70%**	**67.41%**
1.4.2	K_x	Socio-economically scarce material of object *(Lower percentage is more circular)*	**25.30%**	**32.59%**
2.1	H_g	Realistic re-usable output material of object *(Higher percentage is more circular)*	**42.19%**	**17.91%**
2.2	R_e	Percentage realistic recyclable output material of object *(Higher percentage is more circular)*	**48.56%**	**78.81%**
3.1	R_{ew}	Percentage output material used for energy generation *(Lower percentage is more circular)*	**9.23%**	**3.22%**
3.2	R_{st}	Percentage output material used as landfill *(Lower percentage is more circular)*	**0.02%**	**0.05%**

When comparing the scores of circularity to one another, the large differences are immediately visible on different indicators. To maintain a structured approach, the indicators are discussed according to the sequence of the table. Starting with the percentage of secondary input material, which is much higher in the circular project then in the regular project. This can most certainly be explained by the approach of the circular project, since this project was specifically aiming at reusing materials, while the regular project had no intentions whatsoever on reusing materials. The sub indicators of secondary input material show that almost every secondary material in the circular project is a reused secondary material, in contrast to the regular project in which all secondary materials are recycled materials. When taking into account the destination of the applied recycled secondary materials, which are the steel materials, the lack of any circular ambition is once again strengthened. Even more when considering that there was no steering on applying recycled steel, it just so happened to be that approximately 40% of the worldwide steel consists of recycled steel. When looking at the percentage of primary input materials it can be seen that this percentage in the regular project is much higher than that of the circular project. In both the projects, the applied primary materials are made up completely of non-renewable materials, which is also in both cases due to the application of steel and concrete materials. It is interesting to notice that the percentage of socio-economically scarce and non-scarce materials are relatively similar to one another. The circular case project achieved a slightly higher percentage of socio-economically non-scarce materials, which is a good thing. However, it is not likely that any attention was paid on this in the circular project, since it was simply not the scope of the project, similar to that of the regular project. Ultimately, the future potential of applied materials is measured. Even though the circular project was aimed at reusing materials, a relatively large part is still reusable in the future. A much lower percentage of material mass is available for reuse in the regular project, but it does however contain a large percentage of recyclable materials. The percentage of materials used for energy generation is in both projects low, as well as the percentage that will probably be used as landfill, which is almost negligible. The differences between two projects on the future potential is likely subject to the material choices made in both projects. The applied materials in the circular case study are concrete, steel and wood, while the regular case study mainly consists of steel. For steel it is likely that it will not reusable after the lifecycle of the bridges, but recycling is a logical future purpose. Concrete however is a sturdy material of which it is likely that it could be reused once more. Wood on the other hand will be worn out after lifecycle of the bridge and cannot be recycled, therefore it could be used for energy generation instead.

Overall, the circular case project scored better than the regular case project on almost every indicator of circularity. This was an expected result, however, still some improvement could be made in future projects. As was also collected from the interviews, at the start of the project there had been no attention paid to the lifecycle of the applied materials after their current lifecycle. Paying more attention to the entire lifecycle of the materials at the start of a project, may have a positive effect on circularity, since project participants will then be consciously thinking about the future of the materials. Doing so, will have positive effect on indicators 2.1 and 2.2, and hence, increase the circularity of the project.

4.4.2 Project process comparison

The processes of both case projects have been individually assessed in sections 4.1.2 and 4.2.2. After coupling the construction costs to the process components in sections 4.1.4.1 and 4.2.4.1, both projects' processes and costs haven been summarized in figure 4.7.

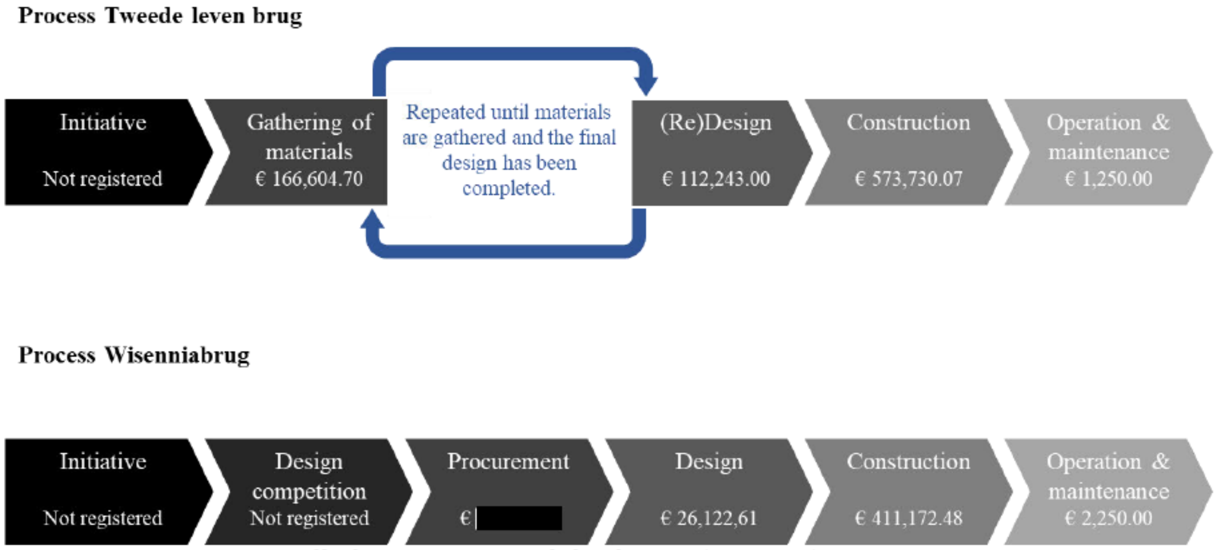

Figure 4.7: Project processes of both case projects coupled to the costs (own image).

By linking the costs to the project process components, the distribution of the construction costs among the project process becomes visible. As can be seen in figure 4.7, the construction costs in the regular project have been mainly incurred during the construction component. The remainder of the project components have relatively low costs. The construction costs in the circular project are more evenly distributed among the project components. However, the emphasis is still on the construction component. It is interesting to notice that the circular project costs more at the start of a project, after its initiation, while the costs of a regular project are mainly incurred at the actual construction of the project. The project components of the circular project responsible for the largest costs are: Gathering the materials, (Re)Design, and Construction. Gathering materials is project process component which can be fully accounted as being a result of circularity in this project. As was concluded in section 4.2.1, this project component had been identified as an extra project component for circular construction projects. Additionally, the (Re)Design component is directly related to the Gathering materials component and interchange frequently during the process of a circular project. This interchange can also be seen in the high costs for this component. The constant design activities in response to the material gathered are most likely the cause for these high costs. Thus, (Re)Design as project component and its related costs, can be accounted as well to circularity.

4.4.3 Construction costs comparison

With the goal of highlighting the differences in costs between the circular project and the regular project, the construction costs of both projects have been compared to each other. For this comparison, the construction costs overviews of both projects in Appendices L and M serves as a foundation. The construction costs have been compared on cost item level. These cost items consist of activities, materials, manhours, equipment and subcontracting, resulting in a detailed comparison between the two projects. By having executed the comparison in this manner, it became visible from what activities the costs originate from. A large number of cost items were subcontracted both in the circular and regular case project. Often, only a price offer from the subcontractor to the main contractor was provided, without any subdivision of materials, activities, manhours or equipment. The subcontractors responsible for cost items of which the subdivision of costs was lacking, were contacted to gather more information on the division of costs and activities. Unfortunately, only a few responded with a with further specified cost items, resulting in a number of cost items that still remained a general price offer without any specifications.

The two cost items have first been assessed on the comparability of the two cost items and the reliability of the results. Whenever two cost items were not similar enough and a fair comparison was not possible, a scenario was created wherein a circular cost item had been transformed into a regular cost item with comparable properties based on key figures and consultation with a cost price expert. Additionally, possible causes for the differences have been discussed and assessed on whether these are a result of circularity or not. Only the cost items consisting of reused materials have been included in this comparison, since newly applied materials in the circular case project are not relevant to compare and investigate on differences in costs. Therefore, the scaffolding and the application of the baffle plates have been excluded from the comparison.

4.4.3.1 Steel piling

In both case projects, the cost item for steel piling was subcontracted. This cost item in the circular case project has been further specified into multiple activities, including the supply and application of the steel piling, inspection and certification, torching of the steel piling, removing ground from steel piling and applying concrete in the piling. It was not possible to further specify the supply and application of steel piling in the circular case. Unfortunately, in the regular case project, it was also not possible to further specify the cost item for steel piling into activities due to missing information from the subcontractor. Hence the price mentioned for the regular case project includes similar activities to the activities mentioned in the circular case project. Table 4.9 shows the cost item steel piling in the circular and regular case projects. The activity codes 200000, 200010, 200020, 200030 from the circular case cost overview in Appendix L and 200000 from the regular case cost overview in Appendix M are included in the tables.

Table 4.9: Cost item steel piling in the circular and regular case projects.

STEEL PILING					
Circular case project			**Regular case project**		
Supply and application steel piling		€ **64.836,00**	**Supply and application steel piling**		€ [redacted]
Supply and application steel tubular pile Ø914mm, average L= 16,05m, 8 pieces	45 453,60 Kg	€ [redacted]	Subcontracting steel piling Ø324mm, average L= 14,07, 12 pieces	[redacted] Kg	€ [redacted]
Inspection and certification steel piling	once	€ [redacted]			
Welder	16 hours	€ [redacted]			
Telescopic crane	12 hours	€ [redacted]			
Vacuum excavation of steel piling	8 times	€ [redacted]			
Carpenter	16 hours	€ [redacted]			
Concrete mixture C30/37	32 m³	€ [redacted]			
Price per kg steel piling	€ **1,43**		**Price per kg steel piling**	€ **1,74**	

As can be seen, the properties of the steel piling differentiates quite a lot from one another. In the circular case project, longer and wider steel piling had been applied in comparison to the piling in the regular case project, which is generally much more expensive in both purchasing and installing. However, a higher number of piling was applied in the regular case project. The differences make it hard to create a fair and reliable comparison between the projects on this cost item. The missing information within both cost items on the unit price of a piece of steel piling makes it even harder. To make a comparison possible, the steel piling in both project has been transformed to price per kg steel piling. For steel piling, this is a rater normal way of determining the price of piling (E. Alink, personal communication, October 28, 2022). The price per kg in the circular case project is € 1.43, while in the regular case project the price per kg is € 1.74. Hence, a circular steel piling would be cheaper than when applied new. This difference in price cannot be easily declared, since a specification of the activities is missing. It was however possible to spot an extra activity which is a result of the circular ambition, this is ''Inspection and certification steel piling'', leading to an extra expenditure of € 900.00. This activity is necessary to ensure the safety when reusing secondhand steel piling. Even though it not possible to conclude anything about the difference in costs about the steel piling itself, it is certain that this circularity related activity has added to the costs of steel piling, which is an interesting find on its own. Knowing that the steel piling was one of the few directly comparable cost items, makes the result of this comparison one of most important ones in this study.

4.4.3.2 Abutments

Both case projects are bridges, thus these projects both have two abutments. In the circular case, this activity was subcontracted. Luckily, the subcontractor provided the specifications of the activities in this cost item resulting in two detailed cost items of both the regular and the circular project case. First the cost item specifications on the abutments of the regular case project is provided in table 4.10. The activity codes 300000, 300010, 300020, 300030, 300040, 300050, 301000, 301010, 302000, 302010, 302020, 302030, 303000, 303010, 303020, 303030, 303040, 303050 from the regular case cost overview in Appendix M were used in table 4.10.

Table 4.10: Cost item abutments in the regular case project.

Regular case project		
Supply and application abutments		**€ 50.441,96**
Laborer	67,41 hours	€ [redacted]
Small track excavator	67,41 hours	€ [redacted]
Mobile excavator	9,28 hours	€ [redacted]
Drilling	[redacted] EUR	€ [redacted]
PVC pipe Ø400mm	7,28 pieces	€ [redacted]
Grouting	[redacted] EUR	€ [redacted]
Truck	37,2 hours	€ [redacted]
Landfill costs	[redacted] EUR	€ [redacted]
Supply of sand	[redacted] EUR	€ [redacted]
Paver	16 hours	€ [redacted]
Pavement various	[redacted] EUR	€ [redacted]
Attachment escavator	2,32 day	€ [redacted]
Carpenter	323,88 hours	€ [redacted]
Concrete pump	1,05 hours	€ [redacted]
Formwork	[redacted] EUR	€ [redacted]
Subcontracting braiding steel	1254,4 Kg	€ [redacted]
Concrete mortar	7,92 m³	€ [redacted]
Small truck load	17,16 m³	€ [redacted]
Bricklayer	193,56 hours	€ [redacted]
Masonry various	[redacted] EUR	€ [redacted]
Crane	3,36 hours	€ [redacted]
Concrete floor plate 250mm thick	0,82 m³	€ [redacted]
Brick 200x65x50mm	28,87 m²	€ [redacted]
Sealing layer	[redacted] EUR	€ [redacted]
Price per abutment	**€ 25.220,98**	

The abutments in the circular case project are constructed from steel, the ones in the regular case project are made from an entirely different material, which is concrete and masonry. This results in an unfair comparison. To tackle this issue and to make a comparison possible, a regular scenario has been created similar to the activities of the circular cost item. This scenario is given in table 4.11 together with the cost item of the circular case project, based on activity code 300000, for comparison purposes.

Table 4.11: Cost item abutments in the regular scenario and circular case project.

ABUTMENTS					
Circular case project			**Regular scenario**		
Supply and application steel abutments		€ **28.322,30**	**Supply and application steel abutments**		€ 26 752,32
Supply of steel material	7141,2 Kg	€ [redacted]	Supply of steel material	7141,2 Kg	€ [redacted]
Transport to treatment location	[redacted] EUR	€ [redacted]	Treatment (sawing, composing, welding)	200 Hours	€ [redacted]
Preparing steel for treatment	24 hours	€ [redacted]	Transport	[redacted] EUR	€ [redacted]
Treatment (sawing, composing, welding)	200 hours	€ [redacted]	Assembly on site	108 hours	€ [redacted]
Transport	[redacted] EUR	€ [redacted]	General costs subcontractor	[redacted] EUR	€ [redacted]
Assembly	108 hours	€ [redacted]			
General costs subcontractor	[redacted] EUR	€ [redacted]			
Price per abutment	€ **14.161,15**		**Price per abutment**	€ **13.376,16**	

In the scenario, the activities identified as a result of circularity were excluded. These activities were ‘’Transport to treatment location’’ and ‘’Preparation before treatment’’. Additionally, the price for supplying steel materials has been altered from the secondhand price of € 1.06/Kg to the price of new steel of € 1.10/Kg. All other activities remained the same. By having created this scenario, the cost items were made comparable.

The price per abutment in the circular case project is € 14,161.15 while an abutment, according to the scenario, would cost € 13,376.16 in a regular project, hence, a similar abutment would be cheaper when applied new. This difference in price can be declared by the extra activities that have to be executed when applying this object element in a circular manner. Even though the price of secondhand steel is less, it has to undergo treatment in order for the material to be further processed as a construction element. Since the scenario cost item is based on the similar materials and activities of the circular cost item, it is deemed a reliable result, but with the caveat that the exact same element has been applied, but then new.

4.4.3.3 Concrete girders

The main body of the bridge is created by its girders. In the circular case the girders were reused from an obsolete bridge. However, in the regular case project, no separate girders were applied. This bridge was made from steel and assembled by a subcontractor, which also results in the cost item of the entire superstructure of the regular bridge. Ultimately, the bridge in entirety was hoisted to its current location. Due to the lack of subdivision of bridge elements of the regular bridge and the fact that it does not contain girders, it is not feasible to compare the cost items of the circular case to the one of the regular case. To tackle this issue and to make a comparison possible, a regular scenario has been created similar to the activities of the circular cost item. The costs for applying circular concrete girders has been summarized in table 4.12, together with the regular scenario. The circular cost item summarized in table 4.12, the circular girders, consists of activity codes 310000, 310010, 310020 and 310050 from the circular case cost overview in Appendix L.

Table 4.12: Cost item concrete girders in the circular case project and regular scenario.

CONCRETE GIRDERS					
Circular case project			**Regular scenario**		
Supply and application girders		**€ 40.416,99**	**Supply and application girders**		**€ 123.244,00**
Measurement girder face ends	[redacted] EUR	€ [redacted]	Supply of concrete girders	6 pieces	€ [redacted]
Sawing girders	[redacted] EUR	€ [redacted]	Carpenter	64 hours	€ [redacted]
Hydrojet girders	1 piece	€ [redacted]	Telescopic crane 300 ton	16 hours	€ [redacted]
Disposal of debris	1485 Kg	€ [redacted]	Bracing of concrete girders on structure	[redacted] EUR	€ [redacted]
Sand blast exposed steel reinforcement	[redacted] EUR	€ [redacted]			
Supply and application of primer	12 piecs	€ [redacted]			
Supply and application of formwork	12 pieces	€ [redacted]			
Supply of concrete mortar	1056 Kg	€ [redacted]			
Applying concrete mortar	12 pieces	€ [redacted]			
Demoulding and finishing girder face ends	13 pieces	€ [redacted]			
Applying girder face ends sealing layer	14 pieces	€ [redacted]			
Finishing openings Dywidag	42 pieces	€ [redacted]			
Supply of concrete girders	6 pieces	€ -			
Carpenter	96 hours	€ [redacted]			
Telescopic crane 300 ton	32 hours	€ [redacted]			
Truck	16 hours	€ [redacted]			
Bracing of concrete girders on structure	[redacted] EUR	€ [redacted]			
Price per girder	**€ 6.736,17**		**Price per girder**	**€ 20.540,67**	

In the scenario, the activities identified as a result of circularity were excluded. These activities were ‘’ Measurement girder face ends’’, ‘’Sawing girders’’, ‘’Hydrojet girders’’, ‘’Disposal of debris’’, ‘’Sand blast exposed steel reinforcement’’, ‘’Supply and application of primer’’, ‘’Supply and application of formwork’’, ‘’Supply of concrete mortar’’, ‘’Applying concrete mortar’’, ‘’Demoulding and finishing girder face ends’’, ‘’Applying girder face ends sealing layer’’, ‘’Finishing openings Dywidag’’, ‘’Truck’’. These activities have all occurred in order to repair the secondhand concrete girders before applying these in a new project and transporting these to the storage facility. Since the concrete girders were already in possession of the contractor, these are regarded as free of charge for this project. In the scenario, a price has been determined for supplying concrete girders, which is € 18,900. All other activities remained the same. By having created this scenario, the cost items were made comparable.

The price per concrete girder in the circular case project is € 6,736.17 while an concrete girder, according to the scenario, would cost € 20,540.67 per girder in a regular project. Hence, the circular girder is significantly cheaper than a newly applied girder. The major reason for this difference in price can be declared by the fact that the girder in the circular case was free, while the girder in the circular project needed to be purchased. When looked at the reused girders, the major part of the price is a result of the repairs that have been executed in order to apply the components. These costs can be accounted as a result of the circular ambitions of the project. Since the scenario cost item is based on the similar materials and activities of the circular cost item, it is deemed a reliable result, but with the caveat that the exact same element has been applied, but then new.

4.4.3.4 Steel beam supports

The bridge in the circular case consists of twelve steel beam support, originating from secondhand steel. As previously explained, the superstructure of the regular case project is constructed as one object, hence, it has been regarded as one cost item. While the materials of both cost items correspond, it is not possible to compare a bridge element of the circular case to an entire bridge superstructure of the regular case. Additionally, different techniques, including welding and laser cutting, were used to construct the superstructure of the regular bridge. To tackle this issue and to make a comparison possible, a regular scenario has been created similar to the activities of the circular cost item. The costs for applying steel beam supports in the circular case project has been summarized in table 4.13 together with the regular scenario. The cost item of circular case project is constructed of activity code 310030 from the circular case cost overview in Appendix L.

Table 4.13: Cost item steel beam supports in the circular case project and regular scenario.

STEEL BEAM SUPPORTS					
Circular case project			**Regular scenario**		
Supply and application steel beam supports		**€ 9.804,74**	**Supply and application steel beam supports**		**€ 8.832,74**
Supply of steel diamond plate material	684 Kg	€ [redacted]	Supply of steel diamond plate material	684 Kg	€ [redacted]
Treatment (sawing, composing, welding)	96 hours	€ [redacted]	Treatment (sawing, composing, welding)	96 hours	€ [redacted]
Transport	[redacted] EUR	€ [redacted]	Transport	[redacted] EUR	€ [redacted]
Assembly	24 hours	€ [redacted]	Assembly	24 hours	€ [redacted]
General costs subcontractor	[redacted] EUR	€ [redacted]	General costs subcontractor	[redacted] EUR	€ [redacted]
Price per beam support	**€ 817,06**		**Price per beam support**	**€ 736,06**	

In the scenario, there were no activities directly identified as a result of circularity. No extra activities were mentioned by subcontractor to prepare the steel to be reused. The supply of the steel however has been adapted from the price of reused steel, € 3.92/Kg, to the price of new steel, which is €2.50/Kg. All other activities remained the same. By having created this scenario, the cost items were made comparable.

The price per steel beam support in the circular case project is € 817.06, while an newly applied steel beam support, according to the scenario, would cost € 736.06 per piece in a regular project. Hence the new steel beam supports are less expensive than reused beam support. This is an remarkable find, mainly due to the fact that new steel is less expensive than reused steel. There are no other costs known that could have influenced the price per beam support other than the material price. The higher material price could be explained by possible activities the subcontractor had already put into these reused materials in order to gather it, for example demolition activities. Unfortunately it is unknown how the price of reused steel was determined. Therefore, it is also uncertain to tell whether the higher costs of reused materials is due to circular practices or not.

4.4.3.5 Steel crossbeams

The bridge in the circular case consists of 29 steel crossbeams, originating from secondhand steel. As previously explained, the superstructure of the regular case project is constructed as one object, hence, it has been regarded as one cost item. While the materials of both cost items correspond, it is not possible to compare a bridge element of the circular case to an entire bridge superstructure of the regular case. Additionally, different techniques, including welding and laser cutting, were used to construct the superstructure of the regular bridge. To tackle this issue and to make a comparison possible, a regular scenario has been created similar to the activities of the circular cost item. The costs for applying steel crossbeams in the circular case project has been summarized in table 4.14, together with the regular scenario. The circular cost item summarized in table 4.14 consists of activity codes 320000, 320010, 320020 from the circular case cost overview in Appendix L.

Table 4.14: Cost item steel crossbeams in the circular case project and regular scenario.

STEEL CROSSBEAMS					
Circular case project			**Regular scenario**		
Supply and application steel crossbeams		**€ 66.488,52**	**Supply and application steel crossbeams**		**€ 66.065,36**
Supply of steel material	19801,2 Kg	€ [redacted]	Supply of steel material	19801,2 Kg	€ [redacted]
Disassembly of initial steel material	87 hours	€ [redacted]	Treatment of steel (sawing, composing, wel	406 hours	€ [redacted]
Preparing steel for treatment	72,5 hours	€ [redacted]	Threaded rod M20, L=5000mm	348 pieces	€ [redacted]
Treatment of steel (sawing, composing, wel	406 hours	€ [redacted]	Bracing	once	€ [redacted]
Threaded rod M20, L=5000mm	348 pieces	€ [redacted]	Transport	once	€ [redacted]
Bracing	once	€ [redacted]	Assembly	261 hours	€ [redacted]
Transport	2 times	€ [redacted]	General costs subcontractor	[redacted] EUR	€ [redacted]
Assembly	261 hours	€ [redacted]			
General costs subcontractor	[redacted] EUR	€ [redacted]			
Price per crossbeam	**€ 2.292,71**		**Price per crossbeam**	**€ 2.278,12**	

In this scenario, the activities identified as a result of circularity were excluded. These activities were ‘’Disassembly of initial steel material’’ and ‘’Preparing steel for treatment’’. Additionally, there is one less transport movement necessary since the new materials can be immediately delivered to the construction site instead of first delivering it at the treatment location. The excluded activities have all occurred in order to repair and prepare the secondhand steel materials before applying these in a new project. The price for the supply of the steel has also been adapted from the price of reused steel, € 0.48/Kg, to the price of new steel, which is € 0.95/Kg. The M20 threaded rod has been newly applied in the circular case study, thus this will not change in the regular scenario. All other activities remained the same. By having created this scenario, the cost items were made comparable.

The price per steel crossbeam in the circular case project is € 2,292.71 while a new steel crossbeam, according to the scenario, would cost € 2,278.12 per crossbeam in a regular project. Hence, similar crossbeams would be a little cheaper when applied new, even though the price of secondhand steel is half of the price of new steel. The cause for the higher costs of applying this element in a circular manner is due to the extra activities that have to be executed in order to apply it. In the regular scenario, the disassembly of the initial steel, preparation of the steel before treatment, and one transport movement is missing, since it are necessary activities when applying new steel. These activities are therefore a result of circularity. Since the scenario cost item is based on the similar materials and activities of the circular cost item, it is deemed a reliable result, but with the caveat that the exact same element has been applied, but then new.

4.4.3.6 Steel support beams

The bridge in the circular case consists of 40 steel support beams, originating from secondhand steel. As previously explained, the superstructure of the regular case project is constructed as one object, hence, it has been regarded as one cost item. While the materials of both cost items correspond, it is not possible to compare a bridge element of the circular case to an entire bridge superstructure of the regular case. Additionally, different techniques, including welding and laser cutting, were used to construct the superstructure of the regular bridge. To tackle this issue and to make a comparison possible, a regular scenario has been created similar to the activities of the circular cost item. The costs for applying steel support beams in the circular case project has been summarized in table 4.15, together with the regular scenario. The cost item of the circular case project summarized in table 4.15 consists of activity code 320030 from the circular case cost overview in Appendix L.

Table 4.15: Cost item steel support beams in the circular case project and regular scenario.

STEEL SUPPORT BEAMS					
Circular case project			**Regular scenario**		
Supply and application steel support beams		€ **17.060,70**	**Supply and application steel support beams**		€ **16.325,60**
Supply of steel material	4980 Kg	€ [redacted]	Supply of steel material	4980 Kg	€ [redacted]
Treatment (sawing, composing, welding)	64 hours	€ [redacted]	Treatment (sawing, composing, welding)	64 hours	€ [redacted]
Transport	[redacted] EUR	€ [redacted]	Transport	[redacted] EUR	€ [redacted]
Assembly	108 hours	€ [redacted]	Assembly	108 hours	€ [redacted]
General costs subcontractor	[redacted] EUR	€ [redacted]	General costs subcontractor	[redacted] EUR	€ [redacted]
Price per support beam	€ **426,52**		**Price per support beam**	€ **408,14**	

In this scenario were no activities directly identified as a result of circularity. No extra activities were mentioned by subcontractor to prepare the steel to be reused. The supply of the steel however has been adapted from the price of reused steel, €1.25/Kg, to the price of new steel, which is €1.10/Kg. All other activities remained the same. By having created this scenario, the cost items were made comparable.

The price per steel support beam in the circular case project is € 426.52, while an newly applied steel support beams, according to the scenario, would cost € 408.14 per piece in a regular project. Hence the new steel support beams are less expensive than reused support beams. This is an remarkable find, mainly due to the fact that new steel is less expensive than reused steel. There are no other costs known that could have influenced the price per support beam other than the material price. The higher material price could be explained by possible activities the subcontractor had already put into these reused materials in order to gather it, for example demolition activities. Unfortunately it is unknown how the price of reused steel was determined by the subcontractor. Therefore, it is also uncertain to tell whether the higher costs of reused materials is due to circular practices or not.

4.4.3.7 Superstructure overall

The individual elements of the superstructure of the circular bridge have been compared to created scenarios of a regular bridge. Unfortunately it was not possible to compare these individual elements of the superstructure of the circular case project to the regular case project due to the fact that the superstructure of the regular case project was constructed as one object by a subcontractor. This resulted a single cost item without any subdivision of smaller elements. However, it could be interesting to compare the overall superstructure of both case projects to one another. This will provide an overall picture of what the influence of circularity on costs is on the superstructure of a bridge. The activity codes 310000, 310010, 310020, 310030, 310050, 320000, 320010, 320020 and 320030 from the circular case cost overview in Appendix L were used in table 4.16 together with activity codes 310000 and 310010 from the regular case cost overview in Appendix M.

Table 4.16: Cost item superstructure of the circular and regular case project.

SUPERSTRUCTURE OVERALL					
Circular case project			**Regular case project**		
Supply and application superstructure		**€ 133.770,95**	**Supply and application superstructure**		**€ 163.773,08**
Supply and application girders		€ [redacted]	Machining steel plates	170 hours	€ [redacted]
Supply and application steel beam supports		€ [redacted]	Sawing steel components	35 hours	€ [redacted]
Supply and application steel crossbeams		€ [redacted]	Cutting steel components	105 hours	€ [redacted]
Supply and application steel support beams		€ [redacted]	Welding of components	1675 hours	€ [redacted]
			Polish stainless steel components	40 hours	€ [redacted]
			Stainless steel	[redacted] EUR	€ [redacted]
			General costs subcontractor	[redacted] EUR	€ [redacted]
			Grouting	[redacted] EUR	€ [redacted]
Total m² superstructure	**324**		**Total m² superstructure**	**70**	
Price per m² superstructure	**€ 412,87**		**Price per m² superstructure**	**€ 2.339,62**	

From table 4.16 can be concluded that the circular bridge is nearly twice as expensive as the regular bridge. But when looked at the price per m², the circular bridge seems less expensive. This comparison and its results is of course of a very low reliability. Firstly, the superstructure of both bridges are constructed from completely different material. Secondly, the dimensions of the bridge are very different as well. Lastly, due to the material choices made, both bridges are constructed in completely different ways. While the circular bridge is assembled with nuts and bolts, the regular bridges has been entirely welded together. However, the assembly method of the circular bridge can be seen as result of circularity, since this assembly method allows all different sources of materials to be attached to one another. The large differences in activities make it impossible to say something about the price of the circular bridge being the result of circularity.

4.4.3.8 Wooden girders bridge deck

The circular bridge consists of 324 m² of wooden bridge deck. A component of this bridge deck are the wooden girders on which the deck planks are mounted. The wood applied in the circular project has been collected by subcontractor from obsolete wooden structures. The bridge deck of the regular bridge is only 70m² large and consists of pavement and concrete. Based on the materials applied, the related activities and the dimensions of the bridge deck, this results in an comparison that is affected by many different factors, thus very unreliable. To tackle this issue and to make a comparison possible, a regular scenario has been created similar to the activities of the circular cost item. The costs for applying wooden girders in the circular case project has been summarized in table 4.17 together with the regular scenario. The cost item of the circular case project summarized in table 4.24, the wooden girders, consists of activity code 400000 from the circular case cost overview in Appendix L.

Table 4.17: Cost item wooden girders of the circular case project and regular scenario.

WOODEN GIRDERS BRIDGE DECK					
Circular case project			**Regular scenario**		
Supply and application wooden girders bridge deck		**€ 51.968,15**	**Supply and application wooden girders bridge deck**		**€ 46.253,49**
Harvest of wood	[redacted] EUR	€ [redacted]	Supply of wood	17,52 m³	€ [redacted]
Supply of wood	17,52 m³	€ [redacted]	Transport	17,52 m³	€ [redacted]
Transport	17,52 m³	€ [redacted]	Sorting, sawing, shortening and planing	17,52 m³	€ [redacted]
Cleaning the wood	17,52 m³	€ [redacted]	General costs subcontractor	[redacted] EUR	€ [redacted]
Sorting, sawing, shortening and planing	17,52 m³	€ [redacted]			
General costs subcontractor	[redacted] EUR	€ [redacted]			
Total m² bridge deck	**324**		**Total m² bridge deck**	**324**	
Price per m² bridge deck	**€ 160,40**		**Price per m² bridge deck**	**€ 142,76**	

In the scenario, only two activities was identified as a result of circularity and were therefore excluded. The activity were ‘’Harvest of wood’’ and ‘’Cleaning the wood’’. The excluded activities have been occurred in order for the secondhand materials to become available, used and sawed in the right dimensions. Normally, one would receive clean wood from the sawmill. Even though sorting, sawing, shortening and planning has not been addressed as an activity as result of circularity, it is expected that this activity would take shorter when new wood is used. This is expected since the sawmill can deliver all different sizes of wood, reducing the activities to reach the desired dimensions. The price for the supply of wood has also been adapted from the price of reused wood, € 267/m³, to the price of new wood, which is € 1800/m³. All other activities remained the same. By having created this scenario, the cost items were made comparable.

The price per m² of the wooden bridge deck, for the wooden girders, in the circular case project is € 160.40, while newly applied wooden girders, according to the scenario, would cost € 142.76 per m² of bridge deck in a regular project. Hence, applying new wood girders would be less expensive as when reused wooden girders are applied. This difference in price can be easily explained by the harvesting of the wood which is necessary in order for the wood to become available. Even though the secondhand wood is more than six times lower than new wood, the harvesting of wood still was a large factor increasing the price per m² of the reused wood. Cleaning the wood is another extra activity in the circular project, but is pricewise irrelevant when compared to the extra costs that are caused by the harvest of wood. This cost increment for reused wood is an immediate result of the implementation of circularity, due to the extra activities as a result of circularity. Since the scenario cost item is based on the similar materials and activities of the circular cost item, it is deemed a reliable result, but with the caveat that the exact same element has been applied, but then new.

4.4.3.9 Wooden deck

The circular bridge consists of 324 m² of wooden bridge deck. A component of this bridge deck are the deck planks which are mounted on the wooden girders. The wood applied in the circular project has been collected by subcontractor from obsolete wooden structures. The bridge deck of the regular bridge is only 70m² large and consists of pavement and concrete. Based on the materials applied, the related activities and the dimensions of the bridge deck, this results in an comparison that is affected by many different factors, thus very unreliable. To tackle this issue and to make a comparison possible, a regular scenario has been created similar to the activities of the circular cost item. The costs for applying the wooden deck in the circular case project has been summarized in table 4.18 together with the regular scenario. The circular cost item summarized in table 4.18 consists of activity code 400000 from the circular case cost overview in Appendix L.

Table 4.18: Cost item wooden deck of the circular case project and regular scenario.

WOODEN DECK					
Circular case project			**Regular scenario**		
Supply and application wooden deck		**€ 90.894,48**	**Supply and application wooden deck**		**€ 159.940,54**
Harvest of wood	[redacted] EUR	€ [redacted]	Supply of wood	30 m^3	€ [redacted]
Supply of wood (already in possession)	30 m^3	€ -	Transport	30 m^3	€ [redacted]
Transport	30 m^3	€ [redacted]	Sorting, sawing, shortening and planing	30 m^3	€ [redacted]
Cleaning the wood	30 m^3	€ [redacted]	General costs subcontractor	[redacted] EUR	€ [redacted]
Sorting, sawing, shortening and planing	30 m^3	€ [redacted]			
General costs subcontractor	[redacted] EUR	€ [redacted]			
Total m^2 bridge deck	**324**		**Total m^2 bridge deck**	**324**	
Price per m^2 bridge deck	**€ 280,54**		**Price per m^2 bridge deck**	**€ 493,64**	

In the scenario, only two activities was identified as a result of circularity and were therefore excluded. The activity were ''Harvest of wood'' and ''Cleaning the wood''. The excluded activities have been occurred in order for the secondhand materials to become available, used and sawed in the right dimensions. Normally, one would receive clean wood from the sawmill. Even though sorting, sawing, shortening and planning has not been addressed as an activity as result of circularity, it is expected that this activity would take shorter when new wood is used. This is expected since the sawmill can deliver all different sizes of wood, reducing the activities to reach the desired dimensions. The price for the supply of wood has also been adapted from the price of reused wood. At the start of the project, the contractors had the wood already in stock, meaning that supply of wood for this cost item is regarded as free. In the scenario, the price for wood of € 4285.71/m^3 is maintained. All other activities remained the same. By having created this scenario, the cost items were made comparable.

The price per m^2 of the wooden bridge deck, for the wooden deck, in the circular case project is € 280.54, while newly applied wooden deck, according to the scenario, would cost € 493.64 per m^2 of bridge deck in a regular project. Hence, the circular cost item is much less expensive than the cost item in the regular scenario. The largest cause for this difference in price can be explained by the lack of purchasing costs for the reused wood. There were however costs incurred for the harvest of wood, but these were also relatively low when compared to the purchasing of new wood. Cleaning the wood is an extra activity in the circular project, but these missing costs in the regular project are irrelevant when compared to the increased material price of new wood. The reused wood being free of charge is however uncommon, thus the result being that the circular cost item is cheaper is not a reliable conclusion to draw.

4.4.3.10 Bridge deck overall

The individual elements of the bridge deck of the circular bridge have been compared to created scenarios of a regular bridge. Unfortunately it was not possible to compare these individual elements of the bridge deck of the circular case project to the regular case project due to the fact that the bridge deck of the regular case project was constructed of entirely different materials in different dimensions, resulting from different activities. However, it could be interesting to compare the overall bridge deck of both case projects to one another. This will provide an overall picture of what the influence of circularity on costs is on the bridge deck of a bridge. The activity codes 400000 and 400010 from the circular case cost overview in Appendix L were used in table 4.19 together with the activity codes 400000, 400010, 400020 and 400030 from the regular case cost overview in Appendix M.

Table 4.19: Cost item bridge deck of the circular and regular case project.

BRIDGE DECK OVERALL					
Circular case project			**Regular case project**		
Supply and application bridge deck		**€ 142.862,63**	**Supply and application bridge deck**		**€ 19.538,57**
Supply and application wooden girders		€ [redacted]	Paver	180,10 hours	€ [redacted]
Supply and application wooden deck		€ [redacted]	Drainage mat 120x30mm	139,19 m²	€ [redacted]
			Pavement various	[redacted] EUR	€ [redacted]
			Truck	37,19 hours	€ [redacted]
			Sand-cement	[redacted] EUR	€ [redacted]
			Concrete brick 200x65x50mm	123,72 m²	€ [redacted]
			Epoxy mortar	7,07	€ [redacted]
			Craftsman	15,02	€ [redacted]
Total m² bridge deck	**324**		**Total m² bridge deck**	**70**	
Price per m² bridge deck	**€ 440,93**		**Price per m² bridge deck**	**€ 279,12**	

From the tables 4.19 can be concluded that the bridge deck of the circular bridge is more expensive than the bridge deck of the regular bridge. This is also represented in the price per m² bridge. This comparison and its results is of course of a very low reliability. Firstly, the bridge decks of both bridges are constructed from completely different materials. Secondly, the dimensions of the bridge are very different as well. Lastly, due to the material choices made, both bridges are constructed in completely different ways. While the circular bridge is assembled with nuts and bolts, the bridge deck on the regular bridge has been paved into concrete and epoxy. However, the assembly method of the circular bridge can be seen as result of circularity, since this assembly method allows all different sources of materials to be attached to one another. The large differences in activities make it impossible to say something about the price of the circular bridge being the result of circularity.

4.4.3.11 Bench on bridge

On the girders of the circular bridge, a wooden bench is placed. The wood applied in the circular project has been collected by subcontractor from obsolete wooden structures. The wooden bench is stretched over the entire length of the bridge, situated on both sides, leading to a total length of 162m. The regular bridge is only 30m long and does not contain any benches. The lack of a similar cost item in the regular case project has led to the creation of a regular scenario which is similar to the activities of the circular cost item. The costs for applying the wooden deck in the circular case project has been summarized in table 4.20 together with the regular scenario. The circular cost item summarized in table 4.20 consists of activity codes 500000 and 500010 from the circular case cost overview in Appendix L.

Table 4.20: Cost item wooden bench of the circular case project and regular scenario.

WOODEN BENCHES ON BRIDGE					
Circular case project			**Regular scenario**		
Supply and application benches on bridge		**€ 35.873,82**	**Supply and application wooden benches on bridge**		**€ 26.579,77**
Harvest of wood	[redacted] EUR	€ [redacted]	Supply of wood	8,262 m^3	€ [redacted]
Supply of wood	8,262 m^3	€ [redacted]	Transport	8,262 m^3	€ [redacted]
Transport	8,262 m^3	€ [redacted]	Sorting, sawing, shortening and planing	8,262 m^3	€ [redacted]
Cleaning the wood	8,262 m^3	€ [redacted]	Check bevels	8,262 m^3	€ [redacted]
Sorting, sawing, shortening and planing the	8,262 m^3	€ [redacted]	General costs subcontractor	[redacted] EUR	€ [redacted]
Check bevels	8,262 m^3	€ [redacted]			
General costs subcontractor	[redacted] EUR	€ [redacted]			
Total m of wooden benches	**162**		**Total m of wooden benches**	**162**	
Price per m wooden bench	**€ 221,44**		**Price per m wooden bench**	**€ 164,07**	

In the scenario, only two activities was identified as a result of circularity and were therefore excluded. The activity were ''Harvest of wood'' and ''Cleaning the wood''. The excluded activities have been occurred in order for the secondhand materials to become available, used and sawed in the right dimensions. Normally, one would receive clean wood from the sawmill. Even though sorting, sawing, shortening and planning has not been addressed as an activity as result of circularity, it is expected that this activity would take shorter when new wood is used. This is expected since the sawmill can deliver all different sizes of wood, reducing the activities to reach the desired dimensions. The price for the supply of wood has also been adapted from the price of reused wood, which is € 1004.71/m^3. In the scenario, the price for new wood of € 1800/m^3 is maintained. All other activities remained the same. By having created this scenario, the cost items were made comparable.

The price per m of wooden bench in the circular case project is € 221.44, while newly applied wooden deck, according to the scenario, would cost € 164.07 per m of bridge deck in a regular project. Hence, applying benches from new wood would be less expensive as when reused wood was applied. This difference in price can be easily explained by the harvesting of the wood which is necessary in order for the wood to become available. Even though the secondhand wood is nearly two times lower than new wood, the harvesting of wood still was a large factor increasing the price per m^2 of the reused wood. Cleaning the wood is another extra activity in the circular project, but is pricewise irrelevant when compared to the extra costs that are caused by the harvest of wood. This cost increment for reused wood is an immediate result of the implementation of circularity, due to the extra activities as a result of circularity. Since the scenario cost item is based on the similar materials and activities of the circular cost item, it is deemed a reliable result, but with the caveat that the exact same element has been applied, but then new.

4.4.3.12 Railing

The circular bridge is provided with a railing consisting of wood and steel. The wood applied in the circular project has been collected by subcontractor from obsolete wooden structures. The steel has been supplied from secondhand sources by another subcontractor. The railing is stretched over the entire length of the bridge, situated on both sides, leading to a total length of 162m. The regular bridge is only 30m long and the railing has been integrated in the superstructure of the bridge. The lack of a subdivision of the superstructure cost item in the regular case project has led to the creation of a regular scenario which is similar to the activities of the circular cost item. The costs for applying the wood and steel railing in the circular case project has been summarized in table 4.21, together with the regular scenario and its costs. The circular cost item summarized in table 4.21 consists of activity codes 510000, 510010 and 510020 from the circular case cost overview in Appendix L.

Table 4.21: Cost item railing of the circular case project and regular scenario.

RAILING					
Circular case project			Regular scenario		
Supply and application railing on bridge		**€ 111.778,73**	**Supply and application railing on bridge**		**€ 97.755,76**
Supply of steel material	2430 Kg	€ [redacted]	Supply of steel material	2430 Kg	€ [redacted]
Treatment of steel (sawing, composing, welding)	200 hours	€ [redacted]	Treatment of steel (sawing, composing, welding)	200 hours	€ [redacted]
Threaded rod M12, L=1000mm	540 pieces	€ [redacted]	Threaded rod M12, L=1000mm	540 pieces	€ [redacted]
Transport	[redacted] EUR	€ [redacted]	Transport	[redacted] EUR	€ [redacted]
Assembly	135 hours	€ [redacted]	Assembly	135 hours	€ [redacted]
Harvest of wood	[redacted] EUR	€ [redacted]	Supply of wooden railway sleepers	22,57 m³	€ [redacted]
Supply of wooden railway sleepers	22,57 m³	€ [redacted]	Transport	22,57 m³	€ [redacted]
Transport	22,57 m³	€ [redacted]	Sorting, sawing, shortening and planing	22,57 m³	€ [redacted]
Cleaning the wood	22,57 m³	€ [redacted]	Chisel costs and setting up machine	[redacted] EUR	€ [redacted]
Sorting, sawing, shortening and planing	22,57 m³	€ [redacted]	General costs subcontractor	[redacted] EUR	€ [redacted]
Chisel costs and setting up machine	[redacted] EUR	€ [redacted]			
General costs subcontractor	[redacted] EUR	€ [redacted]			
Total m of railing	**162**		**Total m of railing**	**162**	
Price per m railing	**€ 689,99**		**Price per m railing**	**€ 603,43**	

In the scenario, only one activity was identified as a result of circularity and was therefore excluded. The activity was 'Cleaning the wood''. The excluded activity has been occurred in order for the secondhand materials to be sawed in the right dimensions. Normally, one would receive clean wood from the sawmill. Even though sorting, sawing, shortening and planning has not been addressed as an activity as result of circularity, it is expected that this activity would take shorter when new wood is used. This is expected since the sawmill can deliver all different sizes of wood, reducing the activities to reach the desired dimensions. The price for the supply of both wood and steel has also been adapted. In the circular case, the steel cost €1.16/Kg and the wood €540/m³. In the scenario, the price for steel of € 0.95/Kg and the price for wood of € 1800/m³ has been maintained. All other activities remained the same. By having created this scenario, the cost items were made comparable.

The price per m of railing in the circular case project is € 689.99, while newly applied railing, according to the scenario, would cost € 603.43 per m. Hence, the railing made from reused materials is more expensive than if the railing would have been applied with new materials. The reused steel material in the railing is more expensive than the new steel, but the reused wood is much cheaper than the new wood. However, the wood must first be harvested from obsolete structures, thus executing an expensive activity. Ultimately, the harvest of wood poses as the largest factor which results in the higher price for a reused railing. This cost increment by reusing wood and steel is an immediate result of the implementation of circularity, due to the execution of activities which are a necessary to apply circular materials. Since the scenario cost item is based on the similar materials and activities of the circular cost item, it is deemed a reliable result, but with the caveat that the exact same element has been applied, but then new.

4.4.3.13 Construction site costs

The first cost item analyzed from the indirect construction costs is the construction site costs. In both projects, the construction site costs have not been further subdivided into activities. This is because usually, for the construction site costs, a percentage of the total direct construction costs is maintained.

The construction site costs are costs for setting up the construction site, facilities for staff, transport and logistics, temporary connections, and other miscellaneous costs. The construction site costs of the both case projects are displayed in table 4.22.

Table 4.22: Construction site costs of the circular and regular case project.

CONSTRUCTION SITE COSTS					
Circular case project			**Regular case project**		
General construction site costs		**€ 40.873,00**	**General construction site costs**		**€ 17.301,66**
General construction site costs	40873 EUR	€ 40 873,00	General construction site costs	[redacted]	€ [redacted]
			Driving lane closure	[redacted]	€ [redacted]
			Detour, including road block	[redacted]	€ [redacted]
Total general construction site costs	**€ 40.873,00**		**Total general construction site costs**	**€ 17.301,66**	

It can be immediately noted that the construction site costs of the circular case project is roughly two times as large as the construction site costs of the regular case project. When taking the size of both project into account, the construction site costs are somewhat similar, since the circular project is also roughly two times as large as the regular project. The difference in costs of both project cannot be immediately explained by circularity, since a specification of costs is lacking. From the interviews however, it became clear that the circular project, next to a construction site, also consisted of a storage location for the reusable materials. The addition of such storage location to a construction site would logically increase the costs of the construction site in general. Thus, this could explain the much larger construction site costs in the circular project. The relatively low costs for the construction site in the regular project can possibly be explained by its project location, which was in a city centre. The limited space available, and the fact that a major part of the bridge was constructed in the subcontractors' factory, resulted in small construction site. Thus leading to lower costs of the construction site itself. Unfortunately, there was no further data available on the exact construction site costs made by both projects.

4.4.3.14 Non-recurring costs

The non-recurring costs are costs that are only incurred once in a project. The non-recurring costs are often very project specific, and are therefore not fit for a comparison. It is however interesting to see what the non-recurring costs are per case project. Table 4.23 shows the non-recurring costs of the circular and regular case project.

Table 4.23: Non-recurring costs of the circular and regular case project.

NON-RECURRING COSTS					
Circular case project			**Regular case project**		
Non-recurring costs		€ [redacted]	**Non-recurring costs**		€ [redacted]
Project preperation subcontractor	[redacted] EUR	€ [redacted]	Test load bridges	[redacted] EUR	€ [redacted]
			Tender costs	[redacted] EUR	€ [redacted]
			MEAT criteria costs	[redacted] EUR	€ [redacted]
			Document duties	[redacted] EUR	€ [redacted]
			Provisional sum bridge landings	[redacted] EUR	€ [redacted]
Total non-recurring costs	€ [redacted]		**Total non-recurring costs**	€ [redacted]	

Even though the non-recurring costs are not comparable, it has been noticed that the non-recurring costs of the circular case project are more than twice as high than the same costs of the regular case project.

In the circular case project, only one activity was noted, the project preparation activities for the construction of the subcontractor. This activity mainly consists of preparatory work, such as designing and creating work descriptions. Further specification on the non-recurring costs of the circular case project can be found in its cost overview in Appendix L. The non-recurring costs of the regular case project are subdivided in much more activities, such as the tender costs, testing costs, document costs, and a provisional sum. One can see that these costs in both project are very project specific, making it impossible to create a reliable comparison and pinpointing a particular activity originating from circular ambitions.

4.4.3.15 Operating costs

The operating costs summarizes the contractors' incurred manhours of both projects. The majority of the manhours are from office personnel, who are responsible for activities such as creating the design, planning, and work preparation. Both case projects were executed based on D&C contract, meaning that there was also some design work included in the project assignment. The costs of this design work is represented by the manhours listed in these costs items of both projects. The costs per hour for each project are determined with help of document 32 mentioned in Appendix O. Table 4.24 shows the operating costs of both case projects.

Table 4.24: Operating costs of the circular and regular case project.

OPERATING COSTS					
Circular case project			**Regular case project**		
Operating personnel		**€ 154.256,00**	**Operating personnel**		**€ 106.157,68**
Paver	10 hours	€ [redacted]	Design staff	31,26 hours	€ [redacted]
Purchaser	3,16 hours	€ [redacted]	Engineering staff	50,02 hours	€ [redacted]
Project planner	477,71 hours	€ [redacted]	Construction engineering staff	31,26 hours	€ [redacted]
Project manager	417,75 hours	€ [redacted]	Project manager	293,07 hours	€ [redacted]
Foreman	683,84 hours	€ [redacted]	Project planner	23,45 hours	€ [redacted]
Surveyors	119,98 hours	€ [redacted]	Process manager	29,31 hours	€ [redacted]
Social return staff	18,04 hours	€ [redacted]	Area manager	48,84 hours	€ [redacted]
Telescopic crane	2 hours	€ [redacted]	Foreman	950,32 hours	€ [redacted]
			Surveyors	48,84 hours	€ [redacted]
			KAM coordinator	12,21 hours	€ [redacted]
Total costs operating personnel	**€ 154.256,00**		**Total costs operating personnel**	**€ 106.157,68**	

First to notice is the higher costs of this cost item in the circular case project when compared to the regular case project. This could be however a result of the larger size of the project. The foreman is in both project responsible for the highest costs and has incurred the most manhours. The regular case project involved a larger and more diverse collection of staff. During the regular case project for instance, area management was necessary due to the project being situated in the city centre, surrounded by local residents. A major part of the costs of this item in the circular project, next to the foreman, is caused by the project manager and project planner. When compared to the regular projects, the share of these two operating personnel functions is much lower, especially of the project planner. It is most probable that the function project planner in the circular case project includes the staff roles of design staff, engineering staff and construction management staff, since these are common roles and have not been mentioned in this case project. Still, without any further detail on the functions and their activities, it remains hard to pinpoint results of circularity in the operating costs. The differences visible in type of staff and incurred manhours are the result of the location where a certain project is situated and the nature of the assignment as issued by the client. Hence, a comparison is deemed unreliable.

4.4.3.16 Overhead costs

The overhead costs of a project is a certain amount of money in a project reserved for the company's fixed charges, also known as the general costs. The general costs comprises among others of office costs, insurances, remaining staff costs. The height of these costs are often determined by taking a percentage of the direct construction costs. Table 4.25 shows the overhead costs of both case projects.

Table 4.25: Overhead costs of circular and regular case project.

OVERHEAD COSTS					
Circular case project			Regular case project		
Overhead costs		€ [redacted]	**Overhead costs**		€ [redacted]
General costs	[redacted] EUR	€ [redacted]	General costs	[redacted] EUR	€ [redacted]
Total overhead costs	€ [redacted]		**Total overhead costs**	€ [redacted]	

The general costs of the circular case project is [redacted]% of the direct costs, while this percentage in the regular case project [redacted]% is. For both case projects, this is a high percentage when taking into account that the percentage reserved for general costs is usually about [redacted]% of the direct costs (D. Koot, personal communication, September 29, 2022). Based on the percentages only, the general costs of the regular case project are relatively higher than those of the regular case project. The lack of specifications however, make it impossible to conclude whether the lower general costs of the circular case project are a result of circularity or not.

4.4.3.17 Total indirect costs

Combining the four previous cost items will form the indirect construction cost. In total the indirect costs for the circular case project adds up to € 349,975.48. The indirect costs of the regular case are € 210,477.10. Once again, the costs of the circular case project are higher, but this project was also larger in scale. When discussing percentages of the indirect costs in relation to the direct costs, it had been noticed that the indirect costs of the circular case study is 59.04% of the direct costs. This percentage is even higher in the regular case project, where the indirect costs are 68.41% of the direct costs. See table 4.41 for the summary of direct and indirect costs of both case projects.

Table 4.26: Total direct and indirect costs of case projects.

Circular case project		Regular case project	
Direct costs	€ 590.682,39	Direct costs	€ 307.683,88
Indirect costs	€ 349.293,09	Indirect costs	€ 210.477,10
	59,13% of direct costs		68,41% of direct costs
Total costs	**€ 939.975,48**	**Total costs**	**€ 518.160,98**

Both projects have unusually high percentages of indirect costs in relation to the direct costs. A common percentage of indirect costs in relation to direct costs is about 25% (E. Alink, personal communication, October 19, 2022). Hence, the percentages of indirect costs in both projects are unusually high. In both projects, the operating costs are the largest influencing factor. From project participants of the circular project, the high operating costs are a result of design supervision and coordination regarding the circular materials. The remaining indirect costs were not recalled as being unusual. The relatively even higher indirect costs of the regular case project were the result of added design activities and the increased area management, according to the project participants. Thus both projects have uncommonly high indirect costs. For the circular project the extra costs are a result of the circular ambitions of the project, leading to increased supervision and coordination.

4.4.3.18 Maintenance costs

Lastly, the maintenance costs of both case project were compared to one another. In contrast to other cost items, the maintenance costs provided are the costs per year. Table 4.27 summarizes the maintenance costs of both the circular case project and the regular case project.

Table 4.27: Maintenance costs of the circular and regular case project.

MAINTENANCE COSTS					
Circular case project			**Regular case project**		
Maintenance costs		**€ 1.250,00**	**Maintenance costs**		**€ 2.250,00**
Inspections	1 250,00 per yea	€ 1 250,00	Inspections	1 250,00 per yea	€ 1 250,00
Large maintenance	TBA	€ -	Preventive maintenance	1 000,00 per yea	€ 1 000,00
			Large maintenance	TBA	
Total maintenance costs per year	**€ 1.250,00**		**Total maintenance costs per year**	**€ 2.250,00**	

As can be seen, the maintenance costs of both projects consists of inspections and large maintenance. The costs for inspections of both bridge is equal to one another, this is a standard maintenance procedure for bridges. The regular case project has one extra cost item, which is preventive maintenance. However, this preventive maintenance is the result of specific materials applied in the regular project.

The large maintenance in both project cases is still unknown. Causes such as wear and tear will lead to large maintenance and are therefore impossible to predict. In addition, once the large maintenance will be executed, a whole different price level is dominating the expenditures on maintenance. It is however expected that the wooden materials in the circular project are in need of more frequent large maintenance. This is however a result of applying wooden materials, which is much more vulnerable to weathering. Hence, it is not necessarily a result of circularity. When the maintenance costs aimed at a specific material are excluded, it can be concluded that both case projects have similar costs for maintenance.

4.5 Findings

The goal of this chapter was to present the results of the executed research by the method described in chapter 3, and hence to answer SQ 3: *How do the activities and costs of a circular infrastructural construction project vary from a regular infrastructural construction project?* The case study and the cross-case comparison have provided an answer to this question, which is presented in this paragraph. To answer this subquestion, the question will be split in two segments: The variation of process or activities in circular projects in relation to regular projects, and the variation of construction costs of circular projects in relation to regular projects.

Table 4.28 summarizes the findings of the cross-case comparison of the case projects. The regular case project or the regular scenario is used, depending on the governing comparison that was applied in the cross-case analysis. Per cost item, the prices of both projects are given, together with an appointing of the largest factor influencing the costs, an assessment on whether this result is the cause of circularity or not, and an explanation on the reliability of the results.

Table 4.28: Summary of findings of the cross case analysis on construction costs. Highlighted in green are the less expensive cost items from either the circular or regular case project. Marked in yellow are the cost items that have been compared with a regular scenario.

Construction element	Circular	Regular	Main factor influencing the costs	Effect of circularity?	Assumptions	Appendix Q source documents
Steel piling	€ 1,43 per Kg	€ 1,74 per Kg	Steel piling in circular case is of larger dimension No subdivision in materials was available, thus no factor could be appointed	Unknown	• Due to different sizes of steel piling applied, costs are translated to €/Kg; • Same activities are executed for applying the	1, 2, 3, 4, 8, 19, 20, 23
Abutments	€ 14 161,15 per piece	€ 13 376,16 per piece	Processing of secondhand materials before these could be reused increased the costs of the circular case	Yes	• Regular scenarios based on the circular cost items, excluding circular activities; • Price of new steel as determined by cost expert is € 1,10/Kg	1, 2, 3, 4, 5, 8, 19, 20, 25
Superstructure overall	€ 412,87 per m²	€ 2 339,62 per m²	Use of different materials in both case projects	No	No assumptions, direct comparison between cost items	1, 2, 3, 4, 8, 9, 19, 20, 22, 31
Girders	€ 6 736,17 per piece	€ 20 540,67 per piece	Lack of purchasing the second girders in the circular case project	Yes	• Regular scenarios based on the circular cost items, excluding circular activities; • Price of a new reinforced concrete girder as determined by a cost expert is € 1200/m³ for a girder of 15,75 m³, resulting in €	1, 2, 3, 4, 8, 19, 20, 22
Steel beam supports	€ 817,06 per piece	€ 736,06 per piece	Purchasing of new steel was less expensive than secondhand steel	Yes	• Regular scenarios based on the circular cost items, excluding circular activities; • Price of new steel as determined by cost expert is € 2,50/Kg	1, 2, 3, 4, 5, 8, 19, 20, 31
Steel crossbeams	€ 2 292,71 per piece	€ 2 278,12 per piece	Processing of secondhand materials before these could be reused increased the costs of the circular case	Yes	• Regular scenarios based on the circular cost items, excluding circular activities; • Price of new steel as determined by cost expert is € 0,95/Kg	1, 2, 3, 4, 5, 8, 19, 20, 31
Steel support beams	€ 426,52 per piece	€ 408,14 per piece	Purchasing of new steel was less expensive than secondhand steel, resulting in lower costs for the	Yes	• Regular scenarios based on the circular cost items, excluding circular activities; • Price of new steel as determined by cost expert is € 1,10/Kg	1, 2, 3, 4, 5, 8, 19, 20, 31
Bridge deck overall	€ 440,93 per m²	€ 279,12 per m²	Harvest of secondhand wood resulted in major extra costs	Yes	No assumptions, direct comparison between cost items	1, 2, 3, 4, 8, 19, 20, 21, 28, 30

Wooden girders	€ 160,40 per m²	€ 142,76 per m²	Harvest of secondhand wood resulted in major extra costs	Yes	• Regular scenarios based on the circular cost items, excluding circular activities; • Price of new wood as determined by cost expert is € 1800/m³	1, 2, 3, 4, 8, 19, 20, 21
Wooden deck	€ 280,54 per m²	€ 493,64 per m²	Purchasing of new wood was more expensive than secondhand wood	Yes	• Regular scenarios based on the circular cost items, excluding circular activities; • Price of new wood as determined by cost expert is € 4285,71/m³, which is based upon € 150/m²	1, 2, 3, 4, 8, 19, 20, 21
Wooden bench bridge	€ 221,44 per m	€ 164,07 per m	Harvest of secondhand wood resulted in major extra costs	Yes	• Regular scenarios based on the circular cost items, excluding circular activities; • Price of new wood as determined by cost expert is € 1800/m³	1, 2, 3, 4, 8, 19, 20, 21
Railing	€ 689,99 per m	€ 603,43 per m	Harvest of secondhand wood resulted in major extra costs	Yes	• Regular scenarios based on the circular cost items, excluding circular activities; • Price of new steel as determined by cost expert is € 0,95/Kg; • Price of new wood as determined by cost expert is € 1800/Kg	1, 2, 3, 4, 5, 8, 19, 20, 21
General construction site costs	€ 40 873,00 once	€ 17 301,66 once	Extra storage location for harvested materials needs to installed	Yes	Due to the lack of specifications of the circular case project, both projects are directly compared to one another without any assumptions	1, 2, 3, 4, 5, 8, 19, 20
Non-recurring costs	€ 72 417,00 once	€ 14 287,07 once	Preparational work of subcontractor in order to apply reusable materials	Yes	Due to the lack of specifications of the circular case project, both projects are directly compared to one another without any assumptions	1, 2, 3, 4, 5, 8, 19, 20
Operating costs	€ 154 256,00 once	€ 106 157,68 once	Circular project experienced increased coordination and cooperation	Yes	• Hourly costs per type of manhours per project have been decided in consultation with manager, see document 32 of Appendix O	1, 2, 3, 4, 5, 8, 19, 20, 32
Overhead costs	€ 81 747,09 once	€ 58 461,61 once	Cannot be appointed	No	No assumptions, direct comparison between cost items	1, 2, 3, 4, 5, 8, 19, 20
Maintenance costs	€ 1 250,00 per year	€ 2 250,00 per year	Similar costs and activities once material specific maintenance is excluded	No	• Based on project maintenance documents the costs have been determined for the regular case • In consultation with project leader, the maintenance costs for the circular case have been	6, 7

As can be seen in table 4.28 above, the majority of the cost items compared in the cross-case comparison were less expensive in a regular project when compared to similar but circularly executed cost items. In many of the items listed in the table above, a regular scenario was ultimately used to compare the circular costs to, due to a great number irregularities between the cost items of both case projects. The steel piling of both case projects is one of the few cost items that was directly comparable to one another. Additionally, the executed activities within the cost item of both case projects was quite similar as well. The results on the cost item of steel piling can therefore be considered as one of the most important. Looking at other cost items, whenever a scenario was applied, the circular case project was used as a basis. Based on the regular cost items and the regular scenarios, the comparison made clear that the costs of elements in regular projects are often less expensive. Hence, regular infrastructural construction projects are deemed less expensive then circular ones. Additionally, this cost increase is often the effect of circularity being applied in the specific elements of the construction project. There is a collection of circular activities responsible for the increment of construction costs in a circular construction project.

The effects of circular practices on the construction costs were often two-sided: Some activities increased the costs and other activities had decreasing effect on the costs. In many cost items, circularity had a decreasing effect on the purchasing and supply costs of the materials. Especially when wooden materials were applied. The purchasing costs of reusable wood was in every cost item cheaper than purchasing new wood. For steel products, the purchasing costs for reusable steel was dependent on the type of steel which were to be applied. Three-quarters of the reusable steel was purchased for an amount less than the price of new steel. Hence, a quarter of the reusable steel was bought for more than the price of new steel, which is interesting. The higher price could be the result of extra activities which had to be executed in order for the steel to become available. This is however uncertain, since there was no further specification available on the purchasing costs. On the purchasing costs of concrete materials it is unfortunately not possible to conclude anything, since the concrete girders in the circular project were already obtained in a previous project. Hence, the girders were ‘’free’’. This is not the normal course of events, and the costs of the reusable concrete girders has become unknown.

Contrary to the cost reducing effects on purchasing materials, circularity also results in a number of extra activities that need to be executed in order for the material to be applied. Extra activities would logically result in extra costs. First of all, before the materials could have been applied in a new circular project, the materials had to be collected from obsolete structures. For the wooden materials, these costs for collecting the wood were called harvesting. Combined, the harvest of wood resulted in € 130,000.00 of costs, to be fully accounted to circularity. Unfortunately, further specification on these costs were not shared with the researcher. Another activity that had been identified as circular was also dedicated to the reusable wooden materials was cleaning the wood. In relation to the costs of other circular activities, cleaning the wood wasn’t that significant. The same accounts for the extra transport that was needed to first deliver the harvested materials to a processing location, before it could be transported to the construction site. At the processing location, the materials were processed from harvested materials into reusable components. For steel materials, this has resulted in the disassembly of steel materials and the preparation of steel for treatment. Another big activity that had to be executed were the repairs made to the concrete girders before these could be applied. This was a costly activity. Additionally, the girder needed to be checked and certified as well, before it was allowed to be applied again.

Circularity also had its influence on the indirect costs. It is however difficult to accurately pinpoint the exact circular activity since the indirect were often lacking in depth specifications of costs. Combined with the input from the interviews, it was possible to determine causes for the increased costs. Firstly, the construction site costs were increased. This was a result of an addition that had to be made to the construction site itself, which is a storage location to temporary store the gathered reusable materials. Gathered materials can often not be immediately applied, thus some extra storage space is needed, resulting in extra costs. Preparational work of the subcontractor was also accounted to the indirect costs. The activities consisted of preparatory work, which is most likely the result of the circular ambitions. Lastly, the implementation of circularity resulted in increased coordination and cooperation between its project participants. This can be seen in the operational cost, which are higher than usual.

With the knowledge that both case projects have been constructed in different years, leads to the projects being subject to a different price level due to inflation. Hence, a direct comparison of the costs between two projects constructed in different years should take the inflation into account. Table 4.29 shows the price index of the infrastructural construction sector from 2015 to 2021, measured from the base year 2015 provided with a value of 100. The regular case project had a running time from 2017 to 2020, which leads to an average price index over the project duration of 108.5. The circular case project lasted from 2020 to 2021, with a governing average price index over the project duration of 114.0. The average price indexes of both projects indicate that the exact same project executed from 2017 to 2020 would be 5.5% more expensive if it were to be executed from 2020 to 2021. Inflation has thus also led to increased costs for the circular case project.

Table 4.29: Price index 2015-2021 of the infrastructural construction sector, measured from base year 2015 = 100 (table adapted from Centraal Bureau voor de Statistiek (2022)).

Year	
2015	100.0
2016	96.0
2017	103.2
2018	106.5
2019	110.3
2020	113.9
2021	114.0

To demonstrate the influence of inflation on the construction costs, the costs per element of the regular case project as provided in table 4.28 will be transformed to the governing price index of the circular case project. This will generate a fair comparison on the same price index. To transform the costs of the elements from the regular price index of 108.5 to the circular price index of 114, formula 4.2 is used. The results of this transformation is given in table 4.30.

$$Transformed\ regular\ price = \frac{Element\ price\ regular}{Price\ index\ regular} * Price\ index\ circular \tag{4.2}$$

Table 4.30: construction costs of elements, taking the inflation into account.

Construction element	**Circular, price index 2020-2021**	**Regular, price index 2017-2020**	**Transformed to price index 2021**	
			Circular	**Regular**
Steel piling	€ 1,43 per Kg	€ 1,74 per Kg	€ 1,43 per Kg	€ 1,83 per Kg
Abutments	€ 14.161,15 per piece	€ 13.376,16 per piece	€ 14.161,15 per piece	€ 14.054,21 per piece
Superstructure overall	€ 412,87 per m²	€ 2.339,62 per m²	€ 412,87 per m²	€ 2.458,21 per m²
Girders	€ 6.736,17 per piece	€ 20.540,67 per piece	€ 6.736,17 per piece	€ 21.581,90 per piece
Steel beam supports	€ 817,06 per piece	€ 736,06 per piece	€ 817,06 per piece	€ 773,37 per piece
Steel crossbeams	€ 2.292,71 per piece	€ 2.278,12 per piece	€ 2.292,71 per piece	€ 2.393,60 per piece
Steel support beams	€ 426,52 per piece	€ 408,14 per piece	€ 426,52 per piece	€ 428,83 per piece
Bridge deck overall	€ 440,93 per m²	€ 279,12 per m²	€ 440,93 per m²	€ 293,27 per m²
Wooden girders	€ 160,40 per m²	€ 142,76 per m²	€ 160,40 per m²	€ 149,99 per m²
Wooden deck	€ 280,54 per m²	€ 493,64 per m²	€ 280,54 per m²	€ 518,67 per m²
Wooden bench bridge	€ 221,44 per m	€ 164,07 per m	€ 221,44 per m	€ 172,39 per m
Railing	€ 689,99 per m	€ 603,43 per m	€ 689,99 per m	€ 634,02 per m
General construction site costs	€ 40.873,00 once	€ 17.301,66 once	€ 40.873,00 once	€ 18.178,70 once
Non-recurring costs	€ 72.417,00 once	€ 14.287,07 once	€ 72.417,00 once	€ 15.011,30 once
Operating costs	€ 154.256,00 once	€ 106.157,68 once	€ 154.256,00 once	€ 111.538,94 once
Overhead costs	€ 81.747,09 once	€ 58.461,61 once	€ 81.747,09 once	€ 61.425,10 once
Maintenance costs	€ 1.250,00 per year	€ 2.250,00 per year	€ 1.250,00 per year	€ 2.364,06 per year

As can be seen in table 4.30, the correction of the costs of elements in the regular project are increased when transformed to the similar price index of the circular project. There are however only two construction elements of the regular case project or scenario which are now less expensive than the similar element of the circular case project. These are the application of the steel crossbeams and the steel support beams. Prior to including inflation in the costs, the costs of these elements were already close together. Hence, including the effect of inflation did not heavily influence the outcomes of the construction cost comparison.

The major findings mentioned above have been summarized in figure 4.8. The figure includes the positive as well as the negative effects of the implementation of circularity on the construction cost. However, take into account that these effects are dependent on the materials applied and that these findings are based on merely a case-specific comparison.

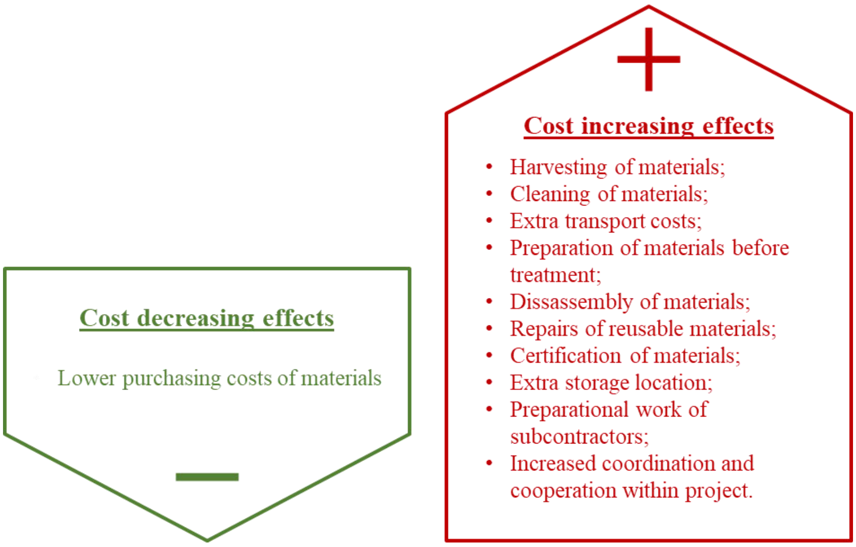

Figure 4.8: Overview of the construction cost decreasing and construction cost increasing effects of implementing circularity (own image).

The process and activities of a circular construction project do not vary much from a regular construction project. When looking at the project process in general, it was concluded that circular infrastructural construction projects include an extra process component, which is Gathering of materials. This extra component is situated between the procurement component and the design component. Additionally, Gathering materials is constantly interchanging with Design, until all necessary materials are gathered and the design is finished. Due to an uncertain availability of reusable materials, it is difficult to reserve a certain amount of time for this. It is however expected to result in a longer project duration. Not only due to the shifting between components, but also as a result of the extra activities introduced by the new process component. See picture 4.2 for the project process of a circular construction project. Zooming in on the project itself, a series of extra activities is noticed, which are ultimately also responsible for the variation of costs of circular projects in relation to regular projects. The activities and their influence on costs are summarized in figure 4.8 above. This data combined with the results on the costs and project process are an answer to SQ3: *How do the activities and costs of a circular infrastructural construction project vary from a regular infrastructural construction project?*

4.6 Validation

The main results of the individual case studies and the cross-case comparison have been discussed with two experts from Dura Vermeer. The experts were selected on their expertise on the infrastructural construction sector and sustainability. The validation session started with an introduction and elaboration on the research approach, followed by an explanation on the executed case study. Ultimately, the results emerged from the case studies and the cross-case comparison have been presented. Further details on the validation protocol have been provided in the validation protocol in Appendix P, which was followed to validate the results.

4.6.1 Confirmed results

The interview started by introducing circularity and its problems towards implementation in the construction industry. This was immediately recognized by the interviewees, who both were certain that the main origin of the lack of implementation of circularity in the construction sector lies at the culture of this sector. First, the identified project process of a circular project was shown, which was affirmed by the interviewees. Both interviewees recognized the extra activities that needed to be executed in a circular project and agreed to the introduction of a new component, which is Gathering of materials. Subsequently, the costs per project component were shown, which illustrated the distribution of costs in the project process. As was expected by the interviewees, even though they have no experience with circular construction projects, the construction costs are more distributed towards the start of the project. When zooming in on the construction costs itself and differences between a circular and a regular project, one of the interviewees was surprised that the construction costs of the circular project were higher. However, after presenting the results of the cross-case analysis and the specific cost items, both agreed to this statement. All in all, the presented findings have been confirmed by both interviewees. Additionally, there were some amendments, which will be discussed next.

4.6.2 Amendments

The first version of the cost overview and the list of activities and costs as a result of circularity included the general costs of the subcontractors in the indirect costs. This choice was initially made, since these costs were separately billed and not aimed at a certain activity. Both interviewees pointed out the importance of moving these costs to the direct construction costs. In the current version of the cost overview and cross-case analysis, this amendment has been implemented.

The regular scenario's, which were often used to compare the circular cost items and activities to similar regular cost items and activities, were deemed a good alternative whenever a fair comparison was not possible. However, the interviewees were questioning whether in a regular project, according to the regular scenario, the applied materials would have been applied with similar dimensions to the circular materials. Certain structural elements from the circular case project were oversized for its purpose, hence, elements of smaller dimensions would also suffice. This amendment has led to a remark in the conclusion of this study.

5

Discussion

This chapter will focus on the interpretation and discussion of the results of the case studies previously analyzed in chapter 4, by reflection on the literature study. The most important findings resulting from the case studies on project process and construction costs in circular and regular projects will be discussed. The findings will be assessed by using the available literature and its implications for both research and practice is discussed. Finally, an answer can be provided to SQ 4: What are the implications of the comparison made between the project process and costs of a circular infrastructural construction project and a regular infrastructural construction project? Paragraph 5.1 first discusses the interpretation of the results. Secondly, a reflection on the research process is provided in paragraph 5.2, in which the difficulties of conducting this study is described. Lastly, paragraph 5.3, elaborates on the implications of the findings of chapter 4.

5.1 Interpretation of results

The findings of the research are currently not much more than a collection of data on the differences between circular and regular infrastructural construction projects. The results of this study in relation to the literature is first discussed. Secondly, the variance within the case study is described, in order to pass judgment on the credibility of the results.

5.1.1 Relation to literature

As Adams et al. (2017) concluded, the execution of a case study would be beneficial in order to deconstruct the barriers towards implementing circularity in the construction sector. This piece of literature formed the starting point of this journey to further investigate the effects of circularity on infrastructural construction projects. The literature study resulted in a theoretical framework, elaborating on how the circular economy is implemented in the construction industry and, more specifically, in infrastructural construction projects.

This study started with a general investigation about circularity and slowly focused more and more on implementation in practice. When investigating the literature about the implementation of circularity in construction projects, it immediately became clear that the literature available focused largely on how to classify the future use of the materials after their service life. A result of this was the 10R-model developed by Reike et al. (2018), which was found most comprehensive. Although the 10R-model was governing, the applied circularity measurement method used a 4R-model, consisting of Reuse, Recycle, Recover and Remine. This was an effect of how this measurement method had been set up. The large role of materials in previously executed research was also reflected in the case studies itself. The differences which were shown between both projects exposed the large role of materials in a circular construction project. This large role was embodied in the extra process step Gathering materials. Additionally, the materials caused the need for extra activities to be initiated. Materials ultimately resulted in the addition of an extra step

Investigations of the implementation of circularity were followed in the literature study by identifying the major components of infrastructural construction project. For the project process to be analyzed, this identification of components was necessary, thus resulted in the components: Initiative, Procurement, Design, Construction, and Operation & maintenance (Kagioglou et al., 2000; Keoki Sears, 2015; Lenferink et al., 2013; The Chartered Institute of Building, 2022). When ultimately gathering information by conducting the interviews, there was unanimously support for the identified components resulting from literature. With caveat, that its sequence was of course dependent on the issued contract type. Investigation of the circular project resulted in the addition of an extra project component, and the frequent interchange between Gathering materials and Design. Hence, Design was altered to (Re)Design. In summary, the regular project followed the determined components from the literature, while the circular project followed its own iteration of these components.

In the literature study, the project components identified from literature were investigated to discover how a specific components is executed in a circular manner. Reflecting on the circular practices identified by previous studies, a selection of these were also present in the executed case studies, more specifically, the circular case project. When first regarding the initiative of a project, literature suggested that every involved party should be motivated and actively contributing to construct a circular project (D’coutho, 2020; Kozminska, 2019; Gorgolewski & Morettin, 2009). The case study showed that the participants fulfilled this motivation and their active contribution to establish a circular project. Circularity in the design could be reached by adhering to one of the six circular design strategies from Platform CB’23 (2021): Design for prevention, design for reducing lifecycle impact, design for future proofness, design with reused objects, design with secondary resources, and design with renewable resources. additionally to these design strategies, the use of flexible and/or performance-based specifications was also seen as a practice that could accommodate innovation, hence circularity (Rose & Manley, 2012). From the mentioned circular practices only design for future-proofness, and performance based specifications were not recognized in the circular project. Thus, the circular design practices were largely followed, in contradiction to those of the procurement component. Literature suggested the use of CPP (Sönnichsen, & Clement, 2020; Alholla et al., 2019), however, a procurement procedure was lacking in the circular project. Circularity in the construction of the project itself is merely focused on the materials and their future use. Specific activities to ensure their future use have resulted from the case studies. Lastly, circular practices on operation & maintenance close the circle and make it a truly circular project by tracking the applied materials, creating input and information for the construction of future structures with these materials (Heisel & Rau-Oberhuber, 2020; Sassi, 2008). Unfortunately this activity was not represented in the circular case project. Only regular maintenance is being executed, but the future potential of the applied materials has not been considered.

Ultimately, the literature study resulted in a definition of a circular infrastructural construction project: *A circular infrastructural construction project is a construction project in which a certain physical infrastructure is constructed which complies to the CE design principles (Design for prevention, design for reducing lifecycle impact, design for future-proofness, design with reused objects, design with secondary resources, and design with renewable resources)*. After conducting this research, executing the case studies and interviewing a group of professionals in the construction industry, this definition seemed not comprehensive enough.

It is suggested to add the end of the life cycle to this definition, since this will make a project truly circular, the end of a project will serve as a start of a new project. However, the end of the life cycle has not been addressed in this study. Addition of the end of life cycle to the definition of a circular infrastructural construction project leads to: *A circular infrastructural construction project is a construction project in which a certain physical infrastructure is constructed which complies to the CE design principles (Design for prevention, design for reducing lifecycle impact, design for future-proofness, design with reused objects, design with secondary resources, and design with renewable resources) and of which the end of life cycle of the applied materials has been taken into account.*

5.1.2 Variance of the results

The main activity of this research was the execution of case studies of a circular and a regular infrastructural construction project. The selected project cases for the case studies were real life, already executed, projects. Being an actual project, and not a fictional one, results in the projects not being executed perfectly, as a project is constantly subject to external and internal factors. Thus, the selected case projects in this research are also affected by this. In this paragraph, the variances of the case projects are discussed.

5.1.2.1 Variances general

First of all, the case study consisted of only two projects, hence the results from this study are case-specific results. This means that the results cannot be generalized for all infrastructural construction projects.

When zoomed in on both case projects, it can be noticed the applied materials in each individual case project differ quite a lot from one another. The circular case project was known first, the regular case project was then chosen to match with the circular case project on a set of metrics, resulting in the Wisenniabrug as best match. Applied materials was one of the metrics that was used, but it wasn't deemed as very important at that time. Ultimately however, it seemed that the applied materials were very important for making a decent comparison.

Project complexity was one of the metrics on which the regular case project was assessed in order to find the best comparable regular case project. In hindsight, it could be argued that complexity is a possible characteristic of circularity in construction projects, since it results in a different project process and other extra activities which could have contributed to the complexity of the project. Hence, complexity could be a result of circularity applied in a project. For future studies in which circular and regular construction projects are compared to one another, it is therefore advised to exclude complexity as a case selection metric.

One of the indicators of the circularity measurement method is the future use of the materials after the lifecycle of the current structure wherein these are applied. Based on the current knowledge, these materials were predicted a future use. For a large number of materials, the less-circular future uses, such as recycling, energy recovery or use as landfill are the most probable future uses. It could however occur that due to future innovations materials will be processed differently, either high- and low-grade processing.

One of the project process components used in this study is Initiative. From the available project data, it was not possible to discover costs incurred during this component. This is probably due to the fact that in this component often transactional costs are incurred. Transactional costs have been excluded from the scope of this research. Hence, it could be argued that the cost data on the Initiative component is missing.

An analysis on construction costs was part of the executed case studies. It should however be noted that both projects were constructed in a different year, the Wisenniabrug from 2017 to 2020 and the Tweede leven brug from 2020 to 2021. Based on general data of the Centraal Bureau voor de Statistiek on inflation in the infrastructural construction sector, inflation and the price indexes were briefly discussed. It could however be possible that there are slight differences with reality, since average values were used to level the price indexes of the case projects to match each other.

A significant number of cost items of the construction costs were subcontracted to other parties. The majority of the subcontractors offered a lump sum to the main contractor, often without any specification of costs. This introduced a new challenge, which was gathering cost information of subcontractors to specify the offered lump sum. Unfortunately, even after contacting the subcontractors multiple times, a number of them still remained hesitant in providing cost specific information. This results in a number of subcontracted cost items still lacking in specifications on costs and activities.

In the cross-case analysis, the cost items of both case projects were compared. However, a number of cost items of the regular case project were not immediately comparable to the circular case project, because the differences were too large. Therefore, the regular scenario was introduced to deal with differences between the two cases. These were set up to be identical to circular case, but then with new materials instead of reused. It is however questionable that if the project was executed in a regular way, the same materials and dimensions would be applied.

5.1.2.2 Variance circular case project

The focus is now laid on the variances in circular case project. When starting on this research, it quickly became clear that are only a handful of circular infrastructural construction projects executed. This limited the choice for a case project, and ultimately the Tweede leven brug was chosen. The limited amount of circular construction projects also makes it difficult to perform a case study with a higher amount of case projects.

Regarding the project process, this was shaped differently. Not only because it was a circular project, but mainly due to the missing procurement component. The project was part of a larger development project of the main contractor of which this bridge was part of. Thus, the contractor was already assigned to the construction of this bridge. It is of course unusual to miss a procurement procedure in a construction project, since contractors have to be able to compete with one another for obtaining a construction assignment. To tackle this exceptional process, the project participants were asked to sketch the process of circular project, including the procurement. This provided the study with input on the process of a circular project, even though this was not how it actually took place.

To investigate the project process, interviews were executed with involved project participant of the case studies. To gather information which is as comprehensive as possible, participants from all directly involved parties were interviewed: Client, main contractor, consultant, and some subcontractors. Initially, the client of the circular case project would have been interviewed. Unfortunately, it was not possible to schedule an interview within the time frame of this research. Therefore, this study was not able to gather input from the client on the project process.

The construction costs of the circular case project consist of materials, equipment, labor and subcontracting. However, in some cost items, the materials were registered as free of charge in the cost documents. This is unusual, because the circular case study showed that even secondhand materials are charged a fee. Since the materials influences the costs substantially, cost items containing free materials are almost always cheap, while realistically this might not be the case. In at least one occasion, the materials were gathered from a previously executed demolition project, hence the costs were already incurred on a different project.

5.1.2.3 Variance regular case project

The regular case project also experienced some irregularities, leading to a variance. This starts already during the initiation of the project. The chosen bridge for the regular case, the Wisenniabrug, was part of a larger project, the Singelparkbruggen. In this project, a series of six bridges needed to be designed and constructed in the historical city centre of Leiden. The regular case being part of a larger project makes it hard to define which costs have been exactly made for that particular bridge. The total construction costs have therefore been divided into shares of costs according to the ratio of the bridge in relation to the total project. This is of course not always 100% accurate.

After the initiation of the project, the client decided to come up with a design competition for the bridges of the project. This is however unusual for infrastructural projects. Normally, a client would procure a project, resulting in contractors tendering to design and construct the requested structure. After the design was awarded, the project was procured and won by the current contractor, with the task to execute the design. Since the design competition occurred before the contractor was involved, no in-depth information was available on that project process component.

From the moment the main contractor was involved, it was set with the task to execute the design of the architect. Ultimately however, the contractor experienced a number of unforeseen design activities. This increased the incurred hours of labor from the operational costs substantially. The cause for this unexpected rise in operational costs and hence the unforeseen design activities were the sudden bankruptcy of a subcontractor and the translation that needed to be made from a design to executional design. Additionally, the operational costs further increased as a result of the increased level of area management that needed to be executed. This was due to the projects' location in the city centre. Summarized, the indirect costs of this regular case project were much higher than the indirect costs usually in a project.

5.2 Reflection on research process

The abovementioned variances on the methodology and the case studies already hinted that the execution of the this research was subject to a number of difficulties experienced during the process. The difficulties mainly occurred when investigating the construction costs of both case projects. Analysis of the level of circularity and the project process did not impose major obstacles. Hence, investigating of the link between circularity and construction costs was a lot harder than initially expected.

The first difficulty that was experienced, was the availability of finished circular infrastructural construction projects. As was mentioned before, only 7 circular infrastructural construction projects are currently finished, and thus interesting to include in the case study. This limited the choice to select a perfectly fit circular case project, and additionally eliminates the possibility to scale up this study and include more Dutch circular case projects.

The majority of the encountered struggles were related to collecting the data of both case projects. One of the major struggles that were encountered was the fact that a lot of data was scattered over different documents located in different file folders. In addition, several versions of these documents were also in circulation, making it quite a search to trace the right data to the source documents. When zooming in on the documents that were available for data gathering, it was sometimes hard to collect the data due to lacking specifications or subdivisions in cost items. Some documents even appeared to be more of a collection of raw data instead of specified project documents. Sometimes, specific project data located in these raw data collections was required for analysis, which resulted in a difficult search in the documents. In addition to this, specified project information on costs of subcontractors were often lacking further specifications other than a lump sum. To further specify the lump sum offered, the relevant subcontractors were contacted and asked for providing specifications to their offered lump sum. Some subcontractors provided further specifications, but the majority did not respond or were not willing to share this info. This is of course understandable, since it are often business secrets, but it is not helpful towards the cause of this research.

In hindsight, comparing two infrastructural construction projects to one another is almost impossible, due to the unique features of every project. This resulted in the challenge of creating and determining a method to make a fair comparison possible. Ultimately, assumptions, generalizations, and scenarios were used to make this comparison. It can however be questioned if the applied method is the best method, or if there are any better methods which would generate a more reliable comparison.

At last, there was almost no data available on the weight of the materials applied in both projects. Usually, material weights are not noted, unless it is the unit of measurement in which the materials are traded. For calculating the level of circularity in the project, the materials weights were required. The lack of known mass of the materials applied resulted in using assumptions to approximate the weights and thus to tackle the problem of the unknown weights. If the masses were known, a more reliable circularity measurement could be executed.

All in all, besides the results mentioned and the conclusion of the research formulated in the next chapter, this study showed the difficulties of trying to couple the implementation of circularity to costs. This displays the infancy of the research topic which is addressed. It is however important to keep investigating this topic, in order to increase the knowledge on both the topic itself as the research strategy or method to investigate the costs of circularity.

5.3 Implication of findings

The major findings of the executed research have led to a series of implications that can be concluded. The distinction has been made between practical implications, aimed at the construction industry, and theoretical implications, aimed at constituting new additions to the theory. It must however be noted that the findings, on which the implications are based, are case specific results.

5.3.1 Implications for practice

Firstly, the practical implications for the construction sector are discussed. The findings of the case studies and the cross-case analysis showed case specific differences between a circular and a regular infrastructural construction project.

Starting with the measurement of circularity, it became clear that the circular case project in comparison to the regular case project was assessed with a better circularity score on every indicator. There were still some new materials applied in the circular project, but the project in general was a good effort to constructing a circular project. However, the level of circularity could be improved by already considering the end of the service life of the materials at the start of the project. Additionally, the circularity measurement score is still under development, but when it is finished, it could be of great value for assessing construction designs.

The analysis and comparison of the project process of both projects showed the introduction of a new project component, Gathering materials to the project process of the circular case project. When initiating a circular infrastructural construction project, the involved parties should take this extra process component into account, and reserve a budget for these activities. Additionally, the project planning should be considered flexible to a certain level, since the components Gathering materials and (Re)Design will often interchange, until all materials are gathered and a final design has been made. Bearing in mind this change in project process prior to the project will be beneficial for the project result, as one can prepare for this.

Regarding the construction costs of circular and regular infrastructural construction projects, it can be concluded that circular projects are more expensive. The extra costs are a result of the introduction of extra activities which need to be executed in order to successfully apply reusable materials. First, there are extra costs for searching and gathering reusable materials. Secondly, extra costs are incurred for the processing of materials, preparing these for installment in the structure. Lastly, the indirect costs are higher due to the installment of a materials storage on the construction site and a risen amount of manhours, resulting from increased coordination and cooperation within the project. Concluding, project participants should take higher construction costs into account when participating in a circular construction project.

In summary, a circular infrastructural construction project is largely similar to a regular project. However, one should be prepared for a different project process, a longer project duration and increased construction costs.

5.3.2 Implications for research

The literature study showed the lack of theory available on the link between circularity in construction projects, project process and costs. This study attempted to pioneer on the combination of aforementioned topics. This resulted in encountering several difficulties when researching this topic and executing the case study. Still, executing case studies remains one of the methods to boost the implementation of circularity. However, the case study executed in this research consisted merely of two case projects. Therefore it is suggested to keep on executing and investigating circular case studies. A guide for executing future circular case studies investigating the costs and project process will be provided. This list of points of attention has been made to guide future case studies and prevent pitfalls experienced by the author:

- Project costs consists of construction costs and transactional costs. As in this study, focus first on the construction costs. Transactional costs are hard to analyze, since these are often not monitored specifically per project, resulting uncertain data;
- When executing a case study based on real life projects, take into account that exactly similar construction projects do not exist. Thus in order to draw a trustworthy conclusion on the

influence of circularity on project process and construction costs more case studies need to be executed;

- When selecting case projects, one of the most important metrics should be the applied materials. The materials largely influence the activities occurring in the project, and they have a significant influence on the construction costs of a project. Additionally, in successive studies, the metric project complexity should be excluded from the case selection metrics, as complexity is a possible characteristic of a circular construction project.
- The researcher should be granted full access to all project information, both of contractors and subcontractors. This project information should also include the incurred costs. Additionally, all project participant need to be willing to be interviewed.

6

Conclusion

This chapter will conclude upon the executed research by first answering the research sub questions and ultimately the main research question of this study: ‘’What are the effects of the implementation of circularity on the project process and costs in infrastructural construction projects?’’ Subsequently, in paragraph 6.2, the limitations of this research on methodology, case studies, and results are presented. Lastly, recommendations for practitioners and future research are given in paragraph 6.3.

6.1 Answer to the research questions

The main research question will be answered by first answering the research sub questions. The answer to these sub questions were answered throughout the different chapters of this study.

SQ 1: How is the circular economy implemented in the construction industry in general and in infrastructural construction projects?

Circularity in the construction industry is not yet fully facilitated due to the limited research available on circularity in supply chain integration, building designs, policy, energy efficiency, land use, offsite manufacturing, cost reduction & cost management, whole life costing & risk, and health & safety. The available literature on circularity in the construction sector mainly focusses on materials, translated into R-models to assess the future use of materials. In practice, the use of different R-models form a foundation on how the circular economy is currently implemented in the infrastructural construction sector. Translated to the project components, different activities can be identified on how the implementation of circularity is stimulated. At the initiation of the project, motivation and an active contribution of the project participants is stimulating circularity. Implementation of circularity due to the design is achieved by: Design for prevention, design for reducing life cycle impact, design for future-proofness, design with reused objects, design with secondary resources, design with renewable resources, flexible specifications, and performance based specifications. The project procurement stimulates circularity by the use of CPP. Circularity in the construction component is focused on materials and stimulated by R-models. Lastly, operation & maintenance can implement circularity in its components by introducing a materials madastre for tracking materials. The input combined resulted in the following definition of a circular construction project: A circular infrastructural construction project is a construction project in which a certain physical infrastructure is constructed which complies to the CE design principles (Design for prevention, design for reducing lifecycle impact, design for future-proofness, design with reused objects, design with secondary resources, and design with renewable resources).

SQ 2: How can the differences in process and costs between a circular infrastructural construction project and a regular infrastructural construction project be disclosed?

The differences in project process and costs between a circular and a regular infrastructural construction project can be investigated by executing a multiple case study. The case study consists of a circular and a regular construction project, which are largely similar to one another on a set of predetermined metrics. By analysis of both projects on circularity, project process and construction costs, a comprehensive overview of both case projects is generated. Subsequently, both case projects have been compared to each other, which has uncovered the differences in circularity, project process and construction costs between a regular and a circular construction project.

SQ 3: How do the activities and costs of a circular infrastructural construction project vary from a regular infrastructural construction project?

When comparing a circular infrastructural construction project to a regular infrastructural construction project it can be concluded that the process and activities do not vary much from one another. When looking at the project process in general, it was concluded that circular infrastructural construction projects include an extra process component, which is Gathering of materials. This extra component is situated between the procurement component and the design component. Additionally, Gathering materials is constantly interchanging with (Re)Design, until all necessary materials are gathered and the design is finished. When considering the activities, it is noticed that the circular case project consists of extra activities, leading to differences in costs when compared to the regular case project. The identified activities are:

- Harvesting of materials;
- Disassembly of materials;
- Preparation and repairs of materials before application;
- Certification of materials;
- Extra transport movements;
- Preparational work of subcontractors;
- Installment of storage location for gathered materials;
- Increased coordination and cooperation with project process.

SQ 4: What are the implications of the comparison made between the project process and costs of a circular infrastructural construction project and a regular infrastructural construction project?

The implications of the major findings from the comparison made between the project process and construction costs of a circular infrastructural construction project and a regular infrastructural construction project are divided into implication for the construction sector and implication for the academic world. For the construction sector, the results implicate that a higher circularity can be achieved by already considering the end of the service life of the materials at the start of the project. Regarding the circular project process, involved parties should take an altered project process into account wherein the Gathering of materials project component is added and is constantly interchanging with (Re)Design, see figure 6.1. Looking at the construction costs, it can be concluded that, based on individual cost items, circular construction projects are more expensive than regular construction projects. To the academic world, the implications of the comparison made can be considered as a first indication of the effects of circularity on project process and construction costs. More importantly, it is a stimulus and guide towards more future research. More executed case studies lead to more reliable results on the effects of circularity on project process and construction costs.

Main research question: What are the effects of the implementation of circularity on the project process and costs in infrastructural construction projects?

The aforementioned research sub questions and their answers provide a foundation for answering the main research question. The case specific findings of the case study and the cross-case analysis indicate various effects of the implementation of circularity on infrastructural construction projects.

From a traditional point of view on the project process, there are a number of project process components identified which, in turn, consist of circular practices that can be executed in each project component according to literature. This resulted in the following definition of a circular infrastructural construction project: A circular infrastructural construction project is a construction project in which a certain physical infrastructure is constructed which complies to the CE design principles (Design for prevention, design for reducing lifecycle impact, design for future-proofness, design with reused objects, design with secondary resources, and design with renewable resources). To show the differences and effects of circularity, a case study was found most useful. Based on the aforementioned definition, a circular infrastructural construction project was selected, and a comparable regular project was chosen, for comparison purposes.

On the project process, the study identified the introduction of an extra project component, Gathering of materials, as an effect of implementing circularity. Implementation of circularity in the circular case project has led to extra activities which were substantial enough to introduce a new project component. This component, Gathering of materials, is directly influencing the design in circular project and was constantly interchanging with it due to alteration in the gathered materials. Hence, the component it was altered from Design to (Re)Design. Additionally, the mentioned constant shift between components has an increasing effect on the project duration.

Regarding the construction costs, this study shows that, based on individual cost items, a circular construction project is more expensive than a regular construction project. Considering the direct construction costs, purchasing reusable materials as a result of circular ambitions, is for most materials less expensive than purchasing new materials. However, the direct construction costs are driven up by the higher costs due to activities that need to be executed in order to apply the material. Think of gathering materials, repairs that need to made, and preparation of materials before assembly. The indirect construction costs of a circular infrastructural construction project are more expensive as well, as a result of manhours to be invested in the increased coordination and cooperation of the project as a result of implementing circularity.

Concluding, the implementation of circularity has an increasing effect on the construction costs, both the direct and indirect construction costs. In addition, the implementation of circularity affected the project process by the introduction of gathering materials as a general project process component and the ongoing interchange between gathering materials and (re)design.

6.2 Limitations of research

In order to rightfully interpret the results, it is important to consider a number of limitation to this research. First, the limitations to the methodology are discussed, followed by the case studies, and finally, the results.

6.2.1 Limitations of methodology

In this study, circularity is only aimed at applying reusable materials. However, circularity is about more than that, for instance about closing the circular process between the end of service life of a material and the initiative of a new project to be constructed.

Regarding the costs, this study focused merely on the construction costs, since these are traceable. Transactional costs were excluded from research scope. These costs however, could be just as interesting as the construction costs.

The project process in this study is only analyzed on an abstract level by using project components. A more detailed focus on the project processes within these project components could lead to more detailed results.

In this research, only two case projects were used in the case studies. The execution of more case projects would lead to more reliable results, and makes it possible to generalize results. Hence, the results presented in this study are merely case specific results.

6.2.2 Limitations of case studies

The case studies included a measurement of circularity of the constructed object. This measurement method was adopted from Platform CB'23 and is still under development. Hence, the circularity measurements could become different when the measurement method is altered.

The case projects included in case study are infrastructural construction projects in which a bridge has been constructed. There are however more types of infrastructural objects that could be created within the definition of an infrastructural construction project. For now the results apply for bridges.

When analyzing the project process, it became clear that both projects have not experienced an ordinary project process regardless of circularity. The regular case project dealt with a design competition in its process, unexpected design activities as result of this design competition, and the obligation to intensive area management. The circular case project did not include a procurement procedure, since it was part of a larger development project already executed by the contractor.

6.2.3 Limitations of results

To collected differences in construction costs between both projects, were the result of cross-case comparison wherein the construction cost were compared per cost item. There is however a difference in price level between both projects. In the regular case project, the 2017 price level is governing, while circular project has been constructed in 2021, thus is subject to the 2021 price level.

Looking at the materials applied in both case studies, it can be seen that both project vary from each other. To tackle this difference, regular scenarios were used to estimate the construction costs for the cost item when applied with new materials and without circular practices. Since it is a scenario, it cannot be completely accurate.

6.3 Recommendations

After concluding upon this research, the author has formulated some recommendations for both the practitioners as for future research that could conducted.

6.3.1 Recommendations for practitioners

Ultimately, the CE must be reached by implementation of circularity by the practitioners. This study helps the construction sector by providing it a more tangible understanding of circularity in infrastructural construction projects. For practitioners, the following recommendations have been determined:

- At the moment, a very low number of circular infrastructural construction projects has been constructed. To gain more understanding and support, more circular projects need to be constructed. The construction of more circular projects also increases the opportunities for future research. It is however necessary that the complete project is extremely well documented.
- It is advised for companies to set up a standardized classification of construction costs in cost estimation documents. Currently, a standardized layout is being used, but an upgrade to a standardized cost specification wherein the estimated costs are coupled to the incurred costs may prove to be useful for analysis and reflection on the project costs;
- When initiating a circular infrastructural construction project, all involved parties should be aware of increased coordination and cooperation between them;
- The client should allocate a larger budget when initiating a circular infrastructural construction project, in order to prevent surprises. Additionally, the involved parties should also account for the extra component in the project process.
- From the moment a circular infrastructural construction project has been initiated, the client should already scout for available reusable materials. Gathering materials is a time consuming job, and one cannot start too early.
- Material passports need to be actively used by all parties in the construction sector. The material passports keep an overview of the available reusable materials, which is essential when trying to construct an object of reusable materials.

6.3.2 Recommendations for future research

This study is one of the many researches done on circularity, but one of the few on the direct effects of it on construction costs and project process. The insights gathered in this study has provided input for future research topics. The suggests the following recommendations for future research:

- It is recommended for future studies to investigate and identify the characteristics of circular infrastructural construction projects. Identification of these characteristics could be beneficial in understanding how circularity is translated in construction projects. In addition, it is also useful for selecting comparable case projects in a scaled-up successive research on this topic;
- Future research should further investigate the effects of circularity on construction costs and project process, since it was found to be useful by practitioners. This research has only executed two case studies due to the limited time available, hence the current results are case specific and cannot be generalized. Therefore it is suggested to execute this study on a larger scale, including

a larger number of case studies, resulting in more reliable results. To prevent pitfalls, see section 5.3.2 for a brief guide;

- While this research focused on bridges as the main object of the infrastructural construction project, it could be interesting to investigate other infrastructural objects as well. This way, the effects of circularity can be further specified per infrastructural object type;
- Several times the interviewees mentioned the increased amounts of meetings that occurred in the circular case project in comparison with regular projects. These meetings can be labeled as transactional costs, since these are not actively monitored. It will be interesting to see how the transactional costs of a construction project are influenced by circularity.

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Appendices

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Appendix A: Characteristics available regular infrastructural construction projects

Tweede leven brug

Figure A1: Tweede leven brug, Almere (Dura Vermeer, 2021).

Description	Bicycle and pedestrian bridge over water
Location	Almere
Contracted costs	€ 817,700.00
Dimensions	Length: 80 m; Width: 5 m; Ratio width/length: 1: 16
Materials	Concrete, steel, wood
Level of complexity	Very complex (4/5 characteristics of complexity) • Structural complexity: Large variety of applied materials with different backgrounds and ages. • Uncertainty complexity: The project was a novelty and has not been tried before. In addition, there was a lot of uncertainty of the availability of materials and related information. • Dynamic complexity: The availability of potential materials influenced the dynamics of project continuously. • Socio-political complexity: The project was of great importance to showcase how circularity could be applied in construction projects.
Contract type	D&C
Year of completion	2021

Prins Clausbrug

Figure A2: Prins Clausbrug, Dordrecht (René van Zuuk Architekten, 2021).

Description	Movable bicycle and pedestrian bridge over water
Location	Dordrecht
Contracted costs	€ 11,667,000.00
Dimensions	Length: 137 m; Width: 14 m; Ratio width/length: 1: 10
Materials	Concrete, steel
Level of complexity	Very complex (4/5 characteristics of complexity) • Structural complexity: Large movable bridge with a great span, causing many interdependencies. • Uncertainty complexity: Novelty in bridge design and levering mechanism. • Socio-political complexity: Large amount of stakeholders which are directly influenced by the project. • Pace complexity: Fast pace during the project assembly to minimize delay for water traffic.
Contract type	D&C
Year of completion	2021

Jan Linzelviaduct

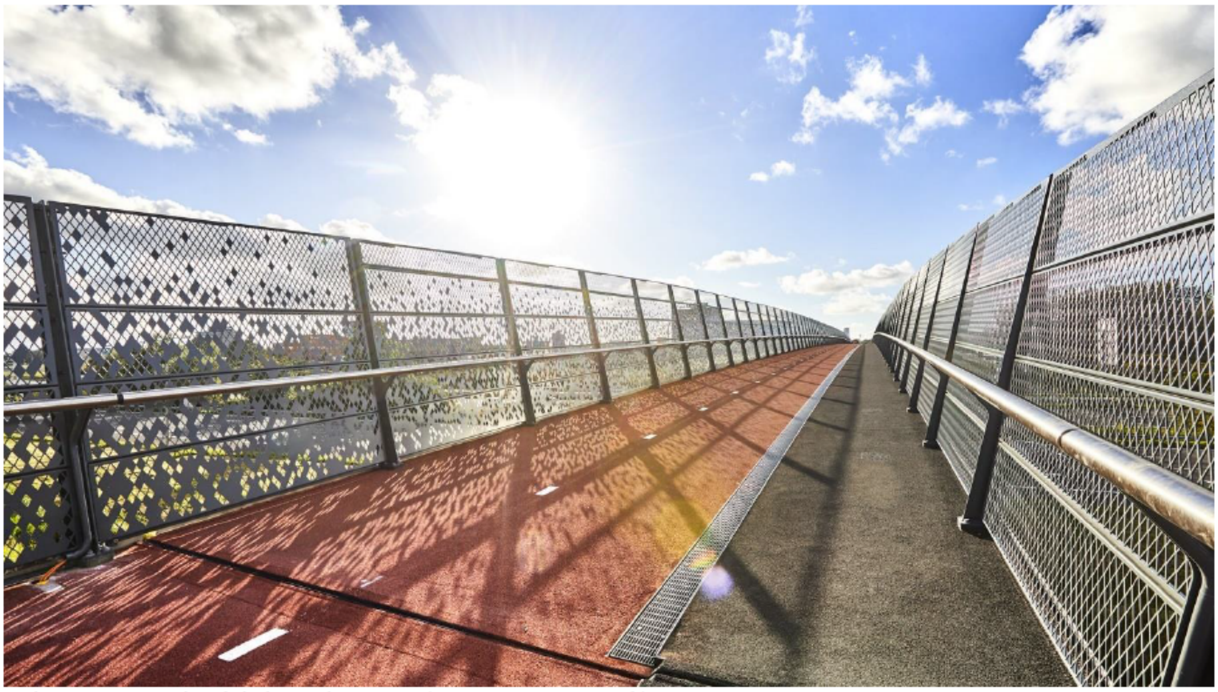

Figure A3: Jan Linzelviaduct, The Hague (Dura Vermeer, 2020b)

Description	Bicycle and pedestrian bridge over highway
Location	The Hague
Contracted costs	€ 9,377,000.00
Dimensions	Length: 335 m; Width: 6.50 m; Ratio width/length: 1: 51.50
Materials	Concrete, steel
Level of complexity	Moderately complex (3/5 characteristics of complexity) • Structural complexity: Large project size and limited space available. • Pace complexity: Fast pace during the project assembly to minimize delay for highway traffic. • Socio-political complexity: Large amount of influential stakeholders involved in this project.
Contract type	D&C
Year of completion	2020

Brug Plaspoelhaven

Figure A4: Composietbrug Plaspoelhaven, Leidschendam (Midvliet, 2022).

Description	Bicycle and pedestrian bridge over water made from composite
Location	Leidschendam
Contracted costs	€ 157,038.99
Dimensions	Length: 22.85 m; Width: 3.90 m; Ratio width/length: 1: 6
Materials	Composite
Level of complexity	Not complex (1/5 characteristics of complexity) • Socio-political complexity: Large number of stakeholders involved in the vicinity of the project.
Contract type	D&C
Year of completion	2018

Fietsbrug Enkele Wiericke

Figure A5: Bicycle bridge Enkele Wiericke, Nieuwerbrug (Hoogheemraadschap De Stichtse Rijnlanden, 2022).

Description	Bicycle and pedestrian bridge over water
Location	Nieuwerbrug
Contracted costs	€ 262,957.29
Dimensions	Length: 21.50 m; Width: 2.50 m; Ratio width/length: 1: 9
Materials	Concrete
Level of complexity	Not complex (0/5 characteristics of complexity)
Contract type	D&C
Year of completion	2022

Verkeersbrug Enkele Wiericke

Figure A6: Traffic bridge Enkele Wiericke, Nieuwerbrug (BR6, 2022).

Description	Traffic bridge over water
Location	Nieuwerbrug
Contracted costs	€ 333,401.88
Dimensions	Length: 17 m; Width: 7 m; Ratio width/length: 1: 2.50
Materials	Concrete
Level of complexity	Not complex (0/5 characteristics of complexity)
Contract type	D&C
Year of completion	2022

Brug Schiebroeksepolder

Figure A7: Bridge Schiebroeksepolder, Schieveen (Midden-Delfland, 2019)

Description	Bicycle and pedestrian bridge over water
Location	Schieveen
Contracted costs	€ 122,137.13
Dimensions	Length: 17.50 m; Width: 4.80 m; Ratio width/length: 1: 3.50
Materials	Concrete
Level of complexity	Not complex (0/5 characteristics of complexity)
Contract type	D&C
Year of completion	2019

Wisenniabrug

Figure A8: Wisenniabrug, Leiden (Ney & Partners, 2020)

Description	Bicycle and pedestrian bridge over water
Location	Leiden
Contracted costs	€ 535,056.59
Dimensions	Length: 30 m; Width: 2 m; Ratio width/length: 1: 15
Materials	Concrete, steel
Level of complexity	Very complex (4/5 characteristics of complexity) • Structural complexity: Limited space available in city center for constructing the project on site. • Uncertainty complexity: There was an uncertainty involving possibly damaging the historic city center when constructing the bridge. • Pace complexity: Fast pace in constructing the project to minimize the nuisance for residents and visitors. • Socio-political complexity: Due to the projects location in the city center, a large group of stakeholders is involved.
Contract type	D&C
Year of completion	2020

Rhijngeest brug

Figure A9: Rhijngeest bridge, Oegstgeest (Dura Vermeer, 2020c)

Description	Bicycle and pedestrian drawbridge over water
Location	Oegstgeest
Contracted costs	€ 215,000.00
Dimensions	Length: 17.80 m; Width: 5 m; Ratio width/length: 1: 3.50
Materials	Steel, composite
Level of complexity	Not complex (1/5 characteristics of complexity) • Structural complexity: The structure is a movable bridge leading to interdependencies between components of the bridge.
Contract type	D&C
Year of completion	2020

Kraanvogelbrug

Figure A10: Kraanvogelbrug, Spijkenisse (Dura Vermeer, 2017).

Description	Movable bicycle and pedestrian bridge over water
Location	Spijkenisse
Contracted costs	€ 1,990,000.00
Dimensions	Length: 34.5 m; Width: 4.75 m; Ratio width/length: 1: 7.5
Materials	Steel
Level of complexity	Slightly complex (2/5 characteristics of complexity) • Structural complexity: The structure is a movable bridge leading to interdependencies between components of the bridge. • Uncertainty complexity: The asymmetric architectural design of the drawbridge makes the project a novelty.
Contract type	Bouwteam
Year of completion	2017

Kickersbloem brug

Figure A11: Kickersbloem bridge, Hellevoetssluis (Lousberg, 2020)

Description	Traffic bridge, including bicycle and pedestrian lanes
Location	Hellevoetssluis
Contracted costs	€ 2,504,324.40
Dimensions	Length: 46.55 m; Width: 25.15 m; Ratio width/length: 1: 2
Materials	Concrete, steel
Level of complexity	Slightly complex (2/5 characteristics of complexity) • Structural complexity: Many interdependencies between different flows of traffic on the bridge. • Socio-political complexity: Great number of stakeholders involved, including the different future traffic flows.
Contract type	D&C
Year of completion	2020

Appendix B: Platform CB'23 Circularity measurement method

Indicator 1.1 secondary materials

Amount of materials which already have served one or more lifecycles before being applied in the current project.

$$S_x = \frac{\sum_i (m_i \times m_{si})}{\sum_i m_i} \tag{B.1}$$

Where

S_x : Percentage secondary input material of total object or sub-object;
m_i : Mass of object (i) in kilograms;
m_{si} : Percentage by mass of secondary input material of object or sub-object.

Indicator 1.1.1 re-used secondary materials

Amount of materials which already have served one or more lifecycles before being applied in the current project. The materials or components are re-used and required little adaptations to be applied.

$$H_x = \frac{\sum_i \left(m_i \times m_{s,hi}\right)}{\sum_i m_i} \tag{B.2}$$

Where

H_x : Percentage re-used input material of total object or sub-object;
m_i : Mass of object (i) in kilograms;
$m_{s,hi}$: Percentage by mass of re-used secondary input material of object or sub-object.

Indicator 1.1.2 recycled secondary materials

Amount of materials which already have served one or more lifecycles before being applied in the current project. The materials or components originate from recycling.

$$R_x = \frac{\sum_i \left(m_i \times m_{s,ri}\right)}{\sum_i m_i} \tag{B.3}$$

Where

R_x : Percentage recycled input material of total object or sub-object;
m_i : Mass of object (i) in kilograms;
$m_{s,ri}$: Percentage by mass of recycled secondary input material of object or sub-object.

Indicator 1.2 primary materials

Amount of materials which are being applied for the first time.

$$V_x = \frac{\sum_i (m_i \times m_{vi})}{\sum_i m_i} \tag{B.4}$$

Where

V_x : Percentage primary input material of total object or sub-object;

m_i : Mass of object (i) in kilograms;

m_{vi} : Percentage by mass of primary input material of object or sub-object.

Indicator 1.2.1 renewable primary materials

Amount of materials which are being applied for the first time. These materials are renewable, according to the NIBE-report ‘’Hernieuwbare grondstoffen’’ (2021) and are either sustainably or unsustainably produced.

$$H_x = \frac{\sum_i (m_i \times m_h)}{\sum_i m_i} \tag{B.5}$$

Where

H_x : Percentage renewable primary input material of total object or sub-object;

m_i : Mass of object (i) in kilograms;

m_h : Percentage by mass of renewable primary input material of object or sub-object.

Indicator 1.2.1a sustainably produced renewable primary materials

Amount of materials which are being applied for the first time. These materials are produced sustainably, according to the NIBE-report ‘’Hernieuwbare grondstoffen’’ (2021), and it’s sustainability has been approved by internationally acknowledged certification or other product data.

$$N_x = \frac{\sum_i (m_i \times m_{ni})}{\sum_i m_i} \tag{B.6}$$

Where

N_x : Percentage sustainably produced renewable primary input material of total object or sub-object;

m_i : Mass of object (i) in kilograms;

m_{ni} : Percentage by mass of sustainably produced renewable primary input material of object or sub-object.

Indicator 1.2.1b unsustainably produced renewable primary materials

Amount of materials which are being applied for the first time. These materials are produced unsustainably, according to the NIBE-report ‘’Hernieuwbare grondstoffen’’ (2021).

$$VN_x = \frac{\sum_i \big(m_i \times (m_{vi} - m_{ni})\big)}{\sum_i m_i} \tag{B.7}$$

Where

VN_x : Percentage unsustainably produced renewable primary input material of total object or sub-object;

m_i : Mass of object (i) in kilograms;

m_{ni} : Percentage by mass of unsustainably produced renewable primary input material of object or sub-object.

m_{vi} : Percentage by mass of primary renewable input material of object or sub-object.

Indicator 1.2.2 non-renewable primary materials

Amount of materials which are being applied for the first time. These materials are non-renewable, according to the NIBE-report ‘’Hernieuwbare grondstoffen’’ (2021).

$$NH_x = \frac{\sum_i (m_i \times m_{nh})}{\sum_i m_i} \tag{B.8}$$

Where

NH_x : Percentage non-renewable primary input material of total object or sub-object;

m_i : Mass of object (i) in kilograms;

m_{nh} : Percentage by mass of non-renewable primary input material of object or sub-object.

Indicator 1.3 physically scarce materials

The physically scarce material indicator has not been developed yet. Currently, CB’23 is investigating the usage of abiotic depletion potential for determining physically scarce materials (Platform CB’23, 2022).

Indicator 1.4.1 socio-economically non-scarce materials

Amount of materials which are according to the list of critical raw materials for the EU (European commission, 2020b) socio-economically non-scarce.

$$NK_x = \frac{\sum_i (m_i \times m_{nk})}{\sum_i m_i} \tag{B.9}$$

Where

NK_x : Percentage socio-economically non-scarce material of total object or sub-object;

m_i : Mass of object (i) in kilograms;

m_{nk} : Mass of socio-economically non-scarce material of object or sub-object.

Indicator 1.4.2 socio-economically scarce materials

Amount of materials which are according to the list of critical raw materials for the EU (European commission, 2020b) socio-economically scarce.

$$K_x = \frac{\sum_i (m_i \times m_k)}{\sum_i m_i} \tag{B.10}$$

Where

K_x : Percentage socio-economically scarce material of total object or sub-object;

m_i : Mass of object (i) in kilograms;
m_k : Mass of socio-economically scarce material of object or sub-object.

Indicator 2.1 output materials available for re-using

Amount of material available for reuse in the next lifecycle in kilograms.

$$H_g = \frac{\sum_i (m_i \times m_{he})}{\sum_i m_i} \quad (B.11)$$

Where

H_g : Percentage realistic re-usable output material of total object or sub-object;
m_i : Mass of object (i) in kilograms;
m_{he} : Mass percentage of which re-use of a composed object is the most realistic scenario.

Indicator 2.2 output materials available for recycling

Amount of materials available for recycling in the next lifecycle in kilograms.

$$R_e = \frac{\sum_i (m_i \times m_{re})}{\sum_i m_i} \quad (B.12)$$

Where

R_e : Percentage realistic recyclable output material of total object or sub-object;
m_i : Mass of object (i) in kilograms;
m_{re} : Mass percentage of which recycling of a composed object is the most realistic scenario.

Indicator 3.1 output materials most likely used for energy generation

Amount of materials in kilograms of which energy generation by incineration is the most likely purpose at the end of the lifecycle.

$$R_{ew} = \frac{\sum_i (m_i \times m_{ew})}{\sum_i m_i} \quad (B.13)$$

Where

R_{ew} : Percentage output material used for energy generation;
m_i : Mass of object (i) in kilograms;
m_{ew} : Mass percentage of which energy generation is the most probable end-of-lifecycle treatment.

Indicator 3.2 output materials most likely used as landfill

Amount of materials in kilograms of which landfill is the most likely purpose at the end of the lifecycle.

$$R_{st} = \frac{\sum_i (m_i \times m_{st})}{\sum_i m_i} \quad (B.14)$$

Where

R_{st} : Percentage output material used as landfill;

m_i : Mass of object (i) in kilograms;

m_{st} : Mass percentage of which landfill is the most probable end-of-lifecycle treatment.

Appendix C: Interview protocol

Interview protocol - Dutch

Datum van interview: __-__-____
Naam deelnemer: ______________________________
E-mail deelnemer: ______________________________
Organisatie: ______________________________
Interviewer: Mark Kanters
E-mail interviewer: m.kanters@duravermeer.nl

Vertrouwelijkheid en verwerking van interview

Voor analysedoeleinden zal dit interview worden opgenomen. Een samenvatting van dit interview zal binnen één week worden opgestuurd naar de deelnemer ter verificatie. Als er binnen één week geen reactie is ontvangen op de samenvatting, neemt men aan dat de deelnemer akkoord gaat met de verstuurde samenvatting en kan de data geanalyseerd worden. De deelnemer zal niet bij naam genoemd worden, enkel de functie, organisatie en gerelateerde project case wordt genoemd in dit onderzoek. Gaat u, de deelnemer, akkoord met deze voorwaarden?

- o Ja, ik ga akkoord
- o Nee, ik ga niet akkoord

Introductie

Introductie van de interviewer

- Tweedejaars student van de Master Construction Management and Engineering aan de TU Delft, met de specialisatie Design and Integration.
- Gestart met mijn Masterthesis in februari 2022 bij Dura Vermeer.
- Onderzoeksonderwerp: Circulariteit in de civiele bouwsector en de invloed daarvan op de processen en kosten van een project.
- Onderzoeksvoortgang: Literatuurstudie en methodologie is afgerond. De volgende stap is de case studie waarvoor de interviews input leveren.

Doel van het onderzoek

Het doel van dit onderzoek is het blootleggen van de verschillen in de toepassing van circulariteit in traditionele projectfasen en bouwkosten tussen traditionele en circulaire infrastructurele bouwprojecten. Hierbij worden extra stappen, werkzaamheden en kosten ook geïdentificeerd om een volledig beeld te schetsen van de verschillen.

Doel van het interview

Er wordt een semi-gestructureerd interview uitgevoerd met deelnemers die een partij vertegenwoordigen dat heeft bijgedragen aan een afgerond project dat deel uit maakt van de case studie. Het interview heeft als doel het vergaren van interne projectinformatie en ervaringen van alle betrokken partijen over het project proces van een bepaald project. De vergaarde informatie zal nieuwe inzichten verwerven in zowel het traditionele als circulaire civiele bouwproject.

Interview structuur

Het interview bestaat uit vijf delen. Het eerste deel is van algemene aard en zal dienen als een introductie van de deelnemer. Vervolgens wordt in het tweede deel de circulaire economie geïntroduceerd en het standpunt van de deelnemer op de circulaire economie wordt verkend. Het derde deel is gericht op het desbetreffende case project en de implementatie van circulariteit in de verschillende projectfasen van het project. Algemene vragen over het case project en de kosten worden gesteld in het vierde deel. Tenslotte volgen er in het vijfde deel nog enkele afsluitende vragen en wordt het interview afgerond.

Algemeen

- Welke partij vertegenwoordigd u?
- Wat is uw rol in deze partij?
- Hoe lang heeft u werkervaring in de bouwsector?

Circulaire economie

- Wat betekent de circulaire economie volgens u en wat is uw mening hierover?
- Wat betekent volgens u de circulaire economie voor de bouwsector?
- Werkt u momenteel aan een circulair project? Zo ja, wat maakt het project circulair?
- Welk aspect van circulariteit in de bouw vindt u het belangrijkst?

Circulaire economie in het case studie project

Vanaf dit punt zal het interview zich focussen op het project ________________. Gelieve de vragen te beantwoorden zoals u dit project heeft ervaren.

- Wat was uw rol in dit project?

- Vanuit de literatuur bevatten bouwprojecten standaard 5 componenten:
  - Initiatie
  - Ontwerp
  - Tender
  - Realisatie
  - Gebruik en onderhoud

  Bent u het eens met deze vijf hoofdcomponenten voor projecten? Waarom wel/niet?

- In welke componenten bent u of uw partij betrokken geweest in het project?

- Denkt u dat deze volgorde van projectcomponenten correct is voor reguliere projecten?

- Wat is de volgorde van projectcomponenten geweest in dit project? Missende componenten mogen worden toegevoegd.

- Waren alle betrokken partijen tijdens de initiatie van het project gemotiveerd om een circulair project te realiseren?

- CB'23 is een platform bestaande uit verschillende partijen, waaronder onderzoekers vanuit de TU Delft, die samen de GWW-sector naar de circulaire economie op weg willen helpen. Nu heeft CB'23 zes ontwerpstrategieën geformuleerd voor het maken van een circulair ontwerp: Ontwerpen voor preventie, ontwerpen voor reductie van levenscyclusimpact, ontwerpen voor toekomstbestendigheid, ontwerpen met hergebruikte objecten, ontwerpen met secundaire grondstoffen, ontwerpen met hernieuwbare grondstoffen. Is het ontwerp voor de Tweede leven brug gemaakt door middel van één of meerdere van de zes circulaire ontwerpstrategieën toe te passen?

- Was het gebruikte aanbestedingsmodel op basis van een product-service model, een publiek-privaat samenwerkingsmodel, een samenwerkingsmodel met meerdere partijen voor hergebruik en deelgebruik, een lease-model, of een terugname-model voor leveranciers?

- Welke circulariteit maatregelen zijn er genomen gedurende de bouw van het project?

- In hoeverre kan het gebouwde object gedemonteerd worden voor de oogst van herbruikbare componenten?

- Gedurende de initiatie van het project, hoe belangrijk was het om een circulair object te creëren?

- Het ontwerp is gemaakt voor een lange levensduur, service of leasing, hergebruik bij productie of materiaal terugwinning.

- In hoeverre draagt de ingediende tender bij aan gesloten energie- en materiaal-kringlopen binnen aanvoerketens, terwijl negatieve milieueffecten en afval wordt geminimaliseerd en in het beste geval worden vermeden over de gehele levenscyclus?

- Zijn er met de leverancier afspraken gemaakt over de terugvordering van materialen na de levensduur van het object?

- In hoeverre zijn er componenten herbruikbaar voor toekomstige projecten na de levensduur van het gebouwde object?

- Waren tijdens de initiatie van het project alle betrokken partijen gemotiveerd en droegen ze actief bij aan het gezamenlijke doel van het realiseren van een circulair object?

- Het basisprincipe van de circulaire economie en het circulair ontwerp is: ‘’Ontwerp zó dat afval en vervuiling worden voorkomen’’. Vormt dit principe ook de basis van het ontwerp van dit object?

- Was de aanbestedingsprocedure prestatiegericht? Bevatte tools zoals life cycle approach (LCA) en life cycle costs (LCC)? Waren er criteria aanwezig voor het hergebruik van materialen?

- Welke maatregelen zijn er genomen om de bouw zelf circulair of duurzaam te maken? (Denk hierbij aan machines, uitrusting, etc.)

- Is er rekening gehouden met het einde van de levensduur van het object en mogelijke toekomstige doeleinden bij de start van dit project?

<u>Project algemeen</u>

- Waren er verschillen of opmerkelijkheden in het project proces vergeleken met een regulier bouwproject?

- Zijn er extra werkzaamheden of stappen die uitgevoerd moesten worden in dit project?

- Zijn volgens u circulaire bouwprojecten duurder of goedkoper dan regulier bouwprojecten?

- Wat is volgens u de reden voor deze hogere of lagere kosten?

- Wat zijn volgens u de beperkingen voor de implementatie van circulariteit in de civiele bouwsector?

Afsluitende vragen

- Heeft u en uw partij de ambitie om in de toekomst aan meer circulaire bouwprojecten mee te werken? Waarom wel/niet?

- Heeft u algemene opmerkingen over het project?

Hartelijk dank voor uw deelname aan dit interview en delen van uw kennis met mij. Binnen één week vanaf vandaag zend ik u een samenvatting van dit onderzoek toe. Mochten er fouten aanwezig zijn in de samenvatting, of u heeft nog aanvullende opmerkingen, dan hoor ik dat graag. Wanneer u akkoord gaat met de samenvatting ontvang ik graag een bevestiging per mail. Mocht ik geen antwoord van u hebben ontvangen binnen één week na het verzenden van de samenvatting, dan ga ik ervanuit dat u akkoord gaat met de samenvatting.

Appendix D: Summaries of interviews circular case project

D.1 Interview participant A

Interviewer

Oké, de opname werkt. Ja, ik heb mijzelf net al even voorgesteld. Het doel van het onderzoek is dus het blootleggen van de verschillen in de toepassing van circulariteit en aan de hand van traditionele projectfasen en de bouwkosten tussen traditionele en circulaire infrastructurele projecten. En hierbij kijk ik ook naar de stappen, werkzaamheden en kosten om eigenlijk een volledig beeld te krijgen. Nu volgt er een semigestructureerd interview.

Participant

Hé kijk, ik fiets met alle plezier door alle structuren heen, dus als jij zorgt dat het gestructureerd is dan vind ik het prima.

Interviewer

Ik ga mijn best doen om structuur aan te brengen. Het interview bestaat uit 5 delen. Eerste deel is een beetje algemeen waarin ik te weten kom wie er tegenover mij zit. Het tweede deel gaat over circulariteit en de circulaire economie in zijn algemeenheid. Vervolgens gaan we naar de projectfasen en de circulaire economie In het project zelf. Én daarna volgen nog wat algemene vragen over project zelf en daarna sluiten we af met wat afsluitende vragen. We kunnen nu dus beginnen. Wie heb ik hier voor mij zitten?

Participant

Voor je zit participant A. Opgeleid als architect én als constructief ontwerper aan de TU Eindhoven. Ik heb altijd al interesse gehad voor beide vakgebieden. Zowel voor esthetisch ontwerp als meer de technische kant. Hoe maak je dingen, hoe bouw je dingen. Ik heb eigenlijk een dubbele studie gedaan, zowel architectuur gestudeerd, architectonisch ontwerpen en constructief ontwerpen. En mijn passie is eigenlijk om op het raakvlak van die twee disciplines actief te zijn. Wat ik me heb afgevraagd na mijn studie is hoe ik het meeste invloed kan uitoefenen op het constructief ontwerp in samenhang met de ruimtelijke beleving van het project. Ik kwam toen tot de conclusie dat je als architect eigenlijk veel meer constructief kan ontwerpen dan als constructeur, omdat je als constructeur heel vaak geconfronteerd wordt met hoe een architect bijvoorbeeld, met name bij gebouwen, dingen heeft georganiseerd, denk aan stramien, vorm van een gebouw. Dus dan ga je uitrekenen dat zo'n architect bedacht heeft. Ik heb na mijn studie eigenlijk de keuze gemaakt om meer vanuit de architectuur bezig te zijn met de constructie. Ik heb 10 jaar voor verschillende grotere architectenbureaus gewerkt en ben daarna in 1999 begonnen met mijn eigen architectenbureau, Arc²-architecten. Vanuit die die passie en mijn competenties, zowel op het gebied van vormgeven als op het gebied van techniek, heel veel opdrachten projecten gedaan, waarbij juist de constructie ook en belangrijk onderdeel vormt van de opgave. Bijvoorbeeld het Spoorwegmuseum, een groot gebouw met grote overspanningen, de Amazonica Dome in Diergaarde Blijdorp, een hele grote geodetische koepel. Maar grotere bruggen zijn allereerst ook constructies die vervolgens ook vormgegeven worden. Dus infrastructuur houden wij onszelf ook mee bezig, kleine bruggen, grote bruggen, tunnels en andere kunstwerken. Door als architect ook een constructieve achtergrond te hebben, weet ik zeker wat ik ontwerp ook constructief mogelijk is. Strategische partners waar ik veel mee samenwerk, zien dit ook wel als een meerwaarde.

Interviewer
Zo, de algemene punten zijn ondertussen afgerond, kunnen we door het volgende onderwerp. Wat betekent de circulaire economie volgens u? En wat is uw mening daarover?

Participant
Ik ontwerp al veel langer gebouwen en bruggen constructies in hout. Ik heb dus het materiaal hout altijd als een mooi constructiemateriaal gezien. Maar het die circulaire en duurzame aanpak is iets wat we 10, 12 jaar geleden pas echt zijn gaan ontwikkelen. Dus ik heb voortgebouwd op die ervaring in het bouwen en construeren met hout. Dus hout is een hergroeibaar materiaal, dus op die manier is het als biologisch materiaal al circulair, maar we zijn ook in gaan zetten op het hergebruik van materialen, maar ook het hergebruik van gebouwen. Bijvoorbeeld de transformatie en herbestemming van een paar forten van de nieuwe Hollandse Waterlinie.

Interviewer
Ik heb ook wel het idee dat ze in de architectuur en utiliteitsbouw al veel verder met de implementatie van circulariteit, klopt dit?

Participant
Ze zijn er niet per se verder mee, maar het wordt al wel wat langer toegepast. Infrastructuur is vaak heel veel staal en beton, hè? Die constructieve component speelt een belangrijke rol, je wilt een zo sterk mogelijk beton hebben. Dan is dat wat lastiger om die op elementen niveau her te gebruiken. Hoewel in de infrastructuur natuurlijk al heel lang asfalt hergebruikt en beton vergruisd wordt. Alleen ben je dan wel aan het downcyclen, maar daar zit ook een vorm van circulariteit in. Maar je wil je hoogwaardigere circulariteit. Maar om toch even terug te komen op circulariteit in de utiliteitsbouw. Daar zie je toch ook maar heel beperkt hergebruik van materialen. Er zijn wel projectvoorbeelden van, maar als je percentagegewijs gaat kijken naar welk percentage van de gebouwde omgeving van de nieuwbouw waarin nou daadwerkelijk circulariteit is toegepast, dan is dat niet indrukwekkend veel. Tenzij je biobased materialen ook als onderdeel van circulariteit ziet, want daarin is een flinke opmars te zien. Er is geen grote aannemer die niet aan het studeren is hoe ze hiermee bijvoorbeeld woningbouw seriematig kunnen uitvoeren. Maar hoe groot die gebouwde hoeveelheid is in vergelijking met het totale bouwvolume moet je je natuurlijk ook afvragen.

Interviewer
Wat denk je dat de circulaire economie nu gaat betekenen voor de bouwsector?

Participant
Geen idee hoe we dit zo snel circulair gaan krijgen. Het lijkt me niet haalbaar, maar van de andere kant zie je ook weer dat er soms enorme versnellingen plaatsvinden. Kijk bijvoorbeeld kijkt naar zonnepanelen. 5 à 6 jaar geleden liep Nederland nog achteraan, nu zijn we op Europees vlak koploper hierin. Dit laat zien hoe snel het kan kantelen, dit zie je momenteel ook met grote wereldevenementen.

Ik verwacht dat er ook op het gebied van primaire, ruwe, nieuwe materialen of hergebruikte materialen ook een soort versnelling en belangrijke verschuiving gaat plaatsvinden. Enerzijds denk ik dat het allemaal veel te traag gaat maar anderzijds zie je af en toe ook weer echt doorbraken.

Interviewer
Welk aspect van circulariteit in de bouwsector vindt u het belangrijkste?
Participant
Het belangrijkste vind ik eigenlijk dat we de enige aardbol die we hebben niet meer belasten dan dat deze aan kan. Er is een jaarlijkse datum waarop we de hoeveelheid primaire grondstoffen die de aarde jaarlijks kan missen al verbruikt hebben, en die datum komt steeds vroeger te liggen. Dus dat geeft wel aan dat we met zijn allen op de afrond afstevenen.

Interviewer
Zijn jullie dan momenteel ook bezig met meer circulaire projecten?

Participant
Ja, momenteel zijn we bezig met een circulaire te tender schrijven.

Interviewer
Oké, en wat maakt dit project dan circulair?

Participant
Nouja, dat is wel leuk om even te vertellen, ook in het kader van het hele bewustzijn rond circulariteit. 10 Jaar geleden werd bekend dat de Floriade naar Almere zou komen. Samen met een andere partij hadden we een paar jaar daarvoor het concept van hergebruik van gesloopte bruggen ontwikkeld. Dit leek ons prima te passen in het thema van de Floriade en hiermee zijn we dus naar de gemeente geweest om te laten zien dat we op het terrein ook zo'n brug kunnen maken. Maar dit wilde de gemeente niet omdat het niet de gangbare manier van zaken is om een oude brug her te gebruiken voor een nieuwe brug. De Floriade was het er wel mee eens dat het in het thema past maar gaf aan dat ze nog niet toe zijn aan het ontwerpen van de infrastructuur. Maar toen was er iemand van de afdeling beheer en onderhoud van de gemeente Almere, die werd directeur van afdeling infra, die vond het toch wel een heel gaaf concept. Waarna wij een pilot hebben uitgevoerd in Almere. Nou jaren later, samen met Dura Vermeer, hadden we die liggers over van een overspanning over de A27 en is het ons toch gelukt om op de Floriade te belanden met een volledig circulaire brug. Gedurende dat project hebben we contact gehad met de gemeente waarvoor we nu een tender schrijven. Maar bij deze tender zie je dus dat de gemeente en dus overheid als uitgangspunt heeft geformuleerd in de uitvraag dat het circulair moet zijn. Dus 10 jaar geleden in Almere moesten ze er niets van hebben en nu is het een uitgangspunt geworden. In het begin is het pionieren maar nu is dat dus doorgedrongen.

Interviewer
En voor die tender die nu geschreven wordt, zijn daar nog speciale eisen voor? Behalve dan dat je circulair moet zijn. Zijn er nog aanvullende eisen die de gemeente stelt?

Participant

Nou, die circulariteit wordt heel erg als uitgangspunt genomen en daar hoort van alles bij. Dus het liefste halen ze de materialen zo dicht mogelijk bij de bouwlocatie. Als het van veel verder moet komen dan krijg je weer te maken met de uitstoot en ze kijken dus ook naar de MKI-score. Ze kijken ook naar demontabel bouwen, maar dan bouw je in feite nu al iets nieuws om het later te hergebruiken. Of dat dan circulair te noemen is vind ik discutabel. Maar duurzaamheid in bredere zin wordt gevraagd, zoals biodiversiteit. Dus er wordt eigenlijk gevraagd, hoe zorgen we nou goed voor ons aarde en ook alles wat erop leeft?

Interviewer
Nu gaan we ons focussen op het circulaire project de Tweede Levenbrug. Wat was uw rol In het project?
Participant
Nou, Ik ben eigenlijk verantwoordelijk voor de architectonische vormgeving.

Interviewer
Uit mijn literatuuronderzoek is gebleken dat er zes standaard fasen waar een project doorheen gaat. De initiatiefase, ontwerpfase, specificatiefase, tenderfase, bouwfase en de gebruik, onderhoud en eind-levensduur-fase. Ben je het eens met deze indeling?

Participant
Ja hoor, dat is een beetje de traditionele volgorde. Maar wat een beetje gangbaarder wordt is het steeds eerder betrekken van de aannemer in het proces. Het voordeel is dan dat er bij je ontwerp al meteen gekeken wordt naar uitvoerbaarheid en kosten. De traditionele manier van werken is dan eigenlijk al ingehaald door alle contractvormen die er ontstaan. Maar traditioneel gezien is er inderdaad sprake van dit lineaire proces.

Interviewer
Bij welke fasen bent u allemaal betrokken geweest in dit project?

Participant
Initiatie, daarvoor heb ik al een conceptontwerp gemaakt, ter acquisitie. Het ontwerp en specificatie ook. Voor de tender en bouwfase hebben we meer een architectonische superviserende rol gehad. Ieder fase zijn wij wel betrokken geweest, behalve in de gebruik, onderhoud en einde-levensduur-fase.

Interviewer
Nu gaan we gewoon iedere fase doorlopen. Ik ga stellingen voorleggen of vragen stellen en dan zit er vervolgens een bepaalde gradatie aan vast. Per vraag geeft u dus een score, en die mag dan nog voorzien worden van een korte toelichting. Deze gaat over de initiatiefase. Waren alle betrokken partijen tijdens initiatie van het project gemotiveerd om een circulair project te realiseren?

Participant
Ik zou zeggen erg gemotiveerd. Dura Vermeer en Arc² architecten waren extreem gemotiveerd, je gaat natuurlijk als je de samenwerking aangaat ook andere gemotiveerde partijen zoeken om mee samen te werken. Verder was de stedenbouwkundige van de gemeente Almere was erg gemotiveerd, en de Ontwikkelcombinatie Amvest Dura Vermeer (OCAD) was licht gemotiveerd.

Interviewer
Bent u bekend met platform CB'23?

Participant
Ik heb er wel eens van gehoord, maar ik ben er eigenlijk niet bekend mee.

Interviewer
CB'23 is een platform bestaande uit verschillende partijen, waaronder onderzoekers vanuit de TU Delft, die samen de GWW-sector naar de circulaire economie op weg willen helpen. Nu heeft CB'23 zes ontwerpstrategieën geformuleerd voor het maken van een circulair ontwerp: Ontwerpen voor preventie, ontwerpen voor reductie van levenscyclusimpact, ontwerpen voor toekomstbestendigheid, ontwerpen met hergebruikte objecten, ontwerpen met secundaire grondstoffen, ontwerpen met hernieuwbare grondstoffen. Het ontwerp van de Tweede Levenbrug is gemaakt door middel van één of meerdere van de zes circulaire ontwerpstrategieën toe te passen, in hoeverre bent u het hiermee eens?

Participant
Helemaal mee eens. Ontwerpen met hergebruikte objecten is uiteraard toegepast. Ontwerpen voor preventie ook, want de brug is een stuk ingekort dan origineel het plan was. Ontwerpen voor de reductie van levenscyclusimpact door de demontabiliteit van de brug. Daarnaast wordt ontwerpen met hernieuwbare grondstoffen ook toegepast door het gebruik van hout. Ik mis alleen in deze lijst het natuurinclusief ontwerpen als strategie, want dat heeft naar mijn idee ook te maken met circulariteit.

Interviewer
In hoeverre waren de specificaties van de opdrachtgever, gevormd in de derde fase, flexibel en niet-beschrijvend?

Participant
De opdrachtgever gemeente Almere is wel heel bereidwillig geweest om de specificaties aan te passen en was dus flexibel. Misschien was het wel beschrijvend, maar is die beschrijving is aangepast voor ons. Dus flexibel en niet-beschrijvend zou je het kunnen noemen.

Interviewer
Ik heb hier een stelling. Het gebruikte aanbestedingsmodel was op basis van een product-service model, een publiek-privaat samenwerkingsmodel, een samenwerkingsmodel met meerdere partijen voor hergebruik en deelgebruik, een lease-model, of een terugname-model voor leveranciers.

Participant
Helemaal mee eens. Er is in ieder geval sprake van de samenwerking met meerdere partijen voor hergebruik en deelgebruik. Daarnaast is de gehele Floriade een Publiek Private Samenwerking.

Interviewer
In hoeverre kan het gebouwde object gedemonteerd worden voor de oogst van herbruikbare componenten?

Participant
Het is wel compleet herbruikbaar.

Interviewer
Gedurende de initiatie van het project, hoe belangrijk was het om een circulair object te creëren?

Participant
Ja, dat was wel cruciaal, dus extreem belangrijk.

Interviewer
Het ontwerp is gemaakt voor een lange levensduur, service of leasing, hergebruik bij productie of materiaal terugwinning.

Participant
Het kan allemaal wel, maar het is volgens mij niet dat daar per se rekening mee is gehouden bij de start van het project. We zijn al lang blij dat het ons is gelukt om met al die tweede leven materialen een brug te kunnen bouwen. Dus neutraal zou ik zeggen.

Interviewer
In hoeverre waren de projectspecificaties prestatiegericht en werd dit gestimuleerd?

Participant
Nou, ik zou het niet weten. Op een bepaalde manier werd het wel erg gestimuleerd om op die Floriade te ontwerpen en te bouwen, hoewel er ook kunstwerken liggen die gewoon met nieuw beton zijn gebouwd. Dus vanuit de Floriade ambities werd het wel erg gestimuleerd. Dus erg gestimuleerd.

Interviewer
De ingediende tender draagt bij aan gesloten energie- en materiaal-kringlopen binnen aanvoerketens, terwijl negatieve milieueffecten en afval wordt geminimaliseerd en in het beste geval worden vermeden over de gehele levenscyclus.

Participant
Helemaal mee eens.

Interviewer
In hoeverre zijn er componenten herbruikbaar voor toekomstige projecten na de levensduur van de tweede leven brug?

Participant
Ja, volgens mij zijn ze wel goed herbruikbaar. De dikte van het staal zal in de loop van de tijd wel afnemen. De betonnen liggers zijn nog wel aardig lang goed te gebruiken, maar het toegepaste hout

neemt ook af in functionaliteit in de loop van de jaren. Dus ik zou zeggen tussen gemiddeld en grotendeels herbruikbaar, en dat komt dan vooral door de veroudering van de materialen.

Interviewer
Tijdens de initiatie van het project waren alle betrokken partijen gemotiveerd en droegen actief bij aan het gezamenlijke doel van het realiseren van een circulair object.

Participant
Ik ben daar wel helemaal mee eens. Gedurende het proces was iedereen verrassend positief en liep alles op rolletjes.

Interviewer
Ik heb weer een stelling voor u. Het basisprincipe van de circulaire economie en circulair ontwerp, ‘’Ontwerp zó dat afval en vervuiling worden voorkomen’’, vormt de basis van het ontwerp van dit object.

Participant
Het belangrijkste van die Tweede Levenbrug is dat de materialen die elders afval vormen, wij weer hebben gebruikt als grondstof. Je krijgt dus ook een andere logica voor de uitvraag van een opdracht. Wil je vooral circulaire materialen hergebruiken? Dan telt het niet dat een bepaald nieuw onderwerp goedkoper is. Die circulariteit is dan juist belangrijk, want dat wordt gemeten en daarop wordt gescoord. Terwijl het oude denken vooral ging om de beste prijs-kwaliteit verhouding. Met dit project hebben we dus afval voorkomen, dus helemaal mee eens.

Interviewer
De aanbestedingsprocedure was prestatiegericht, bevatte tools zoals life cycle approach (LCA) en life cycle costs (LCC), en criteria waren aanwezig voor het hergebruik van materialen.

Participant
Nou, volgens mij was dit allemaal niet het geval. Er was conceptueel omschreven hoe het moest. Als je het breder ziet, het is voor de Floriade dus die Floriade had wel duidelijk zijn eigen ambities. Maar voor de brug zelf was alleen aangegeven dat er lokaal hout gebruikt moest worden, wat de locatie van de brug moest worden en wat de afmetingen zouden zijn. Het was in die zin ook niet een echte tender, het project is niet echt in de markt gezet. Hierom ben ik het hier helemaal mee oneens.

Interviewer
Er is rekening gehouden met het einde van de levensduur van het object en mogelijke toekomstige doeleinden, wat materialen betreft, bij de start van dit project.

Participant
We hebben hier bij de start van het project helemaal niet over nagedacht, dus helemaal mee oneens.

Interviewer

Nu heb ik nog een aantal laatste vragen. Waren er verschillen of opmerkelijkheden in het project proces vergeleken met een regulier bouwproject?

Participant
De geoogste materialen of die geoogste onderdelen zijn nu je startpunt van proces en ontwerpproces, en dus ook van mijn architectonisch ontwerp. Met die onderdelen moet een object gecreëerd worden. Het draait heel erg om het materiaal. En dat is heel anders dan in een traditioneel proces. Hierin maak je eerst een ontwerp en dan ga je er materialen aan toekennen.

Interviewer
Maar zijn er dan ook extra stappen die je moet uitvoeren?

Participant
Ja, een belangrijke extra stap is het beoordelen van het materiaal. Voldoet die aan de specificaties of andersom, welke specificaties heeft het materiaal eigenlijk?

Interviewer
Zijn volgens u circulaire bouwprojecten duurder of goedkoper dan regulier bouwprojecten?

Participant
Als je duur en goedkoop uitdrukt in euro's dan is het nu nog zo dat circulair duurder is omdat het gewoon meer handelingen vraagt. Maar dat kan op korte termijn nog wel veranderen als alle grondstoffen moeilijker te vinden zijn of niet meer beschikbaar zijn. Dat kantelpunt krijg je dan. Maar als je kosten uitdrukt in termen van milieukosten, dan zal is de kans groot dat het goedkoper is. Maar die extra kosten nu zit gewoon in de extra handelingen die uitgevoerd moeten worden en in de onwennigheid en onwetendheid.

Interviewer
Wat zijn volgens u de beperkingen voor de implementatie van circulariteit in de civiele bouwsector?

Participant
Wat in ieder geval een hele grote beperking is, is hoe je omgaat met de logistiek tussen het oogsten en het toepassen van geoogste onderdelen. Want idealiter wil je het gaan oogsten om het vervolgens meteen in een ander project aan te brengen. Maar het moment van sloop kun je niet afstemmen op het moment van bouwen en andersom ook niet. Dus om die logistiek goed te krijgen wordt nog wel een uitdaging. En ik denk dat niet alle architecten, maar wel veel architecten, het lastig vinden om te ontwerpen met gebruikte materialen omdat het je beperkt in vormvrijheid. Het vraagt bij die architecten ook een andere manier van denken en kijken naar een ontwerp.

Interviewer
Ik heb nog één laatste vraag. Heeft u en uw partij de ambitie om in de toekomst aan meer circulaire bouwprojecten mee te werken? Waarom wel/niet?

Participant

Jazeker, een volmondige ja. Wij gaan zeker verder op deze ingeslagen circulaire weg.

Interviewer
Dit was het interview. Bedankt voor uw tijd, moeite en kennis die u met mij heeft gedeeld.

D.2 Interview participant B

Interviewer

De opname werkt, dus we kunnen nu van start gaan. Ik heb mij zojuist al voorgesteld, dus dat kunnen nu even overslaan. Ik ga nu een semigestructureerd interview met u afnemen en dat interview wordt gebruikt voor mijn onderzoek. Het interview bestaat uit vijf delen. Eerst een algemene introductie, dan de circulaire economie in het algemeen en daarna het project de Tweede Leven brug. Tenslotte nog wat algemene vragen over het project en enkele concluderende vragen. Dus dan beginnen we nu even met een introductie. Wie heb ik hier voor mij zitten?

Participant

Participant B, senior projectleider bij de provincie Flevoland. Hier werk ik voor gebiedsprogramma's in Europa. Dat is een uitvoerende afdeling, en de meeste mensen werken daar aan verschillende programma's. Zo ik ook. Ik werk daar ook aan een ander programma waar Dura Vermeer veel aan heeft gedaan, namelijk Lelystad Airport. En dan werk ik aan Floriade Werkt, dit is het programma waarmee de bruggen op de Floriade zijn gerealiseerd. Dit is een economisch programma voor de Floriade, en hierin investeren wij en zorgen we ervoor dat de kennis die in Flevoland zit of die kennis die Flevoland ontwikkeld wordt, breder wordt uitgedragen, en dus beschikbaar is voor de toekomst. Hier ben ik in 2017 mee begonnen. Mijn achtergrond zit eigenlijk in de ruimtelijke ordening, maar ik ben nooit echt in het planologische werkzaam geweest, eigenlijk altijd in projectmanagement. Op dit vakgebied heb ik zo'n 15 jaar werkervaring.

Interviewer

Oké, dus ik kan wel veronderstellen dat u en uw partij in dit project de rol van de opdrachtgever op zich neemt?

Participant

Niet helemaal. Want het is zo dat de enige eigenaar van de Floriade de gemeente Almere is, en wij als provincie zijn een stakeholder daarin, maar de bruggen die komen in het beheer van de gemeente Almere. Dus ik zou zeggen dat wij in eerste instantie een faciliterende rol hebben.

Interviewer

Wat betekent voor u de circulaire economie? En wat is uw mening daarover?

Participant

Voor mij betekent het gewoon een mind shift, een andere manier van denken en doen die ervoor gaat zorgen dat de inzet van grondstoffen, kennis, mankracht en financiële middelen in een traject komen dat zichzelf gaat bedruipen. Dat in plaats van een heel lineair traject waar je telkens maar een nieuwe grondstoffen in toevoegt en traditionele kennis gebruikt. De bouw- en GWW-sector is gewoon een superintensieve sector, met veel arbeidsintensief materiaal, intensieve milieu impact, en dan nog een enorm belang voor hoe we allemaal onszelf voortbewegen en ons leven willen inrichten. Tegelijkertijd is het ook een traditionele sector waarin we in een hele traditionele rolverdeling zijn beland. Maar je ziet tegelijkertijd ook veel initiatief, tests en pilots.

Interviewer

Wat denk je dat de circulaire economie gaat betekenen voor de bouwsector?

Participant
Een grote transitie naar traject waarin je op voorhand weet wat je wanneer gaat bouwen, zodat je rekening kunt houden met materialen die vrijkomen om ze vervolgens weer direct elders in te zetten.

Interviewer
Bent u dan momenteel ook bezig met andere circulaire projecten?

Participant
Wij zijn nu aan het zoeken naar hoe wij onze kennis en ervaring kunnen inzetten om toekomstige projecten circulair te maken en dus meer bruggen gemaakt kunnen worden zoals op de Floriade. Er ook al verschillende projecten in de pijpleiding om uitgevoerd te worden. Daarnaast zijn we vanaf volgend jaar als overheid zijnde verplicht om circulair in te kopen. Het grootste obstakel binnen zo'n overheid zijn nu de vergunningen, onderhoud en beheer, hetgeen wat nog redelijk onbekend is. Een nieuwe manier van bouwen vraagt ook om een nieuwe manier van andere processen. De onderwijs kant is dan extra interessant, omdat je met het curriculum studenten kunt aansluiten op het vakgebied.

Interviewer
Welk aspect van circulariteit in de bouw vindt u dan het belangrijkste?

Participant
Ik denk dat er nog een grote slag te halen valt in de materialen. Het is zo'n materiaal intensieve sector, dus als je de levensduur weet te verlengen en de CO_2-uitstoot weet te verlagen, dan win je hier veel mee.

Interviewer
We gaan door naar het naar derde deel, dit gaat weer over het project de Tweede Levenbrug op het Floriadeterrein. Ik ga nu vragen en stellingen voorleggen aan u en die kunt u dan beantwoorden aan de hand van een schaal van 1 tot 5. Dus nog even ter herhaling, wat was uw rol in het project?

Participant
Ja, een faciliterende rol. Dus we werden benaderd door Dura Vermeer met de vraag van hoe we ervoor kunnen zorgen dat we deze brug kunnen realiseren en dan vervolgens ervan te leren en kennis te delen. Wij hebben een andere brug, hoe we hoe?

Interviewer
Vanuit de literatuur zijn er 6 fasen in een traditioneel bouwproject, dit zijn de initiatiefase, ontwerpfase, specificatiefase, tenderfase, bouwfase en de gebruik, onderhoud en eind-levensduur-fase. Ben je het eens met deze indeling voor traditionele projecten?

Participant

In principe ziet het er redelijk compleet uit. Je zou zelfs nog een fase nul kunnen toevoegen waarin de noodzaak boven water komt.

Interviewer
Ik denk dat de noodzaak ook al wel in de initiatieffase behandeld wordt, gezien het initiatief volgt uit een probleem dat een oplossing vereist. Bij welke fasen bent u betrokken geweest in dit project?
Participant
In fase 1, en een klein beetje in fase 2 en 3.

Interviewer
Dan gaan we nu beginnen met de vragen en stellingen. Waren alle betrokken partijen tijdens de initiatie van het project gemotiveerd om een circulair project te realiseren?

Participant
Ja, ik zou wel zeggen dat iedereen erg gemotiveerd was. Wijzelf en Dura Vermeer waren allebei extreem gemotiveerd, en de rest was ook wel gemotiveerd. De floriade is natuurlijke een evenement waar je mag experimenteren, en dat levert motivatie op.

Interviewer
CB'23 is een platform bestaande uit verschillende partijen, waaronder onderzoekers vanuit de TU Delft, die samen de GWW-sector naar de circulaire economie op weg willen helpen. Nu heeft CB'23 zes ontwerpstrategieën geformuleerd voor het maken van een circulair ontwerp: Ontwerpen voor preventie, ontwerpen voor reductie van levenscyclusimpact, ontwerpen voor toekomstbestendigheid, ontwerpen met hergebruikte objecten, ontwerpen met secundaire grondstoffen, ontwerpen met hernieuwbare grondstoffen. Het ontwerp van de Tweede Levenbrug is gemaakt door middel van één of meerdere van de zes circulaire ontwerpstrategieën toe te passen, in hoeverre bent u het hiermee eens?

Participant
Ja daar ben ik het sowieso helemaal mee eens. Het ontwerpen voor reductie van levenscyclus impact, het ontwerpen voor toekomstbestendigheid, ontwerpen met hergebruikte objecten, ontwerpen voor preventie en het ontwerpen met secundaire grondstoffen is allemaal toegepast in dit project.

Interviewer
In hoeverre waren de specificaties van de opdrachtgever, gevormd in de derde fase, flexibel en niet-beschrijvend?

Participant
Nou volgens mij lag er eerst een ander ontwerp op tafel. De gedachte was een houten brug, maar daar zijn ze vanaf geweken voor dit ontwerp. Ik zou dus denken gemiddeld vastgesteld en beschrijvend.

Interviewer
Het gebruikte aanbestedingsmodel was op basis van een product-service model, een publiek-privaat samenwerkingsmodel, een samenwerkingsmodel met meerdere partijen voor hergebruik en deelgebruik, een lease-model, of een terugname-model voor leveranciers.

Participant
Ik zou niet weten.

Interviewer
Welke circulariteit maatregelen zijn er genomen gedurende de bouw van het project?

Participant
Het is lastig voor mij, ik ben hier heel weinig bij betrokken geweest. Ik heb dus geen idee.

Interviewer
In hoeverre kan het gebouwde object gedemonteerd worden voor de oogst van herbruikbare componenten?

Participant
Ik denk dat deze brug gewoon compleet gedemonteerd kan worden voor hergebruik.

Interviewer
Hoe belangrijk was het om een circulair object te creëren?

Participant
Ja enorm belangrijk. We wilden de lat zo hoog mogelijk leggen.

Interviewer
Een stelling: Het ontwerp is gemaakt voor een lange levensduur, service of leasing, hergebruik bij productie of materiaal terugwinning.

Participant
Ik durf niet zeggen of daar bij het ontwerp naar gekeken is, maar ik zou zeggen dat het voornamelijk ging om hergebruik bij productie. Maar er zijn wel wat aanpassingen en reparaties gedaan aan de componenten, het is niet 1 op 1 overgenomen. Dus ik ben het eens met deze stelling.

Interviewer
In hoeverre waren de projectspecificaties prestatiegericht en werd dit gestimuleerd?

Participant
Geen idee.

Interviewer
De ingediende tender draagt bij aan gesloten energie- en materiaal-kringlopen binnen aanvoerketens, terwijl negatieve milieueffecten en afval wordt geminimaliseerd en in het beste geval worden vermeden over de gehele levenscyclus.

Participant
Ook lastig om iets over te zeggen, want Ik heb de tenderdocumenten in het geheel niet gezien.

Interviewer
Zijn er met de leverancier afspraken gemaakt over de terugvordering van materialen na de levensduur van het object?

Participant
Weet ik niet

Interviewer
In hoeverre zijn er componenten herbruikbaar voor toekomstige projecten na de levensduur van het gebouwde object?

Interviewer
Het gebouwde object is denk ik wel grotendeels herbruikbaar.
Interviewer
Tijdens de initiatie van het project waren alle betrokken partijen gemotiveerd en droegen actief bij aan het gezamenlijke doel van het realiseren van een circulair object.

Participant
Ja, mee eens.

Interviewer
Het basisprincipe van de circulaire economie en circulair ontwerp, ‘’Ontwerp zó dat afval en vervuiling worden voorkomen’’, vormt de basis van het ontwerp van dit object.

Participant
Ja, daar ben ik het wel mee eens.

Interviewer
The projectspecificaties waren flexibel, niet-beschrijvend, en het presteren op onderdelen werd gestimuleerd ten behoeve van het project.

Participant
Weet ik niet.

Interviewer
De aanbestedingsprocedure was prestatiegericht, bevatte tools zoals life cycle approach (LCA) en life cycle costs (LCC), en criteria waren aanwezig voor het hergebruik van materialen.

Participant
Geen idee.

Participant
Dan wordt nog niet, Maar dat.

Interviewer
Welke maatregelen zijn er genomen om de bouw zelf circulair of duurzaam te maken? (Denk hierbij aan machines, uitrusting, etc.)

Participant
Weet ik niet heel specifiek, maar ik zou denken dat hier nog wel een slag te winnen is. Dat heeft er mee te maken dat het op een terrein is waar een heleboel gaande was en waar in korte tijd veel gerealiseerd moest worden. Hierdoor zijn misschien niet de meest circulaire of duurzame mogelijkheden ingezet. Maar dit is een inschatting.

Interviewer
Er is rekening gehouden met het einde van de levensduur van het object en mogelijke toekomstige doeleinden, wat materialen betreft, bij de start van dit project.

Participant
Weet ik niet helemaal zeker. Dat is nog een onderdeel dat wat mij betreft nog beter inzichtelijk gemaakt moet worden. Ik zou daarom zeggen neutraal.

Interviewer
Nu heb ik nog enkele vragen over het project in het algemeen. Waren er verschillen of opmerkelijkheden in het project proces vergeleken met een regulier bouwproject?

Participant
Nee, ik zou denken dat de initiatieffase nu wel anders is geweest omdat Dura Vermeer natuurlijk onderdeel was van het consortium dat de Floriade heeft gerealiseerd. Zij hebben daar dus in feite mogen experimenteren. Ik weet ook niet in welke mate daar een tender heeft plaatsgevonden.

Interviewer
Zijn er nog extra werkzaamheden of stappen die uitgevoerd moesten worden?

Participant
Ja, die brug moet nog wel op milieukwaliteit, kosten, MKI en LCA-achtige wijze inzichtelijk gemaakt worden.

Interviewer
Denkt u dat circulaire bouwprojecten over het algemeen duurder of goedkoper zijn dan reguliere bouwprojecten?

Participant
Ik zou voor nu in ieder geval nog zeggen dat ze duurder zijn. Maar ik denk dat er op termijn is er geen sprake meer is van duurder omdat je dan kosten gaat besparen. Nu is het nog duurder omdat er bijvoorbeeld een andere werkwijze is, er gedemonteerde materialen opgeslagen moeten worden, et

cetera. Als je straks een systeem ontwikkeld waarmee een materiaal-match van een gesloopt object automatisch gemaakt wordt met een te bouwen object, dan gaan je kosten omlaag, maar dit gaat ook al door in te zetten op digitalisering. Uiteindelijk denk ik dat het goedkoper wordt, maar dan moet het wel efficiënter. Maar kostenreductie is niet het doel, de duurzaamheidsslag is het belangrijkst.

Interviewer
Waar zouden deze extra kosten dan in zitten?

Participant
In alles, maar vooral in je logistiek en de onderlinge afstemming tussen gesloopte objecten en te bouwen objecten.

Interviewer
Wat zijn volgens u de beperkingen voor de implementatie van circulariteit in de civiele bouwsector?

Participant
Ik denk de traditionele gegroeide rollen van opdrachtgevers en aannemers. Die ketens zijn ingericht rond inkopen en prestatie op basis van een prijs. Als je dat blijft doen kun je misschien nooit een circulair project realiseren. Je moet degenen die koplopers zijn de kans geven om iets te kunnen doen. Op een gegeven moment zul je die opdracht moeten uitvragen en de ruimte bieden aan partijen om samen te werken in de initiatieffase. Als je ergens iets nieuws wil proberen, moet je misschien toch bereid zijn om andere afspraken te maken.

Interviewer
Heeft de provincie Flevoland nog de ambitie om in nabije toekomst meer circulaire projecten uit te voeren?

Participant
Jazeker

Interviewer
Dit was het interview. Bedankt voor uw tijd, moeite en kennis die u met mij heeft gedeeld.

D.3 Interview participant C

Interviewer

We zullen beginnen met het interview. We gaan kijken naar de verschillen in projectfasen tussen een circulair project en een regulier bouwproject. Tijdens dit interview bespreken we nu het circulaire bouwproject de Tweede Leven brug. Het wordt een semigestructureerd interview bestaande uit 5 delen. We starten met een algemeen deel, waarbij u uzelf voorstelt. Daarna gaan we door naar een tweede deel met enkele algemene vragen over de circulaire economie. Vervolgens focussen we op de Tweede Levenbrug. Het vierde deel bevat nog enkele algemene vragen over de Tweede Levenbrug. Tenslotte sluiten we af met wat concluderende vragen. Nu alles helder is, kunnen we van start. Wie heb ik hier tegenover mij?

Participant

Participant C. Wij als Lukassen-Brokking hebben voor Dura Vermeer constructieberekening gemaakt. Ik ben actief in de bouwwereld sinds 1996 en heb bij verschillende partijen gewerkt, totdat ik samen met een studiegenoot in 2008 een eigen bedrijf ben gestart op het gebied van civieltechnische constructies. Voor de Tweede Levenbrug zijn wij gevraagd door Dura Vermeer om de constructiewerken door te rekenen.

Interviewer

Dus uw rol in het project was dat van een adviserend constructeur?

Participant

Nou, we zijn door Dura Vermeer gevraagd toen het architectonisch ontwerp klaar was en het voorontwerp er lag. Toen zijn we erbij betrokken en hebben we alles doorgelicht, dus het constructieprincipe, de onderdelen die gebruikt konden worden, de huidige situatie, et cetera. We hebben toen een nieuw constructieprincipe opgezet om de brug met materialen in te vullen. Dus kijkende naar wat er hergebruikt moest worden, wat er eventueel beter hergebruikt kon worden en wat er niet hergebruikt kon worden en er een alternatief voor bedacht moest worden. Zo zijn we tot een gezamenlijk ontwerp gekomen.

Interviewer

Wat is volgens u de circulaire economie, En wat is uw mening daarover?

Participant

Ik denk dat niemand precies weet wat dat is. Wat ik wel weet, is dat het natuurlijk voornamelijk gaat over het hergebruik van grondstoffen en constructieonderdelen, maar ook de uitwisselbaarheid. Maar ik denk dat het de combinatie is van grondstofhergebruik, constructiehergebruik. Maar vooral ook de documentatie van alle constructieonderdelen om die weer her te gebruiken. Dat hebben wij ook gemerkt bij de Tweede Levenbrug waarbij er constructieonderdelen gebruikt zijn die gewoon niet goed gedocumenteerd zijn, waardoor je eigenlijk niet weet wat je in je handen hebt. Met de digitalisering gaande, wordt dit natuurlijk allemaal wat makkelijkere om te archiveren. Verder denk ik nog dat energie-neutraliteit ook een aspect is van de circulaire economie.

Interviewer

Wat betekent volgens u de circulaire economie voor de bouwsector?

Interviewer
Voor de bouwsector is de materiaaluitwisseling belangrijk en daardoor ook het labelen van de materialen en onderdelen, zodat de eigenschappen en kwaliteit duidelijk zijn.
Interviewer
Oké, bent u momenteel nog bezig met andere projecten die circulair zijn te noemen?

Participant
Jawel in een zin, met een herberekening van een brug. Dat is dermate circulair te noemen omdat je niet de boel afbreekt en iets nieuws bouwt, maar dat je tot het uiterste gaat om rekentechnisch aan te tonen dat de brug nog voldoet en dat eventuele maatregelen neemt. Dit is een interessant onderdeel van de circulaire economie, dus niet meteen zomaar iets weggooien, maar eerst goed kijken wat er niet goed aan is om dan eigenlijk op een andere manier toch aan de eisen van de opdrachtgever te voldoen.

Interviewer
Welk aspect van circulariteit in de bouw vindt u dan het belangrijkste?

Participant
Het belangrijkste is om gewoon het gebruik van nieuwe grondstoffen te beperken. Dus door hergebruik van grondstof of door het hergebruiken van constructieonderdelen.

Interviewer
Dan gaan we nu focussen op het project de Tweede Levenbrug. Vanuit de literatuur wordt er aangenomen dat er 6 standaard projectfasen zijn binnen een traditioneel bouwproject. Dit zijn dan de initiatiefase, ontwerpfase, specificatiefase, tenderfase, bouwfase en de gebruik, onderhoud en eind-levensduur-fase. Ben je het eens met deze indeling?

Participant
Voor nieuwbouw ben ik het eens met deze indeling. Als je gaat voor het hergebruik van constructieonderdelen, dan lopen alle fasen door elkaar heen. Dit komt omdat je te maken hebt met beschikbare onderdelen, soms kun je dit toepassen, soms ook niet. Daarnaast zit je ook nog met de levensduur, die kan ooit lager zijn dan verwacht en dan kun je deze niet gebruiken. Je moet dus concessies doen.

Interviewer
Bij welke fasen bent u betrokken geweest in het project de Tweede Levenbrug?

Participant
De ontwerpfase, de specificatiefase. De Tender was in dit geval al gebeurd, dus er is niet echt sprake geweest van een tender in dit project. Bij het bouwen zijn we ook betrokken geweest. De gebruik, onderhoud en einde-levensduur fase vloeit eigenlijk voort uit wat je hebt gebruikt aan hergebruikte materialen en de desbetreffende specificaties, deze hebben allemaal een verschillende rest-levensduur.

Interviewer
Nu ga ik per fase vragen stellen of stellingen aan u voorleggen die vervolgens beantwoord worden aan de hand van een schaal van 1 tot 5. Per vraag mag u uw antwoord natuurlijk ook voorzien van een korte toelichting. Het staat ook beschreven bij de vraag zelf, en dan mag u dit ook toelichten als u wil.

Interviewer
Waren alle betrokken partijen tijdens de initiatie van het project gemotiveerd om een circulair project te realiseren?
Participant
Ik weet het natuurlijk niet zeker, want ik ben pas later betrokken bij het project. Maar ze waren naar mijn idee wel erg gemotiveerd om een circulair project te realiseren.

Interviewer
Bent u bekend met platform CB 23?

Participant
Nee.

Interviewer
CB'23 is een platform bestaande uit verschillende partijen, waaronder onderzoekers vanuit de TU Delft, die samen de GWW-sector naar de circulaire economie op weg willen helpen. Nu heeft CB'23 zes ontwerpstrategieën geformuleerd voor het maken van een circulair ontwerp: Ontwerpen voor preventie, ontwerpen voor reductie van levenscyclusimpact, ontwerpen voor toekomstbestendigheid, ontwerpen met hergebruikte objecten, ontwerpen met secundaire grondstoffen, ontwerpen met hernieuwbare grondstoffen. Het ontwerp van de Tweede Levenbrug is gemaakt door middel van één of meerdere van de zes circulaire ontwerpstrategieën toe te passen, in hoeverre bent u het hiermee eens?

Participant
Helemaal mee eens. We werken hier met hergebruikte objecten en er is ook ontworpen voor toekomstbestendigheid. Daarnaast is het toegepaste hout in zekere zin ook een hernieuwbare grondstof, en vermindert dit de levenscyclusimpact.

Interviewer
In hoeverre waren de specificaties van de opdrachtgever, gevormd in de derde fase, flexibel en niet-beschrijvend?

Participant
Soepel en niet-beschrijvend waren ze niet, omdat al bekend was welke onderdelen gebruikt moesten worden. En die onderdelen hebben natuurlijk allemaal individuele specificaties. Daarom waren de specificaties erg vastgesteld en beschrijvend.

Interviewer

Het gebruikte aanbestedingsmodel was op basis van een product-service model, een publiek-privaat samenwerkingsmodel, een samenwerkingsmodel met meerdere partijen voor hergebruik en deelgebruik, een lease-model, of een terugname-model voor leveranciers.

Participant
Ik zou zeggen dat het samenwerkingsmodel met meerdere partijen voor hergebruik en deelgebruik is toegepast hier. Het is een volledige samenwerking, dus ik ben het er helemaal mee eens.

Interviewer
Welke circulariteit maatregelen zijn er genomen gedurende de bouw van het project?

Participant
Er zijn verschillende partijen benaderd om objecten her te gebruiken en te kijken naar wat er beschikbaar was. Dus vanaf het begin is er al gekeken naar wat er beschikbaar was omdat je circulariteit niet later kunt inbouwen natuurlijk.

Interviewer
In hoeverre kan het gebouwde object gedemonteerd worden voor de oogst van herbruikbare componenten?

Participant
Volgens mij kan de brug gewoon volledig gedemonteerd worden. Bijna alles is namelijk gemonteerd met bouten op wat kleine ankertjes na. Alleen de onderbouw zal iets lastiger zijn, gezien daar veel gelast is. Dus is zeg grotendeels herbruikbaar.

Interviewer
Gedurende de initiatie van het project, hoe belangrijk was het om een circulair object te creëren?

Participant
Helemaal mee eens

Interviewer
Het ontwerp is gemaakt voor een lange levensduur, service of leasing, hergebruik bij productie of materiaal terugwinning.

Participant
Helemaal mee eens

Interviewer
In hoeverre waren de projectspecificaties prestatiegericht en werd dit gestimuleerd?

Participant
Lastig om iets over te zeggen, maar er lag een architectonisch ontwerp met allemaal hergebruikte materialen, dus dat stimuleert wel ergens. Die intentie van circulariteit is bij iedereen aanwezig, en is constant aanwezig geweest, dus dat hoefde niet van bovenaf opgelegd te worden. Er gezamenlijk besloten om iets duurzaams te bouwen, dus het is een beetje moeilijk te beantwoorden.

Interviewer
De ingediende tender draagt bij aan gesloten energie- en materiaal-kringlopen binnen aanvoerketens, terwijl negatieve milieueffecten en afval wordt geminimaliseerd en in het beste geval worden vermeden over de gehele levenscyclus.

Participant
Mee eens

Interviewer
Zijn er met de leverancier afspraken gemaakt over de terugvordering van materialen na de levensduur van het object?

Participant
Is bij mij niet bekend.

Interviewer
In hoeverre zijn er componenten herbruikbaar voor toekomstige projecten na de levensduur van het gebouwde object?

Participant
Ja dat heeft een beetje te maken met de levensduur van de objecten die zijn toegepast en hoe lang de brug blijft liggen. Het hout is bijvoorbeeld na 10 jaar al echt klaar, de betonnen liggers zijn ook op na nog eens 50 jaar. Voor het staal hangt het af van de hoeveelheid roest die aanwezig is. Dus ik zou zeggen slecht tot gemiddeld herbruikbaar, maar dit komt gewoon omdat de materialen na een bepaalde tijd versleten zijn.

Interviewer
Tijdens de initiatie van het project waren alle betrokken partijen gemotiveerd en droegen actief bij aan het gezamenlijke doel van het realiseren van een circulair object.

Participant
Helemaal mee eens, voor zover ik erbij betrokken ben geweest.

Interviewer
Het basisprincipe van de circulaire economie en circulair ontwerp, ‘’Ontwerp zó dat afval en vervuiling worden voorkomen’’, vormt de basis van het ontwerp van dit object.

Participant
Ja, ik ben het hier mee eens.

Interviewer
The projectspecificaties waren flexibel, niet-beschrijvend, en het presteren op onderdelen werd gestimuleerd ten behoeve van het project.

Participant
Ja, ze waren dus heel erg beschrijvend omdat er eigenlijk verschillende onderdelen geoogst waren die al bekend waren. Dus oneens.

Interviewer
De aanbestedingsprocedure was prestatiegericht, bevatte tools zoals life cycle approach (LCA) en life cycle costs (LCC), en criteria waren aanwezig voor het hergebruik van materialen.

Participant
Nee, volgens mij is dat niet uitgevoerd. Dus niet van toepassing

Interviewer
Welke maatregelen zijn er genomen om de bouw zelf circulair of duurzaam te maken? (Denk hierbij aan machines, uitrusting, etc.)

Participant
Nou, het materiaal natuurlijk, maar het materieel weet ik niet.

Interviewer
Er is rekening gehouden met het einde van de levensduur van het object en mogelijke toekomstige doeleinden, wat materialen betreft, bij de start van dit project.

Participant
Oneens. We hebben nagedacht over hoe we bestaande materialen nog een keer konden gebruiken, maar we niet nagedacht over nóg een leven na deze brug. Dat is misschien nog wel een leerpunt.

Interviewer
Ik heb nog een aantal vragen die gaan over het project in zijn algemeen. Waren er verschillen of opmerkelijkheden in het project proces vergeleken met een regulier bouwproject?

Participant
Ja wat ik al zei, alle fasen lopen door elkaar keer heen. Het is niet in een rechte lijn naar het resultaat. En je moet kijken hoe je een object kunt laten passen, is het geschikt? Moet ik het anders gebruiken? Wat is de levensduur? Hoe kan ik het toepassen? Er is dus een hele interactie tussen het ontwerp en de hergebruikte onderdelen.

Interviewer

Waren er extra werkzaamheden of stappen die uitgevoerd moesten worden in dit project?

Participant
Naast het constante passen en meten, waren we ook constant berekeningen aan het uitvoeren om te checken of de beoogde gecomponeerde constructie sterk genoeg was. Daarnaast was er veel meer overleg, communicatie en onderlinge afstemming nodig dan normaal. Normaal kun je dit werk in onze rol redelijk autonoom uitvoeren, maar tijdens dit project hadden we wekelijks overleg.

Interviewer
Zijn volgens u circulaire bouwprojecten duurder of goedkoper dan regulier bouwprojecten?

Participant
Ik denk zelf ietsjes duurder.

Interviewer
Waar zitten deze extra kosten dan in, denkt u?

Participant
In ieder geval in de samenwerking door het toegenomen aantal overlegmomenten. Het ontwerp zal ook meer kosten, omdat alle onderdelen gevonden moeten worden. Vervolgens moeten deze onderdelen getransporteerd en weer ergens opgeslagen worden totdat ze gebruikt worden.

Interviewer
Heeft u de ambitie om in de toekomst meer circulaire bouwprojecten uit te voeren?

Participant
Als het op ons pad komt dan lijkt het ons weer leuk te doen. Het was een leuke uitdaging.

Interviewer
En wat denkt u dat momenteel nog beperkingen zijn voor de implementatie van circulariteit in onze sector?

Participant
De mate waarin er onderdelen beschikbaar komen zal de circulariteitsdrang beïnvloeden. Dit zal de grootste dreiging vormen.

Interviewer
Dit was het interview. Bedankt voor uw tijd, moeite en kennis die u met mij heeft gedeeld.

D.4 Interview participant D

Interviewer

De opname werkt, dus we kunnen van start gaan. Ik ga nu een semigestructureerd interview met u afnemen en dat interview wordt gebruikt voor mijn onderzoek. Het interview bestaat uit vijf delen. Eerst een algemene introductie, dan de circulaire economie in het algemeen en daarna het project de Tweede Leven brug. Tenslotte nog wat algemene vragen over het project en enkele concluderende vragen. Dus dan beginnen we nu even met een introductie. Wie heb ik hier voor mij zitten?

Participant

Ik ben participant D, bedrijfsleider bij Dura Vermeer. Daarnaast ben ik ook manager bedrijfsbureau en verantwoordelijk voor de verwerving, maar ook intrinsiek gemotiveerd door duurzaamheid en circulariteit.

Interviewer

In het project de Tweede Levenbrug vertegenwoordigt u dus de aannemer?

Participant

Ja, maar alleen aannemer is nog een beetje te smal verwoord. Ook qua pro-activiteit. Vanuit onze en mijn kant is het project ontstaan zoals die ontstaan is. Wij hebben het initiatief genomen om eerst een brug te oogsten toen we daar nog geen bestemming voor hadden. Toen we de ontwikkelopgave van de Floriade aannamen zagen we daar de kans om de brugdelen circulair in te zetten, ook al was aanvankelijk niet de opgave. Door met elkaar in gesprek te gaan hebben we daar een mooi initiatief opgezet en iets bijzonders laten ontstaan.

Interviewer

Wat voor een contractvorm hadden jullie voor dit project gebruikt? Of viel dit allemaal onder de ontwikkelopgave van het Floriade-terrein?

Participant

De meest vage contractvorm die je kunt bedenken. De constructie was zo bedacht dat het een evenemententerrein moest worden voor de Floriade, met de gedachte dat dit terrein daarna veranderd wordt in een woonwijk. Er moest dus een investering gemaakt worden in de openbare ruimte die zowel geschikt is voor de Floriade als voor de toekomstige woonwijk. Uiteindelijk is er een totale aanbieding gedaan door de ontwikkelaar, waar ook de woningbouw met opbrengsten daarvan inbegrepen zitten. Voor de aanleg van de infrastructuur is Dura Vermeer gevraagd. Er is destijds een grof budget bepaald voor de infra, met onderverdelingen in wegen, grondwerk en bruggen. In totaliteit moesten we binnen het budget blijven en kijken wat voor kaders werden meegegeven door de opdrachtgever in het plan van de Floriade. Dus voor de Tweede Levenbrug zijn er ook groffe kaders gesteld wat zorgde voor een vaag vertrekpunt. Maar dit gaf wel kansen om te kijken of je het toch naar je hand kan zetten. Welke waarde kunnen we creëren en welke kosten kunnen we optimaliseren? In een ontwikkelopgave moet hierin een goede balans zijn, het is economische invulling versus gebiedskwaliteit en verkoopwaarde.

Interviewer

Wat betekent voor u de circulaire economie? En wat is uw mening daarover?

Participant
Het eerste wat in mij opkomt is het boek over de donuteconomie. Dus ik denk dat we in eerste instantie moeten kijken met elkaar hoe we zoveel mogelijk binnen een bandbreedte blijven, als je het echt op mensniveau beschouwd. Dus in die donuteconomie is er een soort binnenring die je minimaal wilt hebben, een bepaalde levenstandaard waar je niet onder wil. En je hebt een buitenring die luxe is en te veel aanslag doet op grondstoffen en afbreuk doet aan de aarde. Dit is de bandbreedte waarin je wil blijven. Doorvertaald naar onze branche betekent het in welke mate je het gebruik van nieuwe grondstoffen kunt beperken, en in welke mate kun je dit leidend maken. Het moet natuurlijk niet doorschieten en uiteindelijk wel financierbaar blijven. Maar we moeten wel de ambitie opzetten om het niet-aanspreken van grondstoffen leidend te maken, in plaats van het oude proces waarin geld leidend is. Naarmate het wordt opgeschaald zal het ook betaalbaarder worden.

Interviewer
Bent u momenteel nog betrokken bij andere circulaire projecten?

Participant
Ja, de circulaire tender voor het project Asterpad in Amsterdam natuurlijk. Daarnaast zijn we nog bezig met een leuke opgave in Haarlem voor het Bouwlab, waar we een nieuw gebouw bouwen van circulaire materialen, afkomstig van een pand in Almere. We gebruiken hier tweede leven materialen, maar kijken ook naar het hergebruik van toegepaste materialen na de levensduur van dit gebouw. We hebben ook nog een raamcontract voor groot onderhoud met Amsterdam, hier zijn we ook actief bezig met het constant monitoren van het vrijkomende materiaal en mogelijke toekomstige toepassingen hiervoor. Tenslotte waren we ook nog bezig met een tender voor een nieuw te bouwen brug in dierentuin Artis, maar die hebben we helaas verloren. Gelukkig hebben we wel een afspraak weten te maken met de winnende partij, waardoor wij de oude brug mogen oogsten voor materialen die potentieel opnieuw ingezet kunnen worden. Dus we proberen proactief te kijken naar objecten en materialen die vrijkomen.

Interviewer
Welk aspect van circulariteit in de bouw vindt u dan het belangrijkst?

Participant
Met name het aspect van hoe we nu met elkaar wat meer wegblijven van het automatisch blijven mobiliseren van nieuwe grondstoffen. Er zit ook wel een uitdaging aan vast. Er is een flinke nieuwbouwopgave, maar om alles circulair te doen wordt lastig omdat er simpelweg niet zo veel materiaal vrijkomt.

Interviewer
We gaan door naar het naar derde deel, dit gaat weer over het project de Tweede Levenbrug op het Floriadeterrein. Ik ga nu vragen en stellingen voorleggen aan u en die kunt u dan beantwoorden aan de hand van een schaal van 1 tot 5. Dus nog even ter herhaling, wat was uw rol in het project?

Participant
Ik denk wel de rol van initiator. Dus het is allemaal begonnen met een initiatief vanuit mij om een te slopen brug te gaan oogsten. Die materialen hebben we vervolgens in een depot opgeslagen totdat ze gebruikt konden worden. Toen we de opdracht van de Floriade kregen, zag ik een kans om de geoogste materialen toe te passen. Helaas was een één op één toepassing niet mogelijk omdat de Floriade een bredere brug wilde. Doordat de productietekeningen bekend waren van de onderdelen van de oorspronkelijke burg, wisten we precies de eigenschappen en konden we er dus ook een nieuwe configuratie mee maken. Dit bleek mogelijk op een verantwoorde constructieve manier. Vervolgens hebben we er een architect bij betrokken voor het ontwerp van de brug. Zo heb ik best wel een prominente rol gehad in het initiatief en het in stand laten komen van de brug samen met de architect. Op gegeven moment heb ik wat meer afstand genomen en wat meer aan het realisatie team overgelaten om het tot een definitief uitvoeringsontwerp te brengen en het ook financieel rond te laten komen. Aan de achterkant van het project hebben we ook veel energie gestoken in het delen van deze leerervaring en kennis via de Bruggencampus. Met het delen van deze kennis ben ik momenteel nog steeds bezig, met name tijdens de kennissessies op de Floriade, het schrijven van artikelen in vakbladen en intern in de organisatie.

Interviewer
Was dit dan ook het eerste circulaire project waaraan je hebt meegewerkt en zo ja, hoe ben je op dit circulair idee gekomen?

Participant
Op deze schaal heb ik nog niet eerder aan zo'n project gewerkt. Voor mij was het destijds proeven van wat er in de markt gebeurd, waar gaat het naartoe, en laten we onze nek eens uitsteken om hier iets te laten ontstaan. Het probleem is natuurlijk dat wij als aannemers, maar ook opdrachtgevers, heel erg projectmatig georganiseerd zijn en zodra iets project overstijgend is wordt het ingewikkeld. Dus het projectteam voor de te slopen brug bij de A27 had vanuit de Rijkswaterstaat maar één opdracht; die brug moet weg. En niemand die er projectmatig mee bezig is zit erop te wachten om het ingewikkelder te maken dan dat het is. Maar dan gaan we die brug oogsten en ontstaat er iets project overstijgend, en dat zouden we vaker moeten doen om dingen verder te brengen. Wat je destijds ook wel zag is dat er steeds meer beweging kwam richting het circulaire en hebben we het toen maar gewoon gedaan. Hiermee hebben we nu iets moois laten ontstaan en referentie opgebouwd qua circulaire bruggenbouw. En met deze referentie zijn wij momenteel ook geselecteerd voor een ander circulair project.

Interviewer
Vanuit de literatuur zijn er 6 fasen in een traditioneel bouwproject, dit zijn de initiatiefase, ontwerpfase, specificatiefase, tenderfase, bouwfase en de gebruik, onderhoud en eind-levensduur-fase. Ben je het eens met deze indeling voor traditionele projecten?

Participant
In basis ben ik het ermee eens. Als je de Tweede Levenbrug op andere plekken een kans wil geven, moet je er heel vroeg bij zijn. Hoe verder de fasen gevorderd zijn, des te moeilijker het wordt om het alsnog te bewerkstelligen. Je moet het vroeg inpluggen om draagvlak te creëren, dat ook heel veel tijd kost. In onze sector zijn we gewend meteen te starten na het aannemen van een project, maar hier moet je dus

voorafgaand aan de opdracht al beginnen. Het kan jaren duren, omdat er een heel politiek proces mee vasthangt om draagvlak te creëren. De initiafase is voor mij wel een eyeopener geweest omdat daar het fundament moet liggen voor circulariteit, maar ook dat het een heel lang traject kan zijn en dat dit in de tijd ook nog wel kan veranderen door veranderende bestuursorganen. Dus in de basis ben ik het eens met je fasen, maar ik wil nadrukkelijk benoemen dat de initiatiefase erg belangrijk is.

Interviewer
Ben je bij alle fasen in dit project betrokken geweest?

Participant
Ja misschien niet helemaal vanaf het begin, want er lag natuurlijk al een initiatief, een soort aanzet waar uiteindelijk gelukkig veel bewegingsruimte in zat. Dus deels de initiatiefase en dan eigenlijk alle andere fasen ook. Ik zit alleen even met die tenderfase, want we hebben niet echt een tenderfase Het is in een één op één traject iets anders. Dus je kunt in die fasen onderscheid maken tussen één op één trajecten en aanbestedingstrajecten.

Interviewer
Nu gaan we gewoon iedere fase doorlopen. Ik ga stellingen voorleggen of vragen stellen en dan zit er vervolgens een bepaalde gradatie aan vast. Per vraag geeft u dus een score, en die mag dan nog voorzien worden van een korte toelichting. We starten met de initiatiefase. Waren alle betrokken partijen tijdens initiatie van het project gemotiveerd om een circulair project te realiseren?

Participant
Veel van de betrokken partijen waren erg gemotiveerd. Alleen hadden we ook een soort interne opdrachtgever, de ontwikkelaar, die toch wel erg financieel gestuurd was en die dus continu overtuigd moest worden. De ontwikkelaar was dus niet tot licht gemotiveerd.

Interviewer
CB'23 is een platform bestaande uit verschillende partijen, waaronder onderzoekers vanuit de TU Delft, die samen de GWW-sector naar de circulaire economie op weg willen helpen. Nu heeft CB'23 zes ontwerpstrategieën geformuleerd voor het maken van een circulair ontwerp: Ontwerpen voor preventie, ontwerpen voor reductie van levenscyclusimpact, ontwerpen voor toekomstbestendigheid, ontwerpen met hergebruikte objecten, ontwerpen met secundaire grondstoffen, ontwerpen met hernieuwbare grondstoffen. Het ontwerp van de Tweede Levenbrug is gemaakt door middel van één of meerdere van de zes circulaire ontwerpstrategieën toe te passen, in hoeverre bent u het hiermee eens?

Participant
Nadrukkelijk het ontwerpen met hergebruikte materialen is toegepast. Dus helemaal mee eens.

Interviewer
In hoeverre waren de specificaties van de opdrachtgever, gevormd in de derde fase, flexibel en niet-beschrijvend?

Participant

Ik zou zeggen licht vastgesteld en beschrijvend.

Interviewer
Het gebruikte aanbestedingsmodel was op basis van een product-service model, een publiek-privaat samenwerkingsmodel, een samenwerkingsmodel met meerdere partijen voor hergebruik en deelgebruik, een lease-model, of een terugname-model voor leveranciers.

Participant
Ik zou zeggen publiek private samenwerking, dus eens.

Interviewer
Welke circulariteit maatregelen zijn er genomen gedurende de bouw van het project?

Participant
Er is niet echt gestuurd op het inzetten van alleen maar emissie loos materieel. Wat wel interessant is, is dat we om de brug te kunnen bouwen een zand dam in de watergang aangebracht hebben om er goed bij te kunnen vanwege het hijswerk en de benodigde zware kraan, maar ook om gewoon veilig te werken. Maar ja, is dat een circulaire maatregel?

Interviewer
In hoeverre kan het gebouwde object gedemonteerd worden voor de oogst van herbruikbare componenten?

Interviewer
Grotendeels herbruikbaar. Als je het helemaal nieuw had gebouwd waarbij je ook op demontabelheid had gestuurd, dan zou het compleet herbruikbaar zijn. Het object kan uit elkaar gehaald worden, maar niet op de meest gewenste manier.

Interviewer
Wat is eigenlijk de beoogde levensduur van de brug?

Participant
Op de ligger hebben we intensief onderzoek gedaan en uiteindelijk ook betonherstel uitgevoerd om uiteindelijk een ontwerplevensduur van 50 jaar te kunnen garanderen. Dus theoretisch gaan de liggers nog 50 jaar mee, en dit geldt ook voor het staal trouwens. Alleen het hout is wat lastiger, dat is niet formeel vastgesteld, maar uitgaande van het type hardhout zou het nog 15 tot 20 jaar mee moeten gaan. Voor het hout hebben we er maximaal op gestuurd om ventilatie rondom houtverbindingen te realiseren om de levensduur te verlengen. De spoorbielzen voor de leuningen zijn ook op zo'n manier gedimensioneerd dat wanneer de bovenkant zwaar is aangetast, er nog een stuk afgeschaafd kan worden.

Interviewer
Hoe belangrijk was het om een circulair object te creëren?

Participant

De opdrachtgever vond circulariteit in de opgave van de Floriade heel erg belangrijk. Daarom hebben ze ook die brug zo gevormd. En daarom kreeg ons initiatief, dat vanuit onze eigen intrinsieke motivatie kwam, heel snel een draagvlak. Dus ik denk uiteindelijk wel erg belangrijk.

Interviewer
Het ontwerp is gemaakt voor lange levensduur, service of leasing, hergebruik bij productie of materiaal terugwinning.

Participant
Ik zou zeggen allemaal niet, want het ontwerp is gemaakt om zoveel mogelijk hergebruikte materialen in te zetten. Dus dan maar helemaal oneens. Dit komt een beetje over alsof er een nieuw ontwerp gemaakt moet worden en je rekening moet houden met één van die factoren, terwijl wij er juist voor gekozen hebben om hergebruikte materialen toe passen, om vervolgens ontdekkend te ontwerpen.

Interviewer
In hoeverre waren de projectspecificaties prestatiegericht en werd dit gestimuleerd?
Participant
Beperkt, een beetje. Vanuit de ontwikkelaar was het heel erg financieel gedreven, bovenliggend vanuit de opdrachtgever natuurlijk. Er lag natuurlijk een heel abstract vertrekpunt, er waren niet hele duidelijk projectspecificaties.

Interviewer
Heeft de ontwikkelaar een actieve rol gehad bij de ontwikkeling van deze brug? Of meer de rol van een geldschieter?

Participant
Ja, uiteindelijk was de projectontwikkelaar degene die ons betaalde en daar werd dus ook op gestuurd. Het moest zo goedkoop mogelijk. Dus dat was wel continu proberen om in balans te komen, want er zaten ook echt wel economische voordelen aan het hergebruik. Maar om onze totale ambitie af te dwingen met tweede leven materialen ging niet altijd even makkelijk.

Interviewer
De ingediende tender draagt bij aan gesloten energie- en materiaal-kringlopen binnen aanvoerketens, terwijl negatieve milieueffecten en afval wordt geminimaliseerd en in het beste geval worden vermeden over de gehele levenscyclus.

Participant
Vind ik lastig om te beantwoorden want we hebben niet echt een tenderfase in dit traject gehad. We hebben ooit als Dura Vermeer onszelf als hoofdaannemer aangeboden voor de Floriade. Die hebben wij verloren en de opdracht ging naar Amvest, en die hebben ons vervolgens als partner gevraagd in deze ontwikkeling. Uiteindelijk was deze brug hier ook onderdeel van en was het eerste idee een houten brug. Uiteindelijk hebben wij het initiatief genomen om dit circulair uit te gaan voeren. Het is dus een ander proces geweest.

Interviewer
Zijn er met de leverancier afspraken gemaakt over de terugvordering van materialen na de levensduur van het object?

Participant
Nee.

Interviewer
In hoeverre zijn er componenten herbruikbaar voor toekomstige projecten na de levensduur van het gebouwde object?

Participant
Ik denk dat al het hout geen waarde meer heeft, want als de tijd echt zijn werk doet, dan is dat hout dusdanig gedegradeerd dat het niet meer in te zetten is. Staal zou een beetje discutabel zijn, maar de betonnen liggers blijven natuurlijk wel interessant om te kijken hoe je die 1) tijdens de levensduur blijft monitoren en op niveau blijft houden en 2) of ze straks nog steeds goed zijn. Ze zijn natuurlijk al 50 jaar oud. We hebben aangetoond dat ze nog 50 jaar meekunnen, dan zijn ze straks in het totaal 100 jaar oud. Het is dan ook nog onbekend welke factoren dan invloed hebben op de levensduur, want er zijn niet zoveel voorgespannen betonnen liggers die ouder zijn dan 100 jaar. Maar misschien zijn nog wel aantoonbaar om straks weer in te zetten. Dus ik zou zeggen dat het slecht herbruikbaar is.

Interviewer
Tijdens de initiatie van het project waren alle betrokken partijen gemotiveerd en droegen actief bij aan het gezamenlijke doel van het realiseren van een circulair object.

Participant
Eens, met uitzondering van de ontwikkelaar.

Interviewer
Het basisprincipe van de circulaire economie en circulair ontwerp, ‘’Ontwerp zó dat afval en vervuiling worden voorkomen’’, vormt de basis van het ontwerp van dit object.

Participant
Eens.

Interviewer
The projectspecificaties waren flexibel, niet-beschrijvend, en het presteren op onderdelen werd gestimuleerd ten behoeve van het project.

Participant
Eens

Interviewer

De aanbestedingsprocedure was prestatiegericht, bevatte tools zoals life cycle approach (LCA) en life cycle costs (LCC), en criteria waren aanwezig voor het hergebruik van materialen.

Participant
Ja eigenlijk niet, want er was ook geen tendervraag.

Participant
Eigenlijk waren die er niet, dus heel seja en al cc was waren geen geen prestatie factoren.

Interviewer
Welke maatregelen zijn er genomen om de bouw zelf circulair of duurzaam te maken? (Denk hierbij aan machines, uitrusting, etc.)

Participant
Beperkt.

Interviewer
Er is rekening gehouden met het einde van de levensduur van het object en mogelijke toekomstige doeleinden, wat materialen betreft, bij de start van dit project.

Participant
Niet echt, dus oneens.

Interviewer
Nu heb ik nog enkele vragen over het project in het algemeen. Waren er verschillen of opmerkelijkheden in het project proces vergeleken met een regulier bouwproject?

Participant
Eén, het was al een bijzondere opgave in de samenwerking, meer een ontwikkelopgave die toch niet zo vaak voorkomt. Maar het bijzondere daarvan was dat het vanaf het begin wel heel veel kansen gaf en het bijzondere daarin was dan dat er heel veel mee bewogen werd met de hoofdambitie om hier gewoon een Tweede Levenbrug te maken. Dus met name vanuit de gemeente, de betrokken stedenbouwkundige en de architect die het vanaf de voorkant mee heeft opgezet. Het is wel bijzonder om mee te maken dat iedereen zo heeft meebewogen om dit object op deze manier gebouwd wordt, opgeleverd wordt en in het beheer areaal komt.

Participant
Is wel heel bijzonder dat hij zo heeft meebewogen om om de ambitie met elkaar waar te maken én dat bijvoorbeeld ervoor te zorgen dat dit ook gewoon op deze manier gebouwd mag worden opgeleverd wordt en ook in een areaal komt, hè? Voor hetzelfde geld, zegt iemand, Maar dat wil ik niet als beheerder.

Interviewer

Zijn er nog extra werkzaamheden of stappen die uitgevoerd moesten worden?

Participant
Toen wij met dit idee kwamen moesten wij langs een zogenoemd kwaliteitsteam. Dit was een team van de Floriade dat alle onderdelen beoordeeld of het past in het totale plaatje. Dit team bestaat uit gerenommeerde stedenbouwkundigen, architecten en landschapsarchitecten. Door een goed plaatje neer te leggen, draagvlak te creëren en een goed verhaal te hebben wisten we het kwaliteitsteam erg enthousiast te maken over ons aangedragen ontwerp. Dus die horde hebben we wel moeten nemen.

Interviewer
Denkt u dat circulaire bouwprojecten over het algemeen duurder of goedkoper zijn dan reguliere bouwprojecten?

Participant
Er zijn twee dingen die dan natuurlijk spelen. Eén, heb je best wel te maken met mensen die denken dat onderdelen uit een geoogst object gratis zijn. Dat is niet zo, er gaat veel energie in zitten om een component gefundeerd op een andere plek toe te mogen passen. Dus de kosten zitten op andere plekken dan dat we gewend zijn en kan ook op onderdelen verschillen. Daarnaast doen we ook nog veel leerervaring op met elkaar, wat ook gewoon geld kost. Even op onderdelen beschouwd, wij hebben die geoogste liggers in een depot gezet waarvoor we ook moesten betalen. Er zit ook het nodige leergeld in van dingen die we nu iets minder handig hebben gedaan, maar de volgende keer wel goed kunnen doen. Maar dan kijk je dus niet naar het grotere plaatje en de duurzame impact en het voorkomen van het effect van het aanspreken van nieuwe grondstoffen. Dus het bewerken van materialen kost geld, het is arbeid en arbeid is gewoon duur, ook belastingtechnisch. Terwijl je over grondstoffen relatief weinig belasting betaald.

Interviewer
Wat zijn volgens u de beperkingen voor de implementatie van circulariteit in de civiele bouwsector?

Participant
De grote beperkingen zitten in het anders werken, het andere proces waarin veel mensen nog aan moeten wennen. Het vraagt om een andere manier van samenwerken en contracteren.

Interviewer
Deze vraag is natuurlijk al deels beantwoordt, maar heeft u de ambitie om in nabije toekomst meer circulaire projecten uit te voeren?

Participant
Uiteraard.

D.5 Interview participant E

Interviewer

Ik ga nu een semigestructureerd interview met u afnemen en dat interview wordt gebruikt voor mijn onderzoek. Het interview bestaat normaliter uit vijf delen. Eerst een algemene introductie, dan de circulaire economie in het algemeen en daarna het project proces van de Tweede Levenbrug. Tenslotte nog wat algemene vragen over het project en enkele concluderende vragen. Dan beginnen we nu even met een introductie. Met wie heb ik het genoegen?

Participant

Ik ben participant E, directeur en eigenaar van Meerdink bruggen en 30 jaar actief in de bouwsector. Wij ontwerpen, prefabriceren en plaatsen brugconstructies in hout, staal, composiet en beton in de kleine en middelgrote projecten. Wij werken in 80-90% van de gevallen als hoofdaannemer in een project, en dan vervolgens weer voor 90% voor gemeentelijke overheden. Dit doen we met een groep van 16 personen.

Interviewer

Wat betekent voor u de circulaire economie? En wat is uw mening daarover?

Participant

Dat we de aarde niet meer vervuilen en uitputten op wat voor manier dan ook. Dus grondstoffen gebruiken die oneindig zijn, bio-based materialen, en dat doen met een schoon proces, dus nul CO_2-uitstoot.

Interviewer

Wat denk je dat de circulaire economie gaat betekenen voor de bouwsector?

Participant

Laten we beginnen met het energieneutraal te doen, de CO_2-uitstoot moet simpelweg naar nul. Hoe we dat gaan doen is een hele grote uitdaging. We moeten toe naar compleet hernieuwbare grondstoffen, dat is mijn visie. De grondstoffen die nu al in omloop zijn, dus staal en beton, die moet je in een gesloten cirkel steeds opnieuw te gebruiken.

Interviewer

Vind u het gebruik van bio-based materialen dan ook het belangrijkste aspect van circulariteit in de bouwsector?

Participant

Ja. Ik denk dat we wat dat betreft terug moeten naar het pre-industriele tijdperk met de technologie van vandaag. Dat tijdperk was nog wel echt biobased. Dus kunststoffen zijn uit den bozen, want dat is gewoon een fossiel product.

Interviewer

Zijn jullie momenteel bezig met een ander circulair project?

Participant
Jazeker, op dit moment hebben we drie bouwteams lopen die een hoge of zeer hoge mate van circulariteit nastreven.

Interviewer
Wat maakt deze projecten dan circulair?
Participant
Proberen het hele proces uit te voeren zonder enige uitstoot en/of energieneutraal te doen. Eén van de projecten bestaat uit alleen maar bio-based materialen. Het tweede project is een verkeersbrug bestaand uit hout, staal en beton. Voor de stalen liggers hebben we hergebruikte liggers gebruikt die nog uit een oud project komen. Het dek is hardhout, dus bio-based. En het beton is voor een groot deel herwonnen uit bestaande constructies. Het derde project gaan we realiseren uit zowel nieuw als hergebruikt hout. Alles bij elkaar hebben we zo'n 25 projecten uitgevoerd die hergebruikte componenten bevatten.

Interviewer
Focussen jullie je dan ook op dit soort circulair projecten?

Participant
Ja. Wij bestaan al 100 jaar en onze basis is gelegd op hout. Wij hebben ook een zusterbedrijf, een houtverwerker. Het is voor ons dus ook makkelijk om bio-based te werken.

Interviewer
Dan gaan we ons nu focussen op het project de Tweede Levenbrug op het Floriadeterrein. Wat was de rol van uw partij in dit project?

Participant
Wij zaten vanaf het begin aan tafel voor het ontwerp van de brug, voor de detailering en voornamelijk het hout. Dus wij hebben de hulpliggers, brugdek, bovenstijlen en bankjes gedaan.

Interviewer
Vanuit de literatuur zijn er 5 componenten in een traditioneel bouwproject, dit zijn de initiatie, ontwerp, tender, bouw en het gebruik en onderhoud. Ben je het eens met deze indeling voor traditionele projecten?

Participant
Ja, voor een traditioneel project wel. Dit project liep een beetje door elkaar heen. Je begint met je materiaal en dan ga je met je materialen je ontwerp maken. En het was een bouwteam, dus dat proces liep daardoor ook wat anders.

Interviewer
Het project is dus ook gemaakt in de vorm van een bouwteam?

Participant
Ja. Tenminste, misschien dat het vanuit Dura Vermeer niet zo benoemd wordt, maar zo is het wel verlopen.

Interviewer
Bij welke componenten bent u betrokken geweest?

Participant
Initiatie en ontwerp.

Interviewer
CB'23 is een platform bestaande uit verschillende partijen, waaronder onderzoekers vanuit de TU Delft, die samen de GWW-sector naar de circulaire economie op weg willen helpen. Nu heeft CB'23 zes ontwerpstrategieën geformuleerd voor het maken van een circulair ontwerp: Ontwerpen voor preventie, ontwerpen voor reductie van levenscyclusimpact, ontwerpen voor toekomstbestendigheid, ontwerpen met hergebruikte objecten, ontwerpen met secundaire grondstoffen, ontwerpen met hernieuwbare grondstoffen. Is het ontwerp voor de Wisenniabrug
gemaakt door middel van één of meerdere van de zes circulaire ontwerpstrategieën toe te passen?

Participant
Ontwerpen voor reductie van levenscyclusimpact, ontwerpen met hergebruikte objecten, ontwerpen met secundaire grondstoffen en ontwerpen met hernieuwbare grondstoffen zijn toegepast.

Interviewer
In hoeverre waren de specificaties van de opdrachtgever, gevormd in de derde fase, flexibel en niet-beschrijvend?

Participant
Lichtelijk vastgesteld en beschrijvend.

Interviewer
Was het gebruikte aanbestedingsmodel was op basis van een product-service model, een publiek-privaat samenwerkingsmodel, een samenwerkingsmodel met meerdere partijen voor hergebruik en deelgebruik, een lease-model, of een terugname-model voor leveranciers?

Participant
Publiek private samenwerking was van toepassing.

Interviewer
Welke circulariteit maatregelen zijn er genomen gedurende de bouw van het project?

Participant
Wij proberen als Meerdink zijnde standaard zonder CO_2-uitstoot te werken. Onze grondstoffen, dus hout, wordt door middel van niet-fossiele brandstoffen naar ons bedrijf in Winterswijk verstuurd. Onze transporteurs rijden op HVO(100). Wij tanken op ons terrein, met de brandstofvoertuigen, ook HVO(100). Daarnaast is al ons materieel elektrisch. Ons hele dakoppervlak ligt vol met zonnepanelen,

waardoor we energie-positief zijn. Wij prefabriceren het meeste bij ons in de fabriek. Op de bouw zelf heeft de autolaadkraan gebruik gemaakt van HVO(100).

Interviewer
In hoeverre kan het gebouwde object gedemonteerd worden voor de oogst van herbruikbare componenten?

Participant
Grotendeels herbruikbaar.

Interviewer
Gedurende de initiatie van het project, hoe belangrijk was het om een circulair object te creëren?

Participant
Het was erg belangrijk om teen circulair object te creëren.

Interviewer
Is het ontwerp gemaakt voor een lange levensduur, service of leasing, hergebruik bij productie of materiaal terugwinning?
Participant
Nee, niet echt.

Interviewer
In hoeverre draagt de ingediende tender bij aan gesloten energie- en materiaal-kringlopen binnen aanvoerketens, terwijl negatieve milieueffecten en afval wordt geminimaliseerd en in het beste geval worden vermeden over de gehele levenscyclus?

Participant
Daar droeg de tender aan bij doordat de materiaal kringloop wordt gesloten.

Interviewer
In hoeverre waren de projectspecificaties prestatiegericht en werd dit gestimuleerd?

Participant
Prestatie werd wel erg gestimuleerd in de specificaties.

Interviewer
Draagt de ingediende tender draagt bij aan gesloten energie- en materiaal-kringlopen binnen aanvoerketens, terwijl negatieve milieueffecten en afval wordt geminimaliseerd en in het beste geval worden vermeden over de gehele levenscyclus?

Participant
Ja, de tender draagt bij aan de gesloten materiaal kringloop.

Interviewer
Zijn er met de leverancier afspraken gemaakt over de terugvordering van materialen na de levensduur van het object?

Participant
Nee, maar we hebben het hier natuurlijk al over hergebruikte materialen.

Interviewer
Maar er zijn dus geen plannen gemaakt om de materialen nog een keer te gebruiken?

Participant
Nee, er zijn geen concrete afspraken over, maar ik sluit het niet uit. De toekomst zal moeten uitwijzen of het mogelijk is.

Interviewer
In hoeverre zijn er componenten herbruikbaar voor toekomstige projecten na de levensduur van het gebouwde object?

Participant
Gemiddeld tot grotendeel herbruikbaar. Het Azobé zou nog wel een ronde mee kunnen, maar de eikenhouten leuning niet.

Interviewer
Waren tijdens de initiatie van het project alle betrokken partijen gemotiveerd en droegen ze actief bij aan het gezamenlijke doel van het realiseren van een circulair object?

Participant
Ja, alle partijen waren gemotiveerd om een circulair object te creëren.

Interviewer
Het basisprincipe van de circulaire economie en het circulair ontwerp is: ‘’Ontwerp zó dat afval en vervuiling worden voorkomen’’. Vormt dit principe ook de basis van het ontwerp van dit object?

Participant
Ja, daar ben ik het mee eens.

Interviewer
Waren de projectspecificaties flexibel, niet-beschrijvend, en werd het presteren op onderdelen gestimuleerd ten behoeve van het project?

Participant
Ja.

Interviewer
Was de aanbestedingsprocedure prestatiegericht? Bevatte tools zoals life cycle approach (LCA) en life cycle costs (LCC)? Waren er criteria aanwezig voor het hergebruik van materialen?

Participant
Er was geen tenderprocedure aanwezig in dit project.

Interviewer
Is er rekening gehouden met het einde van de levensduur van het object en mogelijke toekomstige doeleinden bij de start van dit project?

Participant
Niet echt. Daarnaast heeft het toegepaste eikenhout een geringe levensduur.

Interviewer
Nu heb ik nog enkele vragen over het project in het algemeen. Waren er verschillen of opmerkelijkheden in het project proces vergeleken met een regulier bouwproject?

Participant
Je start met het verzamelen van je materialen en dan ga je pas ontwerpen. Maar dit proces loopt eigenlijk ook door elkaar omdat je telkens nieuw materiaal zoekt en vindt. Het is een heel dynamisch proces van materiaal zoeken en ontwerpen.

Interviewer
Zijn er nog extra werkzaamheden of stappen die uitgevoerd moesten worden?

Participant
Het is veel intensiever en complexer, omdat je tegelijkertijd je materiaal verzamelt en ontwerpt.

Interviewer
Denkt u dat circulaire bouwprojecten over het algemeen duurder of goedkoper zijn dan reguliere bouwprojecten?

Participant
Veel duurder.

Interviewer
Waar zouden deze extra kosten dan in zitten?

Participant
Niet in het materiaal. Het materiaal zelf is in het beginsel goedkoper. Maar het opwerken van het materiaal naar een bruikbaar en toepasbaar materiaal kost veel energie, wat zorgt voor hogere kosten.

Je zou ervoor kunnen kiezen om deze bewerking niet te doen, maar dat gaat dan wel een negatieve impact hebben op de levensduur van je object.

Interviewer
Wat zijn volgens u de beperkingen voor de implementatie van circulariteit in de civiele bouwsector?

Participant
De mentaliteit. Kleine bruggen worden al vaak uitgevoerd in bio-based materialen, maar van grotere verkeersbruggen zijn we gewend deze uit te voeren in beton en staal, terwijl juist deze bruggen ook prima in hout kunnen. Kijk naar bijvoorbeeld Noorwegen, daar zijn de grotere en zwaardere verkeersbruggen ook gewoon in hout uitgevoerd. Het is ook een kwestie van de mensen opleiden, de ontwerpers opleiden, de constructeurs opleiden om ook andere materialen behalve beton en staal toe te passen.

Interviewer
Heeft Meerdink bruggen nog de ambitie om in nabije toekomst meer circulaire projecten uit te voeren?

Participant
Ja, absoluut. We moeten met z'n allen wat anders en het is een hoop pionieren, maar we kunnen hiermee de wereld een stukje duurzamer maken.

Interviewer
Dit was het interview. Bedankt voor uw tijd, moeite en kennis die u met mij heeft gedeeld.

D.6 Interview participant F

Interviewer

De opname is gestart, dus we kunnen beginnen. Ik ga nu een semigestructureerd interview met u afnemen en dat interview wordt gebruikt voor mijn onderzoek. Het interview bestaat uit vijf delen. Eerst een algemene introductie, dan de circulaire economie in het algemeen en daarna het project de Tweede Leven brug. Tenslotte nog wat algemene vragen over het project en enkele concluderende vragen. Dus dan beginnen we nu even met een introductie. Wie heb ik hier voor mij zitten?

Participant 1

Ik ben participant F1, projectleider bij de staalbouw en zelf lasdeskundige. Bij de Tweede Levenbrug heb ik een commerciële rol gehad en participant F2 een technisch inhoudelijke rol, en samen hebben wij vanuit Anton Constructiewerken dit project geleid. Momenteel ben ik al 25 jaar actief in de bouwsector, dus ik heb het hele proces meegemaakt van het aanmodderen tot het steeds serieuzer aanpakken van projecten op het gebied van duurzaamheid en nu dus het circulaire.

Participant 2

Ik ben participant F2, ik ben voor dit project samen met Dura Vermeer verantwoordelijk geweest voor de uitvoering. Dus participant F1 heeft de commerciële en theoretische opzet gedaan en ik heb verder de praktijk compleet begeleid tot aan de oplevering. Ik ben nu zo'n 8 jaar actief in de bouwwereld.

Interviewer

Dus kort samengevat, Joost was de commerciele projectleider en Tom de projectleider voor de uitvoering?

Participant 1

Ja klopt, maar we een projectgroep opgericht, dus van daaruit hebben wij dit project uitgevoerd. Deze groep bestond uit Anton Constructiewerken, Dura Vermeer, Meerdink bruggen en Lukassen-Brokking. We zijn gestart met een schets en toen hebben we dat vertaald naar een ontwerp, alleen niet-circulair gericht, niet circulair haalbaar. Je kunt pas circulair werken als je weet wat je hebt. Waar ook wel eens discussie over ontstaat is dat de staalbouw al circulair is, want staal wat we over hebben is schrot, en schrot gebruiken we weer als grondstof voor nieuw staal.

Interviewer

Het eerste deel hebben we nu afgerond. Dan gaan we verder naar de circulaire economie. Wat betekent de circulaire economie voor jullie en wat is jullie mening daarover?

Participant 2

Ik denk dat de circulaire economie op dit moment in een startende fase is. Ik denkt dat in de bouw, zeker met de steeds strenger wordende eisen, het moeilijker wordt om circulariteit op te zetten. Voor het stalen materialen is het namelijk zo dat certificaten en herkomst bekend zijn, daarnaast moet het materiaal de juiste afmetingen hebben. Er is in staal een dusdanige hoeveelheid diversiteit die het moeilijk maakt om dingen her te gebruiken. In mijn ogen kun je staalconstructies alleen circulair gebruiken als je weet wat je op dat moment hebt en daar vervolgens mee gaat ontwerpen. Maar wat is circulair kun je je ook weer afvragen. In onze ogen is circulair niet een partij staal wat te groot ingekocht is, waarvan 20% overblijft en die hoeveelheid vervolgens in een ander project wordt toegepast.

Participant 1

We hebben wel eens het idee dat vanuit de bouw het staal dat overblijft, nadat er te veel besteld is, wordt hergebruikt om het vervolgens circulair te noemen. Dat is geen circulair staal, want het is nooit als staalconstructie gebruikt. Als ik circulariteit in de breedste zin bekijk, wordt het gezien als een manier waarmee geld wordt bespaard, daar geloof ik niet in. Wij, de mensen, moeten veel meer nadenken over wat we doen, bijvoorbeeld minder vliegen, minder plastic gebruiken, etc. Maar dit alles levert geen geld op, althans nu nog niet. De grootste verandering die er moet gebeuren is dat wij zelf anders moeten gaan denken. De basis is simpel, wat wil je maken? Wat heb je aan materiaal liggen? En dan moet je die twee dingen met elkaar combineren in een ontwerp.

Participant 2

Een architect zal concessies moeten doen in zijn ontwerp. Als je iets circulair wilt maken, zal het niet altijd het initiële gewenste uiterlijk krijgen, maar wel het hoofddoel. En dan is de uitstraling ondergeschikt.

Participant 1

Mag ik de vraag terugstellen? Wat vind jij circulariteit?

Interviewer

Voor mij is circulariteit het ontwerpen en opereren waarin wij onze afvalkringen helemaal sluiten en waarin wij afval niet meer als afval zien, maar als nieuwe componenten en grondstoffen. i Participant 1

Participant 1

Wat is het doel? Waarom wil je dat?

Interviewer

In eerste instantie om onze CO2-uitstoot te verlagen, onze sector is tenslotte een van de meest vervuilende sectoren. Daarnaast is de toenemende schaarste van grondstoffen ook een goede reden om over te schakelen naar een circulaire economie.

Participant 1

Dat ja, zo zien wij dat ook wel. Alleen geloof ik nog niet in een commercieel doel, je doet het om de wereld te verbeteren, niet omdat je er geld aan gaat verdienen. Er is een afvalverwerker, GP groot, die nu al veel producten maakt van ingezameld plastic afval en dat vervolgens weer verkoopt. Daarvan gaat dan een deel van de opbrengst naar de productiekosten en een ander deel gaat naar onderzoek naar circulariteit en ontwikkelingen om meer her te gebruiken. Dit werkt maximaal als mensen de afvalstromen gaan beheersen. Het staal eruit halen gaat makkelijk, maar het plastic is lastig en daar valt denk ik de grootste slag te halen. Wij als staalbouwers gebruiken ons oude staal al in nieuw staal, het enige wat wij kunnen doen is het lichter uitvoeren van onderdelen, dus minder staal gebruiken. Wat ook mogelijk is, is bij iedere stalen balk een certificaat opstellen en stempel plaatsen, dat bewaard wordt gedurende de levensduur van een object. Als je dit doet, dan zou je na de sloop deze balken weer kunnen inzetten, en is het circulair. Hier zie ik wel toekomst in.

Interviewer
Is die registratie van die balken dan het belangrijkste aspect van circulariteit In de bouwsector denk je?

Participant 2
Ja, registratie is alles. Zeker in de staalbouw mogen wij geen constructie leveren zonder dat het voldoet aan een aantal certificaten, hierin is de materiaal samenstelling ook erg belangrijk en dit moet je kunnen aantonen. Als je nog een stapje verder gaat, bijvoorbeeld executieklasse 3, dan moet je zelfs in een constructie ieder los onderdeeltje stempelen vanuit een materiaalcertificaat, waardoor het dus compleet traceerbaar is.

Interviewer
Zijn jullie momenteel nog bezig met andere circulaire projecten?

Participant 1
Nee, niet echt. We hergebruiken wel tijdelijke stutconstructies, dus dat zou circulair genoemd kunnen worden.

Interviewer
We gaan door naar het naar derde deel, dit gaat weer over het project de Tweede Levenbrug op het Floriadeterrein. Ik ga nu vragen en stellingen voorleggen aan u en die kunt u dan beantwoorden aan de hand van een schaal van 1 tot 5. Dus nog even ter herhaling, wat was jullie rol in het project?

Participant 1
Onderaannemer van Dura Vermeer.

Interviewer
Uit mijn literatuuronderzoek is gebleken dat er zes standaard fasen waar een project doorheen gaat. De initiatiefase, ontwerpfase, specificatiefase, tenderfase, bouwfase en de gebruik, onderhoud en eind-levensduur-fase. Zijn jullie het eens met deze indeling voor een traditioneel bouwproject?

Participant 1
Ja, dit is altijd zo geweest.

Interviewer
Bij welke fasen zijn jullie betrokken geweest?

Participant 2
We kwamen bij fase 3 denk ik binnen, maar we zijn teruggegaan naar fase twee om een stukje opnieuw te doen.

Participant 1
Maar ik moet je wel zeggen dat deze traditionele indeling niet van toepassing is bij circulaire projecten denk ik. Je moet al voor fase 1 aan boord komen bij zo'n project als staalbouwer.

Interviewer
Hoe ziet u dan de indeling van de projectfase in een circulair project voor u?

Participant 1
De klant moet eerst kijken wat ze willen. Daarna komt een tender en daarin wordt een bouwteam opgezet met alle betrokken partijen.

Participant 2
Ja, en dan zou het allermooiste eigenlijk zijn dat de opdrachtgever zelf het materiaal heeft of weet waar het te vinden is. Omdat je anders krijgt dat ieder bouwteam met een compleet ander idee komt wat niet met elkaar te vergelijken is, en je dus geen opdracht kunt toewijzen. De opdrachtgever zal dus eerst moeten zoeken naar het materiaal waarmee gebouwd kan worden. De inkoop moet meer bij de opdrachtgever liggen.

Interviewer
Nu gaan we gewoon iedere fase doorlopen. Ik ga stellingen voorleggen of vragen stellen en dan zit er vervolgens een bepaalde gradatie aan vast. Per vraag geeft u dus een score, en die mag dan nog voorzien worden van een korte toelichting. Deze gaat over de initiatiefase. Waren alle betrokken partijen tijdens initiatie van het project gemotiveerd om een circulair project te realiseren?

Participant 2
In de initiatiefase was iedereen wel eigenlijk super enthousiast, dus erg gemotiveerd.

Interviewer
CB'23 is een platform bestaande uit verschillende partijen, waaronder onderzoekers vanuit de TU Delft, die samen de GWW-sector naar de circulaire economie op weg willen helpen. Nu heeft CB'23 zes ontwerpstrategieën geformuleerd voor het maken van een circulair ontwerp: Ontwerpen voor preventie, ontwerpen voor reductie van levenscyclusimpact, ontwerpen voor toekomstbestendigheid, ontwerpen met hergebruikte objecten, ontwerpen met secundaire grondstoffen, ontwerpen met hernieuwbare grondstoffen. Het ontwerp van de Tweede Levenbrug is gemaakt door middel van één of meerdere van de zes circulaire ontwerpstrategieën toe te passen, in hoeverre bent u het hiermee eens?

Participant 2
Het hergebruiken van objecten is toegepast en is ook het idee geweest, dus helemaal mee eens.

Interviewer
In hoeverre waren de specificaties van de opdrachtgever, gevormd in de derde fase, flexibel en niet-beschrijvend?

Participant 2
Erg vastgesteld en beschrijvend. Toen wij betrokken werden was het ontwerp namelijk al klaar, er moest gebouwd worden wat er was ontworpen. Wij kwamen met het idee om minder staal te gebruiken, maar dat paste niet in het ontwerp, dus het werd niet toegepast.

Participant 2
Maar nou komt het weer. Het is echt gewoon wezenlijk van belang bij dit soort projecten dat je niet-conventioneel gaat denken, je hele denkwijze moet omgegooid worden. Voor het beton en staal wil je bijvoorbeeld al vanaf het begin van het project een betonspecialist en een staalspecialist betrekken, zodat je zo veel mogelijk gebruik kunt maken van deze kennis en daarvanuit een ontwerp gaat maken.

Interviewer
Het gebruikte aanbestedingsmodel was op basis van een product-service model, een publiek-privaat samenwerkingsmodel, een samenwerkingsmodel met meerdere partijen voor hergebruik en deelgebruik, een lease-model, of een terugname-model voor leveranciers.
Participant 2
Het was een samenwerking met meerdere partijen voor hergebruik en deelgebruik. Wij zaten eigenlijk voor de constructie aan tafel, en er lag al een ontwerp. Die staalconstructie hebben wij weer aangepast aan de hand van wat we circulair hebben kunnen aanbieden. Die betonbalken zijn uiteindelijk nooit meer op zo'n manier bekeken zoals wij dat met het staal gedaan hebben. Men zou dus nog een extra slag kunnen halen door ook een betonexpert te betrekken, dan was je constructie efficiënter geweest. Om dit alles zou ik zeggen neutraal.

Interviewer
Welke circulariteit maatregelen zijn er genomen gedurende de bouw van het project?

Participant 2
Als ik kijk naar de echt de bouwfase, dan zijn daar niet zozeer circulariteitsmaatregelen genomen. Dit vond meer plaats in de voorbereidende fasen. Tijdens de bouw waren de werkzaamheden zoals vanouds.

Participant 1
Je kunt ook niet echt maatregelen nemen, want je moet binnen bepaalde normen veilig bouwen.

Participant 2
Tijdens de bouw werden er juist meer werkzaamheden uitgevoerd omdat de materialen allemaal gescand moesten worden. Dit kwam er pas uit tijdens de bouw. De vrijheid met die betonnen liggers was in mijn ogen niet goed genoeg besproken.

Interviewer
In hoeverre kan het gebouwde object gedemonteerd worden voor de oogst van herbruikbare componenten?

Participant 2
Ik denk gemiddeld herbruikbaar. Je hebt stalen leuningen, daar kun je niet heel veel meer mee. Het hout zou je nog kunnen gebruiken. De betonnen liggers zitten vol met gaten, dus daar kun je ook niets meer mee. De dragende stalen balken zou je wel kunnen hergebruiken, maar ze zijn maar van een korte lengte.

Interviewer

Gedurende de initiatie van het project, hoe belangrijk was het om een circulair object te creëren?

Participant 1
Voor ons was het erg belangrijk.

Participant 2
In het begin was het eigenlijk heel belangrijk en naderhand werden de tijd en de kosten weer wat belangrijker. We begonnen met een streven van 100% circulair te bouwen. Dat was eigenlijk altijd het streven maar dat werd door het ontwerp steeds minder. Dus daarom zal ik toch zeggen dat het een beetje belangrijk was.

Interviewer
Stelling: Het ontwerp is gemaakt voor een lange levensduur, service of leasing, hergebruik bij productie of materiaal terugwinning.

Participant 2
Oneens. De brug is zeker niet voor lange levensduur gemaakt, het staal is niet geconserveerd dat staal. Er is wel wat overdimensionering. Hergebruik wordt ook lastig. Het is mij verder onbekend wat de insteek van het ontwerp van deze brug was.

Interviewer
In hoeverre waren de projectspecificaties prestatiegericht en werd dit gestimuleerd?

Participant 2
Gemiddeld gestimuleerd. Ik denk dat het in eerste instantie gestimuleerd was en prestatiegericht ook, en dat dit naderhand ook steeds minder werd. Het naampje circulair moest er zeker nog wel aan blijven hangen. De brug moest op een gegeven moment een bepaalde uitstraling krijgen. Ik denk dat dat op een gegeven moment de overhand kreeg.

Interviewer
De ingediende tender draagt bij aan gesloten energie- en materiaal-kringlopen binnen aanvoerketens, terwijl negatieve milieueffecten en afval wordt geminimaliseerd en in het beste geval worden vermeden over de gehele levenscyclus.

Participant 2
Oneens. Wij hadden nog een landhoofd wat we ook uit circulaire HIB-balken wilde maken, zoals alle tussenliggers. Deze balken komen uit een ander project via onze terugkoopregeling waarin we oud staal terugnemen van de klant. Het gebruik van deze landhoofden werd onaantrekkelijk gemaakt door de constructeur die erop zat, omdat het voor meer werk zou zorgen. De wil om te innoveren mistte hierdoor af en toe.

Interviewer
Zijn er met de leverancier afspraken gemaakt over de terugvordering van materialen na de levensduur van het object?

Participant 2
Ja, die zijn volledig gekocht door Dura Vermeer. Wij krijgen geen materialen terug als de brug het einde van zijn levensduur bereikt heeft.

Interviewer
In hoeverre zijn er componenten herbruikbaar voor toekomstige projecten na de levensduur van het gebouwde object?

Participant 2
Slecht tot gemiddeld herbruikbaar. Je kan ze wel hergebruiken, maar je zou heel goed moeten uitzoeken waarvoor.

Interviewer
Tijdens de initiatie van het project waren alle betrokken partijen gemotiveerd en droegen actief bij aan het gezamenlijke doel van het realiseren van een circulair object.

Participant 2
Eens

Participant 1
Je moet zo zien, wij waren ook zoekende hoe we dit project moesten aanpakken, want het was iets nieuws. In eerste instantie waren we heel terughoudend en later zijn we wat meer meegegaan.

Participant 2
Maar je moet het eigenlijk vaker doen om het goed te kunnen. Er zit op een gegeven moment ook een kantelpunt in. Hoe ver wil je gaan? Hoeveel geld heb je ervoor over? Want je kan super circulair zijn, maar dan kost het ook super veel geld en daar zal je een keuze in moeten maken. Vandaar dat ik denk in de initiatiefase eens en in de ontwerpfase oneens.

Interviewer
Het basisprincipe van de circulaire economie en circulair ontwerp, ‘’Ontwerp zó dat afval en vervuiling worden voorkomen’’, vormt de basis van het ontwerp van dit object.

Participant 2
Oneens, want uiteindelijk ontstaat er wel afval.

Interviewer
De projectspecificaties waren flexibel, niet-beschrijvend, en het presteren op onderdelen werd gestimuleerd ten behoeve van het project.

Participant 1
Oneens, het ontwerp van de architect was leidend.

Interviewer
De aanbestedingsprocedure was prestatiegericht, bevatte tools zoals life cycle approach (LCA) en life cycle costs (LCC), en criteria waren aanwezig voor het hergebruik van materialen.

Participant 1
Eigenlijk is er nooit een tenderfase geweest.

Participant 2
Bij ons is LCA en LCC niet toegepast, maar er waren criteria aanwezig voor het hergebruik van materialen. Dus ik neig naar tussen neutraal, omdat ik niet precies weet hoe dit bij Dura Vermeer, de hoofdaannemer, is gegaan. Maar bij ons waren alleen die criteria aanwezig.

Interviewer
Welke maatregelen zijn er genomen om de bouw zelf circulair of duurzaam te maken? (Denk hierbij aan machines, uitrusting, etc.)

Participant 2
Tegen de tijd dat we begonnen met bouwen, stond er een behoorlijk druk op de ketel, omdat het voortraject enorm veel tijd ingenomen had. En toen er eindelijk een klap gegeven werd op het financiële plaatje was het eigenlijk roeien met de riemen die je hebt.

Interviewer
Er is rekening gehouden met het einde van de levensduur van het object en mogelijke toekomstige doeleinden, wat materialen betreft, bij de start van dit project.

Participant 2
Er is rekening gehouden met het einde van de levensduur, volgens mij hebben ze 10 jaar gesteld. En wat materialen betreft is er bij de start van dit project niets over toekomstige doeleinden beschreven of besproken. Dus ik ga voor oneens.

Interviewer
Nu heb ik nog enkele vragen over het project in het algemeen. Waren er verschillen of opmerkelijkheden in het project proces vergeleken met een regulier bouwproject?

Participant 1
In eerste instantie niet, alleen waren we zoekende met het circulaire. Dus hoe om te gaan met een bouwteam en hoe maak je iets circulair?

Participant 2
Wat vonden wij circulair? Wat vond de opdrachtgever circulair? Er werd niet echt een eisenpakket neergelegd vanuit een tender. Je merkt dat het uiteindelijk gewoon weer een beetje budget en tijd-gestuurd wordt.

Interviewer
Zijn er nog extra werkzaamheden of stappen die uitgevoerd moesten worden?

Participant 1
Je moet kijken wat er beschikbaar is? Wat heb je liggen en kun je hergebruiken?

Interviewer
Denken jullie dat circulaire bouwprojecten over het algemeen duurder of goedkoper zijn dan reguliere bouwprojecten?

Participant 1
Des te meer circulaire je wil, des te duurder.

Interviewer
En wat zorgt voor deze hogere kosten denkt u?

Participant 2
Met name het voorbereiden van de onderdelen. Wij hadden bijvoorbeeld gespoten balken met allemaal plaatjes, lipjes, dingetjes, en dat moest er allemaal vanaf om het opnieuw te kunnen gebruiken. Dus er gaat gewoon veel tijd zitten in het voorbereiden van materialen voorafgaand aan de toepassing.

Interviewer
Wat zijn volgens u de beperkingen voor de implementatie van circulariteit in de civiele bouwsector?

Participant 1
Je moet starten met jezelf, wil je het wel echt als bedrijf? En het winstoogmerk moet je kwijtraken, want dat is er op dit moment niet. Je moet de hele keten aanpakken, van bouwer tot sloper.

Participant 2
Er moet vanuit de opdrachtgever bereidheid zijn om extra te betalen voor circulariteit. Er vereist een groter traject aan de voorkant waarbij de opdrachtgever verantwoordelijk is voor de beschikbare materialen.

Interviewer
Hebben jullie nog de ambitie om in nabije toekomst meer circulaire projecten uit te voeren?

Participant 1
Absoluut, je kan ook niet anders. Ik denk dat je het ook breder moet zien dan je eigen partij en dat je de hele aanpak van project moet herzien.

Participant 2
Er moet meer met open kaart gespeeld worden. De opdrachtgever moet eigenlijk zorgen voor materiaal, om vervolgens een tender eerlijk te laten verlopen.

Participant 1
Ik denk dat ze ons als staalbouwer ook eerder moeten betrekken in het proces, zodat we onze ervaringen en expertise kunnen delen, een aan kunnen geven wat we nog aan materiaal hebben liggen.

Participant 2
Zo zou je ook een betonbouwer en een funderingsspecialist aan tafel moeten zetten met ervaring. Toen wij er in dit project bijkwamen waren de architect en constructeur al klaar en dat was achteraf gezien niet slim volgens ons. Zoals wij het nu hebben gedaan zal ik het nooit meer doen, maar ik heb wel een hoop geleerd.

Appendix E: Summaries of interviews regular case project

E.1 Interview participant G

Interviewer

De opname werkt, dus we kunnen van start gaan. Ik ga nu een semigestructureerd interview met u afnemen en dat interview wordt gebruikt voor mijn onderzoek. Het interview bestaat uit vijf delen. Eerst een algemene introductie, dan de circulaire economie in het algemeen en daarna het project Singelparkbruggen, specifiek de Wisenniabrug. Tenslotte nog wat algemene vragen over het project en enkele concluderende vragen. Dus dan beginnen we nu even met een introductie. Wie heb ik hier voor mij zitten?

Participant

Ik ben participant G en werk al 30 jaar in de bouwsector voor de Gemeente Leiden in de rol van senior technisch projectleider en coördinerend senior. Ik ben ooit het project Singelparkbruggen begonnen als projectmanager, maar dit paste niet in mijn beschikbare tijd. Dit is toen door een collega, ingehuurde projectmanager, opgepakt voor voornamelijk het ontwerpaspect tot de realisatie. Toen is hij gestopt met het project en ben ik weer teruggekomen als projectmanager om dit project af te ronden. Mochten er vragen zijn waarop ik niet direct kan antwoorden, dan schrijf ik dat even op en kom ik hier later op terug.

Interviewer

Dat is goed om te horen. Dan gaan we ons nu even richten op de circulaire economie. Wat betekent voor u de circulaire economie? En wat is uw mening hierover?

Participant

Nou, het wordt steeds belangrijker. We hebben er een hele lange tijd minder mee gedaan, niets uitgevoerd, eigenlijk geen aandacht aan besteed. Wij gingen gewoon ontwerpen en we trokken ons nergens wat van aan. We worden ons er steeds meer bewust van het belang van duurzaamheid en circulariteit. Want alle grondstoffen zijn natuurlijk niet onuitputtelijk, dus we zullen wel degelijk daar een bijdrage aan moeten leveren. Vanuit onze gemeente hebben we al 5 jaar een groep medewerkers die hiervoor beleid opstelt en ons bewust maakt van wat er allemaal mogelijk is om de belasting op onze omgeving te verminderen.

Interviewer

Wat denk je dat de circulaire economie specifiek gaat betekenen voor de bouwsector?

Participant

Dat we sowieso beleid krijgen, dat hebben we nu al. Dus als wij nu gaan slopen, dan gebeurt dat circulair. Dat vergt dan natuurlijk aanpassingen in je hele planning, dus dat kun je dan veel eerder kenbaar maken en daardoor meer kansen bieden. Maar we zullen ook de markt uitdagen door het mee te nemen in onze selectiecriteria en EMVI-aspecten.

Interviewer

En wat denkt u dan dat het belangrijkste aspect is van de circulaire economie in de bouwsector?

Participant
Vanuit mijn gezichtsveld is dat beperkt, hiervoor kun je beter contact opnemen met een van onze beleidsmedewerkers die zich focust op circulariteit in de bouw in de Gemeente Leiden. Ik zal je gelijk de contactgegevens geven.
Interviewer
Dankjewel, ik ga nog wel even kijken of ik hiervoor nog wat tijd voor kan vinden om het mee te nemen in mijn onderzoek.

Participant
Ik ben wel enigszins sceptisch over het circulaire, omdat we het heel vaak roepen dat we het moeten toepassen, maar vervolgens toch weer nieuwe materialen gebruik doordat we het handboek voor de kwaliteit van de buitenruimte in Leiden volgen. Dit is voornamelijk het geval bij openbare ruimtes en niet zozeer bij bruggen. We hebben in de stad gestapelde ambities. We willen de stad uniform maken, daar hebben we een standaard handboek voor, maar we willen ook materialen hergebruiken. Sommige stenen zijn bijvoorbeeld nog prima geschikt om te hergebruiken, maar ons handboek schrijft een ander materiaal voor, dus gaan die stenen eruit en worden verkocht of gaan de puinbreker met als resultaat puinfundering. Dat vind ik wel zonde.

Interviewer
Bent u nu bezig met het uitvoeren van een circulair project?

Participant
Ja. Wij zijn met een ingenieursbureau van ruim 50 man, dus we hebben zeker projecten in de voorbereiding die circulariteit bevatten conform onze circulaire beleidskaders. Desalniettemin is ons handboek hierin nog steeds leidend. Qua bruggen hebben we recent circulaire brug aangelegd in Leiden Lammenschans. Dit is een hergebruikte brug afkomstig van de bruggenbank. Ook plaatsen wij zelf verwijderde bruggen uit Leiden op de bruggenbank om opnieuw gebruikt te kunnen worden. Ik ben dan wel weer sceptisch voor het hergebruik hiervan. Hoe goed is het voor de aarde om een brug op te halen aan de andere kant van het land om vervolgens voorzieningen te treffen en aanpassingen te maken alvorens deze wordt aangelegd? Als je alles doorberekent, financiën zijn ondergeschikt aan duurzaamheid en circulariteit, vraag ik me toch af of de aarde er per saldo beter van wordt. We moeten hierin niet doordraven dus het zou mooi zijn als dit inzichtelijk gemaakt zou worden.

Interviewer
Hierin hoop ik met mijn onderzoek iets te kunnen betekenen. We gaan nu inzoomen op het project Singelparkbruggen en dan met name de Wisenniabrug. Uw rol in het project was projectmanager vanuit de opdrachtgever. Vanuit de literatuur bevatten bouwprojecten standaard 5 componenten, namelijk initiatie, ontwerp, tender, realisatie en gebruik onderhoud. Bent u het hiermee eens?

Participant
Ja, dat klopt wel.

Interviewer
Bij welke componenten bent u betrokken geweest?

Participant
De initiatie, realisatie en het gebruik en onderhoud oftewel beheer en onderhoud. Maar het onderhoud ligt nu voornamelijk bij onze onderhoudsafdeling.

Interviewer
Bent u bekend met platform CB'23?
Participant
Nee.

Interviewer
CB'23 is een platform bestaande uit verschillende partijen, waaronder onderzoekers vanuit de TU Delft, die samen de GWW-sector naar de circulaire economie op weg willen helpen. Nu heeft CB'23 zes ontwerpstrategieën geformuleerd voor het maken van een circulair ontwerp: Ontwerpen voor preventie, ontwerpen voor reductie van levenscyclusimpact, ontwerpen voor toekomstbestendigheid, ontwerpen met hergebruikte objecten, ontwerpen met secundaire grondstoffen, ontwerpen met hernieuwbare grondstoffen. Is het ontwerp voor de Wisenniabrug gemaakt door middel van één of meerdere van de zes circulaire ontwerpstrategieën toe te passen, in hoeverre bent u het hiermee eens?

Participant
Ik denk het wel, maar weet dat niet zeker. Het ontwerp is gemaakt door een architect, dus die kan jou meer vertellen over het ontwerp. In de vraagspecificatie staat het ontwerp beschreven zoals het uitgevoerd moet worden door de aannemer, dus daar zou je ook kunnen kijken. Maar het hoofdidee van deze bruggen is in ieder geval het maken van een verbinding en esthetische route door het singelpark.

Interviewer
Ik zal de vraagspecificatie hiervoor even doornemen. Ik ga toch nog even terug naar de 5 componenten van een project. Klopt voor dit project de volgorde initiatie, ontwerp, tender, realisatie en dan beheer en onderhoud?

Participant
Ik denk dat deze volgorde wel logisch is.

Interviewer
Oké, goed om te weten. Desondanks u niet betrokken bent geweest bij de aanbesteding, vroeg ik mij toch af of u een beeld heeft van hoe deze is verlopen?

Participant
Ja, dit kan ik allemaal vinden in de eisen die staan in de selectieleidraad van dit project. Ik weet natuurlijk niet hoe dat allemaal precies is gegaan toen, maar ik weet wel dat buurtparticipatie een belangrijk thema was. Daarnaast wilden we natuurlijk bruggen die passen in de kwaliteitsambities van Leiden. Zo hebben we als Leiden veel ambities, maar die stapelen ook en kunnen elkaar dan bijten. De ene ambitie kan de

andere ambitie negatief beïnvloeden. Het is maar net waarop je de nadruk legt. Hierin moeten we een duidelijke balans vinden.

Interviewer
Was er gedurende de initiatie van het project een ambitie om een circulair of duurzaam project te creëren?

Participant
Ik denk het niet. Ook in de vraagspecificatie staat niet echt iets op het gebied van duurzaamheid en circulariteit, wel staat de onderhoudsvriendelijkheid beschreven.

Interviewer
Denkt u dat de Wisenniabrug gedemonteerd kan worden en dus geschikt is voor een tweede leven na de huidige levenscyclus?

Participant
Ja, maar niet in het bijzonder. Het beton van de landhoofden kan gebruikt worden, maar het zou ook gebroken kunnen worden voor puinfundering. Het staal kan gerecycled worden en de gebakken stenen ook. Dus ik denk dat een groot deel wel gerecycled kan worden. Maar we kunnen het dus niet demonteren en elders weer opbouwen.

Interviewer
Hebben jullie voorafgaand aan de tender al een ontwerp gemaakt of hebben jullie meteen alles aanbesteed aan de aannemer?

Participant
Wij hebben het ontwerp apart aanbesteed aan een architect. Vervolgens hebben we opnieuw een uitvraag gedaan met het gemaakte ontwerp voor de realisatie van het ontwerp.

Interviewer
Dus kijkende naar de projectcomponenten is het proces eigenlijk gelopen volgens de volgorde initiatief, aanbesteding ontwerp, ontwerp, aanbesteding realisatie, realisatie, gebruik en onderhoud?

Participant
Ja, klopt. Maar het is maar net hoe je die invulling ziet. Wij hebben op het begin aangegeven waar we de bruggen willen hebben liggen. Alleen de specifieke invulling van het ontwerp van de brug hadden we nog nodig. Je kan heel veel dingen eisen, maar uiteindelijk is er een weging die de uitkomst van de tender bepaald. En met die toetsingen en wegingen kun je bepalen waar de nadruk op ligt in zo'n tender. In deze tender was dat het ontwerp, en deze is uiteindelijk gewonnen door Ney & Partners. Het zou kunnen zijn dat duurzaamheid daar al een rol heeft gespeeld, dat weet ik niet.

Interviewer

Oh oké. Gezien u wel betrokken bent geweest bij de realisatie, weet u of er met leveranciers afspraken gemaakt zijn over de terugvordering van materialen na de levensduur van deze brug?

Participant
Ik denk niet dat dat gebeurd is.

Interviewer
Zijn er verder nog andere duurzaamheids- of circulariteitsmaatregelen getroffen gedurende de bouw van dit project.

Participant
Het schiet me zo niet te binnen en ik denk ook dat dat behoorlijk meevalt. Buiten dit contract om hebben we voor de betonnen straatmaterialen van de brug wel een raamcontract met een betonleverancier waarmee we de afspraak hebben dat al het vrijgekomen betonmateriaal weer terug geleverd kan worden. Maar dit is ook vanuit het betonakkoord.

Interviewer
Is er tijdens de start van dit project rekening gehouden met het einde van levensduur van deze brug? Zijn daar plannen voor gemaakt?

Participant
Nou, we hebben een lange levensduur wel als randvoorwaarde meegegeven in de opdracht. Dus de gebruikte materialen zijn daar wel op uitgekozen.

Interviewer
Oké, dit waren de component gerichte vragen. Van andere personen heb ik te horen gekregen dat dit project best wel uniek is. Wat maakt dit project volgens u uniek?

Participant
Wat het uniek maakt is dat het ontwerp. RVS in combinatie met Cortenstaal is een gewaagde keuze, en dan ook nog ingemetselde klinkers in het brugdek. Daarnaast maakt deze brug deel uit van een heel netwerk aan bruggen en is het allemaal op visueel gebied familie van elkaar. In Leiden vinden wij de kwaliteit van de openbare ruimte erg belangrijk.

Interviewer
Waren er in dit project proces nog opmerkelijkheden vergeleken met andere projecten?

Participant
Er is meer vanuit de gebruikers gekeken, dus in het proces is meer aandacht geweest voor de gebruikers van de brug en de onderliggende grachten.

Interviewer
Dus geen extra werkzaamheden of stappen die uitgevoerd moesten worden?

Participant
Nee.

Interviewer
Om maar even terug te gaan naar circulaire bouwprojecten, denkt u dat circulaire bouwprojecten duurder of goedkoper zijn dan regulier bouwprojecten?

Participant
In eerste instantie duurder.

Interviewer
En wat is de reden voor deze verhoogde kosten denkt u?

Participant
Puur de investeringskosten, omdat we nog te veel vanuit emotie opereren en dan maar gewoon de financiën op de tweede plaats zetten. Maar met in het achterhoofd houdende dat de natuurlijke grondstoffen niet onuitputtelijk zijn. Op het begin is het dus duurder, maar op termijn, wanneer materialen schaarser worden, zal het kantelen en is het goedkoper. En de doorlooptijd van project maakt het ook duurder omdat het complexer is.

Interviewer
Wat zijn momenteel volgens u nog beperkingen voor de implementatie van circulariteit in onze bouwprojecten.

Participant
Inzichtelijkheid in wat het materiaal doet op functioneel niveau. Dus bepalen wat de voordelen en nadelen zijn van hergebruikte producten. Daarnaast moet je ook kijken hoe je het uitvoerbaar maakt. Dit zal in kleine stapjes moeten gebeuren, en dat begint met bewustwording. Het moet een standaard onderdeel worden van onze denkwijze. Hiervoor zullen we risico's moeten lopen en af en toe de mist in gaan, maar daar leren we van.

Interviewer
Hebben jullie, als de Gemeente Leiden, de ambitie om in de toekomst meer circulaire bouwprojecten uit te voeren?

Participant
Ja, deze ambitie is er zeker vanuit het bestuur en vanuit het beleidmakers. Ik denk dat we heel goed bezig zijn en dat we hele goede en enthousiaste collega's hebben die op dit onderdeel goed beleid kunnen maken. Dus Leiden heeft deze ambitie zeker wel.

Interviewer

Dit was het interview. Bedankt voor uw tijd, moeite en kennis die u met mij heeft gedeeld.

E.2 Interview participant H

Interviewer

De opname werkt, dus we kunnen van start gaan. Ik ga nu een semigestructureerd interview met u afnemen en dat interview wordt gebruikt voor mijn onderzoek. Het interview bestaat uit vijf delen. Eerst een algemene introductie, dan de circulaire economie in het algemeen en daarna het project Singelparkbruggen, specifiek de Wisenniabrug. Tenslotte nog wat algemene vragen over het project en enkele concluderende vragen. Dus dan beginnen we nu even met een introductie. Wie heb ik hier voor mij zitten?

Participant

Ik ben participant H en ben nu zo'n 14 jaar werkzaam bij Ney & Partners, nu ook als partner. Mijn functie is nu teamleader en ten tijde van het Singelparkbruggen project was ik projectingenieur. Bij ons is dit project al gestart in 2015, dus als projectingenieur heb ik toen de stabiliteitsberekeningen gedaan en dan later ook de volledige opvolging van het project. Ik weet niet of je ons kantoor een beetje kent en wat wij doen?

Interviewer

Nee, eerlijk gezegd niet echt.

Participant

Wij zijn een bureau met stabiliteitsingenieurs of constructeurs zoals dat bij jullie heet. In de eerste plaats doen wij puur stabiliteitsstudies voor gebouwen, maar daarnaast voor bruggen en speciale constructies doen wij zowel de architectuur als de stabiliteit, het volledige ontwerp pakket eigenlijk. Dit hebben we ook voor de singelparkbruggen gedaan. In onze ontwerpen proberen we de krachtwerkingen te vertalen naar het ontwerp. In de Singelparkbruggen zijn de krachtlijnen van de individuele bruggen weergegeven door middel van de bollenlijn. Vanuit de opdrachtgever hebben we de vraag ontvangen om één familie aan herkenbare bruggen te ontwerpen die samen een oneindig singelpark vormen.

Interviewer

Dan gaan we ons nu even richten op de circulaire economie. Wat betekent voor u de circulaire economie? En wat is uw mening hierover?

Participant

Dat is een heel breed onderwerp en momenteel ook populair, maar ook relevant met de huidige energieschaarste en materiaal schaarste. Dus het is zeker nodig om over na te denken. Circulair wordt vaak gebruikt voor iets wat je zó ontwerpt, dat het kan opnieuw gebruikt worden. Ik ben er niet 100% zeker van dat het altijd realistisch is, eerlijk gezegd. Ik denk dat het voor gebouwen relevanter is dan voor bruggen. Stel ik ontwerp een brug bewust iets te breed om toekomstige inrichting toe te laten, dan is dat absurd in de zin van materiaal schaarste. Je maakt het te groot, maar dan weet je nog altijd niet hoe dat in de toekomst gaat passen, dus in die zin geloof ik er niet altijd in. Wat ook soms gedaan wordt is het hergebruik van elementen door het demontabel te maken, maar dat is in de praktijk ook moeilijk. Je weet niet wat er met de elementen z'n levensduur gebeurd is, kun je dan nog wel kwaliteitsgaranties geven? Ik denk dat vooral de focus moet liggen op materiaalgebruik. Hoe gebruik je die zo efficiënt mogelijk?

Interviewer
Vindt u het materiaalgebruik dan ook het belangrijkste aspect van de circulaire economie in de bouwsector?

Participant
Ja, zeker het meest realistische denk ik.

Interviewer
Bent u nu bezig met het uitvoeren van een project waarin circulariteit vertegenwoordigd is?

Participant
Eén á twee jaar geleden hebben we het innovatieproject circulaire viaducten van Rijkswaterstaat gedaan met concurrenten van Dura Vermeer, Besix. Hiervoor hebben we samen een concept ontwikkeld voor een vezelbeton met een ultra hoge sterkte. Wat mij betreft een heel goed initiatief van Rijkswaterstaat om zoiets te lanceren om partijen te verplichten of eigenlijk de kans te geven om erover na te denken en daar energie, tijd en geld in te steken. We zaten bij de laatste 10 partijen waarvan er 3 werden geselecteerd, maar helaas zaten we daar niet bij. Naast dit project houden we ons nu ook veel bezig met houtconstructies. Dus met name materiaalgebruik en efficiënt materiaalgebruik zijn de dingen waar wij ons op focussen momenteel.

Interviewer
We gaan nu inzoomen op het project Singelparkbruggen en dan met name de Wisenniabrug. Uw rol in het project was projectingenieur vanuit de architect. Vanuit de literatuur bevatten bouwprojecten standaard 5 componenten, namelijk initiatie, ontwerp, tender, realisatie en gebruik en onderhoud. Bent u het hiermee eens?

Participant
Ja.

Interviewer
Hebben de component gedurende dit project ook in deze volgorde plaatsgevonden? Of heeft er een ander volgorde plaatsgevonden, of zijn er nog componenten die ontbreken?

Participant
Ik denk in het algemeen dat de componenten ontwerp en tender nog wel eens kunnen wisselen, afhankelijk van het project, maar in dit project was dit wel de volgorde. In eerste instantie hebben wij schetsen voor de brug voorgelegd aan de bewoners voor commentaar. Daarna hebben we een definitief ontwerp gemaakt dat vervolgens door de gemeente is uitgevraagd in een tender die Dura Vermeer uiteindelijk heeft gewonnen. Wat een beetje atypisch was, is dat Dura Vermeer de ontwerpverantwoordelijkheid van de bovenbouw heeft overgenomen, maar dat was op zich ook wel een goede en logische beslissing. Dus eigenlijk is het ontwerp opnieuw definitief gemaakt door Dura Vermeer, maar daarin is op de funderingen na, weinig gewijzigd. Dus samengevat is in component 2

een schetsontwerp gemaakt en een definitief ontwerp van de bovenbouw. Daarna is in component 3 het definitieve ontwerp opnieuw gemaakt in combinatie met het funderingsontwerp.

Interviewer
Kijkende naar component 2, heeft de gemeente Leiden jullie direct gecontacteerd voor deze opdracht, of is daar ook nog een uitvraag voor geweest?

Participant
Er is vanuit de gemeente Leiden een architectuurwedstrijd geweest voor het ontwerpen van de Singelparkbruggen.
Interviewer
Bent u bekend met platform CB'23?

Participant
Nee, zegt mij niets.

Interviewer
CB'23 is een platform bestaande uit verschillende partijen, waaronder onderzoekers vanuit de TU Delft, die samen de GWW-sector naar de circulaire economie op weg willen helpen. Nu heeft CB'23 zes ontwerpstrategieën geformuleerd voor het maken van een circulair ontwerp: Ontwerpen voor preventie, ontwerpen voor reductie van levenscyclusimpact, ontwerpen voor toekomstbestendigheid, ontwerpen met hergebruikte objecten, ontwerpen met secundaire grondstoffen, ontwerpen met hernieuwbare grondstoffen. Is het ontwerp voor de Wisenniabrug gemaakt door middel van één of meerdere van de zes circulaire ontwerpstrategieën toe te passen?

Participant
Er is sowieso ontworpen voor efficiëntie, dus ontwerpen voor preventie klopt. Dit zit ook wel in onze genen, we proberen altijd zoveel mogelijk functies te combineren in onze ontwerpen. Ontwerpen voor reductie van levenscyclus hebben we ook toegepast door gebruik te maken van onderhoudsarme materialen die herconservering nodig hebben gedurende de levensduur. Wat ook belangrijk is, is dat alle bruggen integraalbruggen zijn en dus onderhoudsarm. Aan de rest van de ontwerpstrategieën is geen aandacht besteed. Ik denk ook dat als je impact wilt maken met circulariteit dat je je juist moet focussen op de grotere infra projecten in plaats van een klein project zoals dit.

Interviewer
Bent u bij alle componenten betrokken geweest in dit project?

Participant
In beperkte mate bij de initiatie. Het ontwerp was ons hoofddeel uiteraard, maar bij de tender en bouw zijn we ook veel betrokken geweest door te consulteren en mee te denken aan oplossingen. Gebruik en onderhoud hebben we vooraf wel over nagedacht, maar hierin zijn we verder niet betrokken geweest.

Interviewer
Hoe zag de aanbesteding eruit?

Participant
Het was eigenlijk een uitvraag naar een aannemer waarbij in eerste instantie een voorselectie is gebeurd op basis van referenties van de aannemers. Later zijn er 3 kandidaten geselecteerd en uitgenodigd om een tender in te dienen. Bij het beoordelen van de tender hebben wij deel uitgemaakt van de jury om de kwaliteit te waarborgen.

Interviewer
In uw mail gaf u aan dat dit project een vernieuwend project is geweest. In welke zin is het vernieuwend?

Participant
Ik denk dat het constructief concept vernieuwend is, maar ook het materiaalgebruik door Corten staal toe te passen. Daarnaast was de context ook vrij uniek doordat het allemaal kleine bruggetjes waren in een bepaalde familie die samen een park moeten verbinden.

Interviewer
Denkt u dat de Wisenniabrug gedemonteerd kan worden en dus geschikt is voor een tweede leven na de huidige levenscyclus?

Participant
Ik ben daar geen specialist in, maar ik denk dat er vast en zeker onderdelen zijn van de bovenbouw die gerecycled kunnen worden. Daarnaast lijkt het mij lastig om de fundering of delen daarvan te recyclen.

Interviewer
Zijn er met de leveranciers afspraken gemaakt voor de terugvordering van materialen na de levensduur van de brug?

Participant
Nee.

Interviewer
Zou u het tenderproces bestempelen als prestatiegericht door middel van tools zoals LCA en LC?

Participant
Niet door middel van LCA en LCC, maar wel doordat er een kwaliteitsdossier opgeleverd moest worden wat meer richtte op uitzicht, robuustheid en dergelijke.

Interviewer
Zijn er tijdens de bouw van deze brug nog enkele duurzaamheidsmaatregelen getroffen of andere circulaire maatregelen?

Participant
Ik denk dat je die vraag beter aan Dura Vermeer kunt stellen.

Interviewer
Is er bij de start van het project nagedacht over de toekomstige doeleinden van het project na levensduur van de brug?

Participant
Nee, niet per se.

Interviewer
Wat waren de verschillen of opmerkelijkheden in het project proces vergeleken met andere projecten?

Participant
Zoals ik zei, het vond plaats in een heel specifieke context, een dichtbebouwd park. Het was toch wel een uitdaging om een concept te vinden wat hierin toepasbaar was. Ook het participatieve onderdeel door met iedereen rekening te houden, was een uitdaging.

Interviewer
Zijn er dan ook extra werkzaamheden of stappen die zijn uitgevoerd in dit project vergeleken met andere projecten?

Participant
Initieel was het idee van de opdrachtgever om een architect aan te stellen om een concept te ontwikkelen wat vervolgens door de aannemer verder uitgewerkt zou worden. Maar gezien in ons concept architectuur, vormgeving en de constructie sterk samenhingen met elkaar, is er besloten om gedurende het proces meer door ons te laten doen. Dus het proces is ergens wel aangepast op ons ontwerp en zijn er wat kleinere werkzaamheden bijgekomen.

Interviewer
Denkt u dat circulaire bouwprojecten duurder of goedkoper zijn dan reguliere bouwprojecten?

Participant
Het is afhankelijk van hoe het circulaire project concreet vertaald wordt naar de praktijk. Als er rekening gehouden wordt met de toekomst en het object wordt groter gemaakt dan nodig, dan is dat uiteraard per definitie duurder. Dat geldt ook als je het demontabel maakt. Als je naar nieuwe materialen kijkt, denk ik dat het in eerste instantie duurder is omdat technologieën nog niet zo ver gevorderd zijn om het goed te kunnen volgen. Maar ook omdat ik het idee heb dat er bij aannemers het idee heerst dat wanneer zij risico's zien de prijs gaat stijgen, wat ik overigens wel kan begrijpen. De onzekerheid maakt het project duurder. Maar op termijn zullen deze kosten wel minder worden.

Interviewer
Wat denkt u dat nu nog de beperkingen zijn voor de implementatie van circulariteit in bouwprojecten?

Participant
Ik denk dat er nog te weinig innovatieprojecten gebeuren. In klassieke projecten krijgen we als ontwerper, maar ook de aannemer, niet de kans om te innoveren. De criteria zijn vaak zo gesteld dat het project snel gerealiseerd moet worden en dat er dus ook nog vaak op prijs geselecteerd wordt. Hierdoor krijgen we eigenlijk niet de kans om te innoveren. Hierdoor denk ik ook dat de eerste stap bij de overheid ligt.

Interviewer
Hebben jullie de ambitie om in de toekomst circulaire projecten uit te voeren?

Participant
Absoluut. Vast en zeker. Ik heb vaak gezegd dat het niet mogelijk is in projecten, maar er zijn ook projecten waar het wel kan, en daar ligt dan onze volle focus op. In elk geval zijn wij er intern als bureau ook al mee bezig door gebruik te maken van een parameter om te bepalen waar het wel en niet goed zit in een project. Zo kunnen we ons voorbereiden voor de toekomst.

Interviewer
Dit was het interview. Bedankt voor uw tijd, moeite en kennis die u met mij heeft gedeeld.

E.3 Interview participant I

Interviewer

De opname werkt, dus we kunnen van start gaan. Ik ga nu een semigestructureerd interview met u afnemen en dat interview wordt gebruikt voor mijn onderzoek. Het interview bestaat uit vijf delen. Eerst een algemene introductie, dan de circulaire economie in het algemeen en daarna het project Singelparkbruggen, specifiek de Wisenniabrug. Tenslotte nog wat algemene vragen over het project en enkele concluderende vragen. Dus dan beginnen we nu even met een introductie. Wie heb ik hier voor mij zitten?

Participant

Mijn naam is participant I, ik ben bedrijfsleider civiel bij Dura Vermeer en ben ook projectleider geweest voor het project Singelparkbruggen, waarvan de Wisenniabrug een van de onderdelen was.

Interviewer

Wat is uw werkervaring In de bouwsector?

Participant

Nadat ik de TU heb afgerond ben in bij een andere grote aannemer gaan werken, en heb ik daar een traineeship gelopen. Sinds 2015 zit ik bij Dura Vermeer. In het totaal heb ik nu zo'n 15 jaar werkervaring.

Interviewer

Dan gaan we ons nu even richten op de circulaire economie. Wat betekent voor u de circulaire economie? En wat is uw mening hierover?

Participant

Volgens mij betekent dat dat je zoveel mogelijk materiaal hergebruikt, en dat je zo min mogelijk nieuwe materialen gebruikt, en waar je nieuwe materialen gebruikt, dat dat dan zoveel mogelijk duurzame materialen zijn. Hier ben ik een groot voorstander van. Vanuit de uitdaging die we als maatschappij hebben ten aanzien van het milieu en klimaatverandering moeten wij daar als bouwbedrijf echt stappen in gaan zetten.

Interviewer

Wat denkt u dat de circulaire economie betekent voor de bouwsector?

Participant

Ik ben dan wel echt werkzaam in de civiele kant van de bouwsector, maar je ziet in de civiele wereld dat er nog best veel vervangingsopgaven zijn. Op het moment dat het technisch nog gewoon goed is maar het niet meer voldoet aan zijn functie vanuit de gebruikerskant dan gaan we het slopen en bouwen we gewoon weer iets met nieuwe materialen. Duurzaam omgaan met materialen is dan vaak zo min mogelijk nieuwe materiaal toepassen en materiaal wat vrijkomt op een goede manier hergebruiken. Maar dat is vaak meer dan alleen je afval gescheiden afvoeren. Hierin hebben nog wel wat stappen te zetten in onze branche. Tegelijkertijd is dat vaak ook toe te wijden aan hoe opdrachtgevers het werk op de markt brengen.

Interviewer
Dus u denkt dat er aan de opdrachtgevers kant nog wel een slag te halen valt?

Participant
Ja.

Interviewer
Wat vindt u het belangrijkste aspect van circulariteit In de bouw?

Participant
Wat ik belangrijk vind is dat we niet alleen proberen te scoren op financiële prikkels. Als we circulariteit en duurzaamheid belangrijk vinden, dan moet je je daar ook gewoon op kunnen onderscheiden. Alleen geld moet geen drijfveer zijn. En ik vind in de stappen die we nu met elkaar maken een stukje bewustwording belangrijk, maar dus ook vooral aan de voorkant van je proces al nadenken over wat je precies wil met circulariteit en duurzaam bouwen.

Interviewer
Bent u nu bezig met het uitvoeren van een project waarin circulariteit vertegenwoordigd is?

Participant
We zijn wel bezig met projecten waarin duurzaamheid een rol speelt. Er is een vervangingsopgave van een kademuur in Den Haag. Hierin was duurzaamheid ook een onderdeel van de EMVI-uitvraag. Er is hiervoor dus ook een MKI-berekening gemaakt. Hetzelfde geldt voor een ander project dat we momenteel uitvoeren waarin duurzaamheid ook een thema is.

Interviewer
We gaan nu inzoomen op het project Singelparkbruggen en dan met name de Wisenniabrug. Uw rol in het project was projectleider vanuit de onderaannemer. Vanuit de literatuur bevatten bouwprojecten standaard 5 componenten, namelijk initiatie, ontwerp, tender, realisatie en gebruik en onderhoud. Bent u het hiermee eens?

Participant
Ik vind het heel herkenbaar, Ik denk dat het gewoon goede componenten zijn van een project.

Interviewer
Hebben de component gedurende dit project ook in deze volgorde plaatsgevonden? Of heeft er een ander volgorde plaatsgevonden, of zijn er nog componenten die ontbreken?

Participant
De vijf componenten en de volgorde klopt wel. Alleen na de initiatie heeft de gemeente een architectuurwedstrijd georganiseerd voor het ontwerp, welke vervolgens als tender op de markt is gebracht. Toen zijn wij als aannemer pas aangehaakt in het proces, op basis van een Design & Construct

contract. Wij hebben ook na de tender nog een behoorlijk intensief stukje ontwerp gehad, dus ik zou zeggen dat ontwerp zowel voor als na de tender voor komt.

Interviewer
Wat maakt dit project uniek?

Participant
Het was in zoverre uniek dat we een bindend ontwerp opgelegd kregen van architect, waarin in onze ogen nog wel een aantal dingen technisch niet helemaal in orde waren.

Interviewer
Waar moet ik dan aan denken?

Participant
Het was vooral van toepassing op de beweegbare brug van singelparkbruggen, dus niet de Wisenniabrug en dus niet zo relevant voor deze case. Maargoed, gezien de beweegbare brug een machine is, moet deze voldoen aan een aantal eisen en regels waaraan eerst niet was voldaan. Zo heeft de architect gedurende het gehele project nog vaak meegedacht om de architectonische uitstraling in stand te houden. Er was dus constant een samenwerking met de architect.

Interviewer
Bent u betrokken geweest bij alle componenten van het project?

Participant
Vanaf de tender zijn betrokken geraakt bij dit project. Dus tender, stukje ontwerp weer, constructie, gebruik en onderhoud.

Interviewer
Hadden jullie vooraf al het idee om een duurzaam of circulair project te creëren?

Participant
Nee.

Interviewer
Nou oke.

Interviewer
Bent u bekende platform CB'23?

Participant
Ja.

Interviewer

CB'23 heeft zes ontwerpstrategieën geformuleerd voor het maken van een circulair ontwerp: Ontwerpen voor preventie, ontwerpen voor reductie van levenscyclusimpact, ontwerpen voor toekomstbestendigheid, ontwerpen met hergebruikte objecten, ontwerpen met secundaire grondstoffen, ontwerpen met hernieuwbare grondstoffen. Is het ontwerp voor de Wisenniabrug gemaakt door middel van één of meerdere van de zes circulaire ontwerpstrategieën toe te passen?

Participant
Misschien niet heel bewust hoor, maar ik denk ontwerpen voor toekomstbestendigheid. Die brug is elders geproduceerd en vervolgens in drie delen daar naartoe gebracht en gemonteerd. Dus ze zijn in principe ook weer demontabel om ze in de toekomst te verplaatsen. Het zijn simpelweg drie brugdelen en twee steunpunten.

Interviewer
Hoe zag de aanbesteding eruit?

Participant
Dat was een Desgin & Construct uitvraag met EMVI waarop we punten konden scoren.

Interviewer
Wat waren de thema's waarop punten gescoord konden worden?

Participant
Dat was risicobeperking, ontwerpmanagement en omgevingsmanagement.

Interviewer
Zijn er met de leveranciers afspraken gemaakt voor de terugvordering van materialen na de levensduur van de brug?

Participant
Nee.

Interviewer
Als de levensduur van deze brug straks voorbij is, in hoeverre zouden onderdelen of materialen nog bruikbaar zijn voor andere projecten?

Participant
Zoals ik het zie, kunnen we gewoon die drie dekdelen demonteren weer ergens anders gebruiken als ze technisch nog in een goede staat zijn. Je zou eventueel de brug ook kunnen slopen en dan vervolgens de materialen recyclen, maar dat natuurlijk vanuit een circulair standpunt wel minimaal. Je zou ook nog kunnen kijken naar de fundering en kade elementen, die zijn waarschijnlijk nog wel goed herbruikbaar. Maar in de ontwerpfase hebben we hier eigenlijk niet naar gekeken.

Interviewer
Hebben jullie zelf nog bepaalde duurzaamheid- of circulariteitsmaatregelen getroffen tijdens de bouw?

Participant
Nee.

Interviewer
Is er bij de start van het project nagedacht over de toekomstige doeleinden van het project na levensduur van de brug?

Participant
Nee

Interviewer
Waren er verschillen of opmerkelijkheden in het project proces vergeleken met andere projecten.

Participant
Zonder in de herhaling te willen vallen, maar in feite dat het ontwerp van de architect heilig was, en dat was merkbaar door het gehele proces.

Interviewer
Heeft dat dan ook voor extra stappen gezorgd In het proces?

Participant
Jazeker. Normaal gesproken zou je vanuit een set eisen een aantal opties bedenken en de slimste kiezen om uit te voeren. Alleen nu zaten we al vast aan een ontwerp, waardoor je soms aan het uitvogelen was hoe je een bepaald object of detail kon realiseren. Terwijl je je normaal bij een Design & Construct opdracht bezig bent met het bedenken van een hoofdverbinding van A naar B. Het feit dat beeldvorming op één staat zorgt er eigenlijk voor dat je niet meer altijd de keuzevrijheid hebt, waaronder een keuze voor duurzaamheid.

Interviewer
Oké, dan nu even iets compleet anders, denk je dat circulaire bouwprojecten duurder of goedkoper zijn dan reguleren bouwprojecten?

Participant
Ja, dat vind ik machtig interessant. Ik hoop goedkoper. Het zou eigenlijk goedkoper moeten zijn, als je in de basis ervanuit gaat dat je slimmer gebruikt maakt van je resources en dus niets weggooit. Maar op dit momen vraagt dat nog best wel een hoop tijd en energie aan de voorkant, maar ik denk zeker op de iets langere termijn, als er ook wat te oogsten valt, dat het dan wel geld moet opleveren in plaats van kosten. Dat komt dan voornamelijk door lagere kosten voor de inkoop van materialen.
Het is alleen wel een beetje anders denken. Je moet misschien enige concessies doen dat je brug net iets breder of smaller is dan gewenst. Hierin zullen we wat flexibeler moeten zijn.

Interviewer
Wat zijn volgens u nog beperkingen zijn voor de implementatie van circulariteit in bouwprojecten?

Participant
Dat is de onbekendheid bij mensen en organisaties over hoe we hiermee omgaan. De bouwindustrie is toch wel een vrij traditionele industrie, en daar zie ik nog wel uitdagingen in het feit dat er een andere manier van denken nodig is. Je moet denken vanuit bestaande objecten in plaats van denken vanuit een ontwerp wat je wil hebben.

Interviewer
Hebben jullie de ambitie om in de toekomst circulaire projecten uit te voeren?

Participant
Jazeker. Ik voel wel gewoon als persoon een verantwoordelijkheid om die planeet een beetje heel te houden en toekomst te geven aan toekomstige generaties. Ik voel de druk die hier op rust om echt iets te veranderen. En tegelijkertijd merk je ook dat je in je dagelijkse gang van zaken toch geneigd bent om gewoon de gebaande paden te lopen.

Interviewer
Dit was het interview. Bedankt voor uw tijd, moeite en kennis die u met mij heeft gedeeld.

E.4 Interview participant J

Interviewer

De opname werkt, dus we kunnen van start gaan. Ik ga nu een semigestructureerd interview met u afnemen en dat interview wordt gebruikt voor mijn onderzoek. Het interview bestaat uit vijf delen. Eerst een algemene introductie, dan de circulaire economie in het algemeen en daarna het project de Tweede Leven brug. Tenslotte nog wat algemene vragen over het project en enkele concluderende vragen. Dus dan beginnen we nu even met een introductie. Wie heb ik hier voor mij zitten?

Participant

Ik ben participant J en werk bij PT Structural. Ik heb een opleiding als staalconstructeur en betonconstructeur gevolgd. Na het VWO ben ik in dienst gegaan en daarna ben ik begonnen met werken in de bouwsector in combinatie met een opleiding aan de HTI Amsterdam. Ik heb bij verschillende bedrijven gewerkt en hierdoor dus veel in de praktijk geleerd. In het totaal heb ik nu zo'n 37 jaar ervaring in de bouwsector en werk ik nu al 16 jaar voor PT Structural waar ik projectleider ben. Maar het liefst doe ik het rekenwerk en ontwerp ik bouwwerken.

Interviewer

Wat betekent voor u de circulaire economie? En wat is uw mening daarover?

Participant

De circulaire economie is vooral het hergebruik van materialen waarbij er zo weinig mogelijk energie ingestopt hoeft te worden en je zo min mogelijk materiaal kwijt raakt. Dus niet alleen het hergebruik van materialen maar ook het afval wat ermee genereert en de energie die je nodig hebt om het circulair te doen. Staal is op zichzelf volledig circulair, want je kunt het blijven gebruiken en recyclen, maar dit kost wel weer energie. Maar het vervelende van staal is dat het vaak geconserveerd wordt. Dat heeft natuurlijk wel een milieutechnisch effect, want die verf moet er vanaf. Met zink is dat wat minder, want zink kan meegenomen worden wanneer je het ijzer opnieuw smelt. Zo zijn veel dingen al circulair, maar ik twijfel of het allemaal doelmatig is.

Interviewer

Wat betekent volgens u de circulaire economie voor de bouwsector?

Participant

Die circulaire economie gaat steeds meer en zou ook veel meer moeten betekenen. Er zijn bijvoorbeeld heel veel bruggen die ontworpen moeten worden en geen enkele is hetzelfde. Er zou een bepaalde standaardbrug moeten zijn zodat je onderdelen kunt uitwisselen. Iets standaard maken is misschien minder positief voor de economie, want er moeten minder ontwerpen gemaakt worden en dus minder manuren aan besteed worden, maar het is wel positief voor de circulaire economie. Daarbij wordt het mogelijk om bruggen te verplaatsen, elders te gebruiken of onderdelen uit te kunnen wisselen.

Interviewer

Vind u dat dan ook het belangrijkste aspect van de circulaire economie?

Participant

Het is wel een van de speerpunten ja.

Interviewer
Bent u momenteel nog betrokken bij andere circulaire projecten?

Participant
Nee, niet echt. We hebben wel eens in het verleden wat bruggen berekend voor Janson Bridging, dat zijn de demonteerbare bruggen.

Interviewer
We gaan nu inzoomen op het project Singelparkbruggen en dan met name de Wisenniabrug. Wat was uw rol in dit project?

Participant
Wij zijn gestart in opdracht van Weelde staalbouw. Hiervoor zouden wij het ontwerp maken op basis van het voorontwerp van de architect. Dit bedrijf is vervolgens failliet gegaan en toen heeft Dura Vermeer dit overgenomen en zijn wij in opdracht van deze partij aan de gang gegaan.

Interviewer
Vanuit de literatuur bevatten bouwprojecten standaard 5 componenten, namelijk initiatie, ontwerp, tender, realisatie en gebruik onderhoud. Bent u het hiermee eens?

Participant
Ja dat klopt wel.

Interviewer
Bij welke componenten bent u betrokken geweest?

Participant
Bij de initiatie ben ik natuurlijk niet betrokken geweest, want dat was de Gemeente Leiden. Bij de andere vier componenten wel. Dus ontwerp en tender, nog met de failliete partij, en vervolgens de uitvoering en beheer en onderhoud.

Interviewer
Wat is de volgorde van projectcomponenten geweest in dit project?

Participant
Initiatie, voorontwerp, tender, definitief ontwerp, constructie en dan beheer en onderhoud.

Interviewer
Bent u bekend met platform CB'23?

Participant

Nee

Interviewer
CB'23 is een platform bestaande uit verschillende partijen, waaronder onderzoekers vanuit de TU Delft, die samen de GWW-sector naar de circulaire economie op weg willen helpen. Nu heeft CB'23 zes ontwerpstrategieën geformuleerd voor het maken van een circulair ontwerp: Ontwerpen voor preventie, ontwerpen voor reductie van levenscyclusimpact, ontwerpen voor toekomstbestendigheid, ontwerpen met hergebruikte objecten, ontwerpen met secundaire grondstoffen, ontwerpen met hernieuwbare grondstoffen. Is het ontwerp voor de Wisenniabrug gemaakt door middel van één of meerdere van de zes circulaire ontwerpstrategieën toe te passen, in hoeverre bent u het hiermee eens?

Participant
Het staat hier allemaal natuurlijk mooi omschreven, maar ik kan me niet herinneren dat dit een item is geweest. Het ontwerp was helemaal vorm-gestuurd. Ontwerpen voor toekomstbestendigheid is misschien wel toegepast, maar daar is naar mijn idee niet doelbewust op gestuurd. Secundaire grondstoffen zou toegepast kunnen door het gebruik van staal, dat kan gerecycled zijn. En in feite kan dit staal ook weer hergebruikt worden voor de productie van nieuw staal.

Interviewer
Zijn jullie begonnen aan dit project met de gedachte dat jullie iets duurzaams of circulair wilde neerzetten?

Participant
Ik denk dat de architect duurzaamheid wel heeft benoemd in zijn ontwerp, maar dat is natuurlijk tegenwoordig ongebruikelijk als je dat niet doet.

Interviewer
Wat maakte dit project uniek?

Participant
Sowieso de uitvoering van de brug in gekozen materialen. Roestvast staal combineren met weervast staal wordt afgeraden en toch hebben wij het gedaan. Dit had idee van de architect had een behoorlijke impact op het ontwerp. Daarnaast was het ook uniek gezien het een boogbrug was die is toegepast. Dit zie je normaal niet veel in Nederland omdat de grondslag zich er vaak niet voor leent. Doordat het ontwerp vorm-gestuurd was, werd dit toch toegepast, wat toch wel een uitdaging bleek.

Interviewer
Als de levensduur van deze brug straks voorbij is, in hoeverre zouden onderdelen of materialen nog bruikbaar zijn voor andere projecten?

Participant
In principe kun je alles demonteren en hergebruiken, alleen moet je dan wel te maken hebben met de dezelfde overspanning. Dan kun je de brug één op één hergebruiken.

Interviewer
Is het ontwerp gemaakt voor een lange levensduur, service, leasing, hergebruik bij productie of materiaal terugwinning?

Participant
Volgens mij zijn de bruggen allemaal ontworpen voor minimaal 50 jaar, maar dat zou ook 100 jaar kunnen zijn voor deze opdracht, maar dat weet ik niet zeker. Maar ze zouden 100 jaar zeker wel vol kunnen houden.

Interviewer
Zijn er met de leverancier afspraken gemaakt over de terugvordering van onderdelen of materialen na de levensduur van de brug?
Participant
Nee, die bruggen zijn gewoon eigendom van de opdrachtgever.

Interviewer
Na de levensduur van de brug van 50 of 100 jaar, in hoeverre zouden de materialen of onderdelen nog herbruikbaar zijn?

Participant
De brug zelf zal niet meer herbruikbaar zijn, maar het staal kun je natuurlijk weer in de hoogovens gooien om weer nieuw staal van te maken.

Interviewer
Zijn er tijdens de bouw van de brug zelf nog duurzaamheids- circulariteitsmaatregelen getroffen?

Participant
We hebben wel wat dingen gedaan om de levensduur wat te kunnen verlengen, onder het maaiveld bij de fundatie, maar dat mag geen naam hebben.

Interviewer
Is er bij de start van het project nagedacht over de toekomstige doeleinden van het project na levensduur van de brug?

Participant
Nee, daar is niet over nagedacht.

Interviewer
U had al aangegeven dat het proces anders verliep dan normaal doordat jullie initiële opdrachtgever failliet ging, maar waren er nog meer verschillen of opmerkelijkheden in het project proces vergeleken met andere projecten?

Participant

De veranderende opdrachtgever was uniek aan dit project, maar een ander puntje was de montage van de boogbrug. Deze bleek eerst niet te monteren zijn zoals de architect het had bedacht, dus hebben we wat aanpassingen aan het ontwerp moeten doorvoeren. Verder moesten we erg opletten met de tussensteunpuntjes van de Wisenniusbrug, gezien deze toch wel slap waren. Daarnaast kwamen de drukbogen precies terecht op de steunpunten waarop deze gemonteerd moesten worden. De bevestigingsplaten moesten daar ter plekken nog aangebracht worden.

Interviewer
Zijn er extra werkzaamheden of stappen die zijn uitgevoerd in dit project vergeleken met andere projecten?

Participant
Ja, dat was natuurlijk het faillissement, maar met name de RVS ballen die in de brug zijn verwerkt. Dit kon niet gefabriceerd worden, dus dit hebben we opnieuw moeten uitwerken en wat aanpassingen zijn gedaan. Uiteindelijk hebben we een mock-up gemaakt waarmee we aan de architect konden laten zien hoe de brug eruit kwam te zien en ging deze akkoord.

Interviewer
Denkt u dat circulaire bouwprojecten duurder of goedkoper zijn dan reguliere bouwprojecten?

Participant
Ik denk dat circulaire projecten in het begin duurder zijn, maar uiteindelijk zal het goedkoper worden. Als je bruggen gaat standaardiseren en je dus onderdelen kunt gaan hergebruiken en minder op voorraad nodig hebt, dan zal het een economisch voordeel geven.

Interviewer
Wat is dan de oorzaak van deze verlaagde kosten denkt u?

Participant
In het geval van de standaardisering van de bruggen denk ik dat dit vooral komt door de engineering van de brug. Doordat deze gestandaardiseerd is, zullen er minder voorraadkosten en rekenwerk en aan verbonden zijn.

Interviewer
Wat zijn volgens u nog beperkingen zijn voor de implementatie van circulariteit in bouwprojecten?

Participant
Toch wel het ontbreken van de standaardisering op bruggen. Daarnaast ook wel de cultuur. Hierin is ook een verandering nodig. Iedereen wil zijn eigen auto, en zo wil iedere gemeente ook zijn eigen type brug. We moeten accepteren dat er meer dingen hetzelfde eruit zullen zien zodat we kunnen standaardiseren voor hergebruik. Ook de gewenning speelt een rol. Zo wordt er in Nederland heel veel beton toegepast, omdat de betonlobby hier sterk is, terwijl in het buitenland staal veel meer wordt toegepast. Zo kunnen we ook kijken om hout meer toe te passen. We moeten accepteren dat de aanschaf

duurder is, om er vervolgens een langere levensduur of herbruikbaarheid voor terug te krijgen. Deze cultuuromslag zal ook zeker bij de overheid moeten plaatsvinden.

Interviewer
Heeft u de ambitie om in de toekomst meer circulaire projecten uit te voeren?

Participant
Ja, maar daar hebben wij vaak niet zo heel veel invloed op. Architecten bepalen en ontwerpen vaak het object en dan worden wij erbij betrokken als adviseurs en constructeurs. Wij zijn bijna nooit aanwezig bij de opstart van projecten waardoor het lastig is om nog circulariteit te initiëren. Waar mogelijk zullen we het natuurlijk wel aankaarten bij onze opdrachtgever.

Interviewer
Dit was het interview. Bedankt voor uw tijd, moeite en kennis die u met mij heeft gedeeld.

E.5 Interview participant K

Interviewer

De opname werkt, dus we kunnen van start gaan. Ik ga nu een semigestructureerd interview met u afnemen en dat interview wordt gebruikt voor mijn onderzoek. Het interview bestaat uit vijf delen. Eerst een algemene introductie, dan de circulaire economie in het algemeen en daarna het project Singelparkbruggen, specifiek de Wisenniabrug. Tenslotte nog wat algemene vragen over het project en enkele concluderende vragen. Dus dan beginnen we nu even met een introductie. Wie heb ik hier voor mij zitten?

Participant

Participant K, destijds was ik op het project Singelparkbruggen projectleider vanuit Van der Zalm Metaalindustrie. Ik heb een technische achtergrond, lucht- en ruimtevaarttechniek gestudeerd en uiteindelijke bij Van der zalm terechtgekomen in 2013, dus zo'n 9 jaar werkervaring in de bouwsector. Het stukje techniek dat Van der Zalm doet is samen te vatten in grote staalconstructies, variërend van offshore tot scheepsbouw, bruggenbouw, remmingswerken en havenvoorzieningen. Eigenlijk allemaal groot staalwerk. Civiele werken doen we meestal alleen in samenwerking met aannemers zoals Dura Vermeer en dan als onderaannemer.

Interviewer

Dan gaan we ons nu even richten op de circulaire economie. Wat betekent voor u de circulaire economie? En wat is uw mening hierover?

Participant

Ik zie het als een stukje hergebruik, misschien niet helemaal correct. Maar ik ben in ieder geval wel voorstander van, waar mogelijk, het zoveel mogelijk hergebruiken van materialen of in ieder geval duurzaam te kiezen. In de staalwereld is dit natuurlijk een makkelijke keuze omdat onze grondstof, staal, her te gebruiken is door het te recyclen. Daarnaast zijn er ook producten die je één op één kunt hergebruiken, neem bijvoorbeeld buispalen. Lukt dat niet, dan kun je deze elementen nog altijd smelten en dan maak je er nieuw staal van.

Interviewer

Wat denkt u dat de circulaire economie betekent voor de bouwsector?

Participant

Het moment dat je bijvoorbeeld een stalen brug hebt en je hebt de mogelijkheid om de levensduur hiervan te verlengen met een upgrade, dan is dat een goed initiatief. Het is alleen lang niet altijd mogelijk met de huidige normen die we hebben, deze zijn ook best wel verzwaard door de tijd. Wat ik nu in de markt zie, is dat het versterken van bruggen wel toeneemt. Dit is natuurlijk ook financieel gezien veel aantrekkelijker dan iets nieuws te bouwen. Het is natuurlijk nog gunstiger om te proberen om dingen rechtstreeks te hergebruiken zonder het eerst om te moeten smelten in een nieuw object.

Interviewer

Wat is dan volgens u het belangrijkste aspect van de circulaire economie in de bouwsector?

Participant
Dat is het proberen om onderdelen direct te hergebruiken zodat er zo min mogelijk proces aan voorafgaat. Dat is weer extra energie die niet per se nodig is. Als een brug door domweg wat draagbalken te verzwaren weer voldoet aan de gebruiksbelasting, dan moet daar de nadruk op liggen in plaats het meteen willen vervangen van de hele brug.

Interviewer
Bent u nu bezig met het uitvoeren van een project waarin circulariteit vertegenwoordigd is?

Participant
Ja, we zijn bijvoorbeeld op dit moment bezig met een demontabele systeembrug. Hierdoor kan deze overal worden toegepast en weer worden afgebroken, maar door kleine aanpassingen kun je deze brug ook zo maken dat deze voor zwaarder verkeer geschikt is. In het maken van remmingwerken passen we het ook vaak toe. Buispalen die uit het ene werk komen zijn vaak prima weer direct toe te passen in een ander werk.

Interviewer
We gaan nu inzoomen op het project Singelparkbruggen en dan met name de Wisenniabrug. Uw rol in het project was projectleider vanuit de onderaannemer. Vanuit de literatuur bevatten bouwprojecten standaard 5 componenten, namelijk initiatie, ontwerp, tender, realisatie en gebruik en onderhoud. Bent u het hiermee eens?

Participant
Ja, maar ik denk ook dat component 2 en 3 ook regelmatig onderling gewisseld worden met elkaar.

Interviewer
In feite maakt de volgorde voor nu niet uit, ik zie het nu als losse componenten.

Participant
Dan kloppen de componenten wel ja.

Interviewer
Hebben de component gedurende dit project ook in deze volgorde plaatsgevonden? Of heeft er een ander volgorde plaatsgevonden, of zijn er nog componenten die ontbreken?

Participant
Dit project was voor ons redelijk bijzonder, want in eerste instantie had Dura Vermeer deze opdracht uitbesteed aan een andere partij die failliet ging. Wij werden vervolgens onverwacht gebeld met de vraag of wij de opdracht van failliete partij over konden nemen. De constructeur was toen al in een afrondende fase met het definitief ontwerp. Wij hebben toen eigenlijk alleen het laatste stukje van het uitvoeringsontwerp meegekregen en de uitvoering zelf.

Interviewer
Dus jullie zijn eigenlijk betrokken geweest bij componenten 3 en 4?

Participant
Ja inderdaad, maar eigenlijk pas vanaf halverwege component 3.

Interviewer
Zijn jullie ook nog betrokken geweest bij de gebruik en onderhoud component?

Participant
Nee, niet echt. Maar wij leveren natuurlijk wel de onderhoudsvoorschriften.

Interviewer
Wat maakt dit project uniek?

Participant
Uniek is een groot woord. Maar het was wel bijzonder door de combinaties van materialen en een architectonisch ontwerp.

Interviewer
Bent u bekend met platform CB'23?

Participant
Ja, heel minimaal.

Interviewer
CB'23 is een platform bestaande uit verschillende partijen, waaronder onderzoekers vanuit de TU Delft, die samen de GWW-sector naar de circulaire economie op weg willen helpen. Nu heeft CB'23 zes ontwerpstrategieën geformuleerd voor het maken van een circulair ontwerp: Ontwerpen voor preventie, ontwerpen voor reductie van levenscyclusimpact, ontwerpen voor toekomstbestendigheid, ontwerpen met hergebruikte objecten, ontwerpen met secundaire grondstoffen, ontwerpen met hernieuwbare grondstoffen. Is het ontwerp voor de Wisenniabrug gemaakt door middel van één of meerdere van de zes circulaire ontwerpstrategieën toe te passen?

Participant
Ik weet niet of dat bewust gedaan is, maar het hergebruiken van objecten is gebeurd door staal toe te passen. Staal is goed te recyclen dus dat zou je hergebruikt kunnen noemen. Het is alleen wel lastig te herleiden hoeveel gerecycled staal er aanwezig is in nieuw staal.

Interviewer
Hoe zag de aanbesteding eruit?

Participant
Ja dat is dus wel een beetje bijzonder geweest, want wij zijn uiteindelijk onderhands benaderd voor deze opdracht, gezien de beoogde partij failliet was gegaan.

Interviewer
Denkt u dat de Wisenniabrug gedemonteerd kan worden en dus geschikt is voor een tweede leven na de huidige levenscyclus?

Participant
Alles kan natuurlijk, maar simpel is anders, want op locatie is alles aan elkaar gelast. Je zou dan alles weer kapot moeten snijden en dan zou je deze brug in 3 segmenten eruit kunnen halen. Doordat de krachtboog door de leuning loopt zal het wel lastig worden om deze brug her te gebruiken.

Interviewer
Zijn jullie begonnen aan dit project met de gedachte dat jullie iets duurzaams of circulair wilde neerzetten?

Participant
Nee. Het was voor ons gewoon werk. We hadden daar ook geen invloed op, want het ontwerp was dus al klaar.

Interviewer
Zijn er met de leveranciers afspraken gemaakt voor de terugvordering van materialen na de levensduur van de brug?

Participant
Nee, dat gebeurt eigenlijk ook uiterst zelden.

Interviewer
Zie je het dan wel gebeuren in projecten?

Participant
Nee, niet in de staalbouw. Maar tijdelijke constructies zijn wel gebruikelijk. Dan duurt de bouw bijvoorbeeld twee jaar en dan nemen we de tijdelijke constructie daarna weer terug.

Interviewer
Als de levensduur van deze brug straks voorbij is, in hoeverre zouden onderdelen of materialen nog bruikbaar zijn voor andere projecten?

Participant
Niet één op één, maar het staal kan gerecycled worden in de hoogovens.

Interviewer
Jullie hebben dit object op locatie in elkaar gelast. Hebben jullie zelf nog bepaalde duurzaamheid- of circulariteitsmaatregelen getroffen tijdens de bouw hiervan?

Participant
Nee. Ja goed, we hebben te maken gehad met een aantal eisen ten aanzien van uitstoot van CO2, maar verder hebben we geen aanvullende maatregelen getroffen.

Interviewer
Is er bij de start van het project nagedacht over de toekomstige doeleinden van het project na levensduur van de brug?

Participant
Bij mijn weten niet. Maargoed, ik heb het ontwerp ook niet gemaakt. Misschien dat de architect hier wel over nagedacht heeft. Eerlijk gezegd zie ik dat in onze branche ook nog niet echt gebeuren omdat staal nou eenmaal makkelijk te recyclen is.

Interviewer
U had al een paar keer aangegeven dat het proces anders verliep dan normaal doordat jullie er later bij betrokken zijn geraakt, maar waren er nog meer verschillen of opmerkelijkheden in het project proces vergeleken met andere projecten?
Participant
Op wat bijzondere elementen en materialen in het ontwerp na, niet echt. Wij hebben wij nog een move gemaakt bij de veerpleinbrug, waar we deze brug in twee delen hebben aangevoerd, over land en over water. Vervolgens is deze brug ter plekke aan elkaar gelast.

Interviewer
Zijn er extra werkzaamheden of stappen die zijn uitgevoerd in dit project vergeleken met andere projecten?

Interviewer
Nee.

Interviewer
Denkt u dat circulaire bouwprojecten duurder of goedkoper zijn dan reguliere bouwprojecten?

Participant
Dat wisselt. Dat hangt heel erg af van het type project. Monumentale projecten hebben vaak bepaalde eisen voor het uiterlijk, dus hierin zal het duurder zijn. Simpelere objecten zoals een klein bruggetje zal een goedkoper resultaat tot gevolg hebben. Deze kun je ook makkelijker weer elders toepassen als er nog een restlevensduur is.

Interviewer
Dus die kosten zullen dan voornamelijk komen door het materiaal?

Participant

Ja, daarnaast scheelt het ook in de arbeidskosten omdat je niet alles weer in elkaar moet lassen. En door de tijd heen wordt energie ook steeds duurder, dus het produceren van materialen wordt ook duurder.

Participant
Uren en materiaal kosten Natuurlijk.

Interviewer
Wat zijn volgens u nog beperkingen zijn voor de implementatie van circulariteit in bouwprojecten?

Participant
Ik denk vooral het inzicht in wat er gebeurd is met het materiaal in zijn vorige levensduur, zodat je weet welke normen je moet aanhouden. Hierdoor kun je materiaal ook weer waardig toepassen.

Interviewer
Hebben jullie de ambitie om in de toekomst circulaire projecten uit te voeren?

Interviewer
Te doen In de toekomst?

Participant
Jazeker. Als wij een steentje kunnen bijdragen aan een beter milieu, dan zullen we dat zeker doen. Als ik puur naar de financiële kant kijk, dan merk ik dat ik daar nu nog niet de behoefte aan heb. Maar vanuit een stukje verantwoording richting het milieu zullen we dit zeker gaan doen.

Interviewer
Dit was het interview. Bedankt voor uw tijd, moeite en kennis die u met mij heeft gedeeld.

Appendix F: Overview circular case project interview data

Number	Question	Participant A	Participant B	Participant C	Participant D	Participant E	Participant F
General							
1	Which company do you represent?	Arc² architecten	Province of Flevoland / Bruggencampus	Lukassen-Brokking	Dura Vermeer	Meerdink bruggen	Anton Constructiewerken
2	What is your role in the company?	Architect and owner	Projectleader	Advisor and owner	Manager	Director and owner	Project leader
3	Experience in the construction sector?	33 years	15 years	26 years		30 years	25 years
4	What is the circular economy according to you and what is your viewpoint about this?	It is about applying materials which can be used again or grown again But also the reuse of old deserted buildings	It is a different way of thinking wherein we need to ditch the linear process of environmentally intensive construction projects	I think that no one exactly knows what the circular economy is What I do know is that it is mainly about reusing raw materials and components, the interchangability of materials, energy neutrality and the documentation of components	As mankind we need to stay within a level of (excessive) material use, however, there is also a living standard we like to maintain We need to stay within this bandwidth	The circular economy means that we as humans will no longer pollute and exhaust the earth in any way possible, with no CO2-emissions	The circular economy is currently in a starting phase As mankind, we will need to decrease the damaging effects of our behaviour on the planet
5	What does the circular economy imply to the construction sector?	I have no idea on how we are going to achieve this in the construction sector, but on the other hand, there are often great accelerations of transitions But it will mainly come down to change in our thinking	A large transition to a system wherein we know in advance when we are going to build what, in order to take the released materials into account, which can be applied directly elsewhere	For the construction sector it is mainly the interchange in materials, and therefore also the labeling of materials	In our industry we need to check to what extent you can limit the use of new raw materials, and to what extent you can make this guiding in projects, while remaining affordable We need to define the ambition to make the material use leading instead of finances	Our industry needs to go system wherein we only use renewable or bio-based materials The non-renewable materials need to be put into closed circular process to use these over and over	In our sector, the circular economy will become harder to achieve due to the increased amount of certifications necessary Besides that, the materials need to be of the right dimensions For steel it may become even harder due to great amount of steel diversities
6	Are you currently working on any other project which is considered circular? If yes, what makes it circular?	Yes, it is a project in which we will apply reused materials	Not really , but we are currently investigating on how we can apply our knowledge and experience gained with the circular bridge on future circular projects	Yes, we are currently working on a bridge of which we identify the current technical state in order to check where we can make improvements to comply with the requirements This way we do not have demolish the bridge, but first make some improvements	Yes, a project in Amsterdam and one in Haarlem Both projects will constructed of reused materials	Yes, there are currently three projects which strive to high level of circularity by executing the process in a energy-neutral fashion and by only applying bio-based materials Our company aims at constructing projects with bio-based materials	No, not really We do keep on reusing our temporary support structures though
7	What aspect of circularity in the construction industry do you think is the most important?	Not using and applying more raw materials than that our planet can take	A lot can be gained in the materials itself, by for example lengthening of the lifespan or reducing the CO2-exhaustion when producing	It is most important to restrict the use of new materials	Changing our way in thinking to automatically apply new raw materials	We need to go back to the pre-industrial age in material use, but including our modern day technologies	Registration and certification of resued materials, making it completely traceable
Circular economy							
8	What was your role in this project?	Architect	Both a facillitating and knowledge-sharing role	Advisor	Contractor, but also initiator	Subcontractor for the wooden components of the bridge	Subcontractor for the steel components
9	Do you agree with the 5-component model for construction projects? Why or why not?	Yes, this is the traditional sequence of a project But it went different in this project	Yes, this seems complete You could even add the necessity of the project upfront	I agree with this sequence for new construction projects When you apply reused objects, all components are mixed since you need to search for available materials with different lifespans and apply them in your design, which could lead to redesigns	Yes, but the Tweede leven brug didn't follow the usual process Most importantly, the initiation components is really important to generate support	For a traditional project yes During this project, some components were mixed We started with the materials, leading to a design with these materials You could even argue that this project used a Bouwteam, creating a different process	This is indeed the sequence of a traditional construction project, but this was not the case in this project In circular projects it is different The client starts determining a goal and then a bouwteam will be set up I think it would be beneficial if the client was responsible for the purchasing of reused materials

10	In which components were you involved in the project?	Initiation, design, procurement, construction	Initiation, design, procurement	Design, procurement, construction, operation & maintenance	Initiation, design, procurement, construction, operation & maintenance	Initiation, design	Design, construction
Circular economy in case study project							
Initiation							
11	Were the parties participating in the initiation of the project motivated to create a circular project?	Very motivated except for one party, which was lightly motivated	Everyone was very motivated, us and Dura Vermeer probably extremely motivated, especially because the Floriade offered room for experimentation	I'm not sure since I was involved later on in the project, but everyone seemed very motivated	A lot of parties were very motivated to produce a circular project A financially oriented party however was not that motivated	Very motivated	Very motivated
12	During the initiation of this project, how important was the goal of creating a circular project?	That was crucial, so extremely important	Extremely important, we wanted to set the bar as high as possible	Extremely important	Very important	Very important	Very important at the start, but when time progressed, the costs became important as well, which limited the circularity
13	When this project was initiated, all parties were motivated and contributed actively to the common goal of creating a circular project	Completely agree	I agree	I agree	Agreed, except for one party	I agree	I agree, at first we were a bit hesitant because it is something new for us
Design							
14	The design of this project was created by making use of one or more of the six circular strategies mentioned	Totally agree Design with reused objects, design for prevention, design for reduction of lifecycle impact were all applied in this project	Totally agree, a large number of these circular design strategies were applied in this project	Completely agree, since a majority of the design principles were applied	I completely agree, since we used reused materials	Totally agree, the majority of these circular design strategies were applied in this project	I agree, the reuse of objects has been applied in this project
15	This project was either designed for longevity, service/leasing, re-use in manufacture or material recovery	It could all be possible, but we didn't take it into account when we started this project	The main aim of this project was to produce a structure with reused components, so reuse at production has been applied	Completely agree, since the lifespan of its materials has been extended, so longetivity has been adressed	No, it was not	No, I don't think so	Disagree
16	The first principle of the circulair economy and circular design, ''Design out waste and pollution'', has been integrated into the design of this project	By reusing materials in this project, we prevented materials from becoming waste, so I think we adhered to this principle	I agree	I agree	Agreed	I agree	Disagree, because ultimately waste is created
Procurement							
17	The procurement models or procedures used were either a product-service system, public private partnership, cooperation model with parties on re-use and sharing, leasing model or a model containing a take-back system for suppliers	Totally agree, there is a public private partnership	I don't know	I agree, since it was collaboration between different parties for use and reuse	I agree with the public private partnership	I agree	There was collaboration between different parties for reuse and shared use When we were involved, a design was already there, which had to be adapted because of the availability of reusable materials
18	The submitted tender contributes to closed energy and material loops within supply chains, whilst minimizing, and in the best case avoiding, negative environmental impacts and waste creation across their whole life-cycle	Totally agree	I don't know	I agree	Hard to answer, since we did not really had a tender procedure The overarching project was already a project of us, but we initiated to execute it in circular manner	I agree	Disagree We had access to reusable components which were not applied, but could have replaced the abutments The drive to innovate was missing sometimes
19	The procurement procedure in the project was performance based and included tools like the life cycle approach, life cycle costs, and contained criteria for reuse of materials	There were no such tools or anything included in the tender	I don't know	There was no procurement, so this hasn't been done	No, since there were no tender requirements	There was no procurement procedure in this project	There was no procurement procedure in this project, but there were requirements for the reuse of materials

Construction							
20	What circularity measurements were taken during the construction of this project?	Nearly all materials and construction elements are reused, the mounting materials and lights are new	I haven't been involved in the construction, so I don't know	Different parties have been contacted for the availability or reusable materials	The application of reused materials	As standard, we execute our projects using zero emissions So the activities we executed for this project were done in a sustainable manner	Activities of the construction were no different from that of regular projects Circularity measurements were mainly taken during the preparation phases
21	Have agreements been made with the supplier of materials for the recovery of materials after their lifespan?	No	I don't know	Not that I know of	No	No, but this is logical since these are reused materials	The materials have been purchased by Dura Vermeer, so we will not collect the materials after its lifespan
22	What measurements were taken to make the construction itself circular (or sustainable)? (Think of equipment, machinery, etc)	I don't know	I don't know that specifically, but I think there is room for improvement Since there was a tight schedule and a busy construction site, I can imagine that during the construction not most sustainable or circular choices were made	The materials were reused of course, but I don't know about the equipment	No measurements were taken really	Our equipment is either electrical or runs on HVO100 (biodiesel) Our logistics are also executed by vehicles that run on HVO100	No measurements were taken due the time pressure to finish the project
Operation & maintenance							
23	To what level can the project be dismantled for the harvest of future components?	It is completelty reusable	I think this bridge can be deconstructed completely for reusable materials	Largely reusable The majority can be deconstructed except for probably the foundations	Materials and parts of the structure are largely detachable	The bridge components are largely reusable	Moderately reusable, some parts will be worn out
24	Are project components after its service life in this project reusable for new future projects?	For a large part it should be reusable, but some materials will detoriate faster than others	For a large part reusable	Depends on the lifespan of the applied materials Some materials can be reused once again, but others are worn out	I think that a large part of the materials are not reusable since these will be worn out at the end of the lifecycle of the bridge	Largely reusable, but some parts will be worn out after the lifespan of this bridge	Poorly or moderately reusable due to detoriation
25	The end-of-service life and possible future plans, considering the materials used, have been taken into account at the start of this project	At the start of the project we didn't think of the end of its service life	I don't know that for sure, but I do think that we need pay more attention to this	We didn't think about another lifecycle for the materials after its current lifecycle This could be a learning point for future projects	No, not really	No, since some components have a relatively short lifespan, making these worn out after the lifespan of the project	No, there were no future goals discussed for the materials after the lifespan of this bridge
Project general							
26	Were there any differences or particularities in the project process when compared to the process of regular construction projects?	The harvested materials were our starting point, so the proces was completely centered around the materials, leading to a different sequence of activities	Not really I think, except for the initiation and procurement Since Dura Vermeer was already constructing the Floriade, there wasn't really a procurement procedure which normally would occur of course, leaving room for experimenting with circularity	All components or phases are mixed There is no straight path leading to results In addition, there is a lot of interaction between the design and reused materials	There was a special collaboration between a lot of different parties, and everyone really did their best to achieve the circular goal	In this project, we started with gathering materials before we made a design But this process also mixes quite often since we constantly find new materials, and therefore need to redesign It is dynamic process of searching for materials and redesigning	At first not, but we were seeking on what to do with the circular requirements of the project
27	Were there any extra activities or steps that needed to be taken?	Yes, gathering materials and assessing materials if they are qualified for application	For now, the bridge needs to assessed on ECI and LCA	We needed to constantly fit and measure materials to make sure they could be applied	Because it was on the Floriade site, our design needed to pass a quality assurance team	You need to constantly search for materials and redesign, making the project way more intensive and complex	Searching for reusable materials
28	Are circular construction projects, according to you, more or less expensive?	Expressed in euros it is more expensive, but when expressed in damage to our planet it is much cheaper	For now these projects are more expensive But ultimately we will save costs	More expensive	More expensive for now, but once we scale up, the price will decrease	Much more expensive	More expensive

29	What is the reason for these higher or lower costs?	The sources of the extra costs are the extra activities which need to be executed	Right now it more expensive since it is simply a different way of working, needing a mindshift There are also extra costs for transport, storage and preparation of components Ultimately, digitalisation will smoothen this process But we need to remember that cost reduction is not the goal of circularity, increased sustainabilty is	There are more meetings, communication and coordination regarding applying the materials There is also an increase in costs due to searching, preparing and transporting the materials	Firstly, harvested materials are not for free, so these need to be paid Secondly I think that the costs of the project are differently divided over the project There are more costs for preparing a materials before application and there are a lot costs for searching for a certain component	Not the price of the materials, these are cheaper However, preparing these materials for applying in a project makes these more expensive The costs are basically in the extra activities to make the components fit in the project	Most importantly the preparation of the materials before these are being applied in the project
30	What may pose limitations towards circularity in construction projects?	It will be a challenge to cope with the logistics between harvesting a component and applying it in a new structure In an ideal situation you can apply a material immediately after harvesting Furthermore, I think that some architects will struggle with designing with used materials which are bound to certain dimensions	The traditionally grown roles of client and contractor The processes are aimed at performance based on price We will need to collaborate more early on in the project and provide the frontrunners of in the sector with the room to experiment and innovate	The greatest limitation is the availability of reusable materials	Changing our way of thinking, working, collaborating and contracting	The mentality of our sector Small bridges are often made of wood or other bio-based materials, while large bridges are not Constructing with biobased materials is however also possible for larger structures There are many examples of these in Scandinavia	Initiate circularity by first looking at yourself Then the entire sector needs to be willing to change In addition, the client must be willing to pay more for circular projects Or the client should be responsible for obtaining the reusable materials Also, there should be more openness between parties
Closing remarks							
31	Do you have the ambition to participate in (more) circular construction projects in the future, and why?	Yes, of course	Yes, it is the future of our sector	It was a nice challenge, so if encounter such a project once again, we will participate in it	Of course	Yes, absolutely	Absolutely, there is no other way
Summarized responses							
	Sequence of components as suggested by participant	Initiation - Procurement - Material gathering - Design - Construction - Design - Construction (Repeating components Material gathering - Design occur until design is finished) - Operation & Maintenance	Necessity of project - Inititiation - Procurement - Design - Construction - Operation & Maintenance	Initiation - Procurement - Material gathering - Design - Construction - Design - Construction (Repeating components Material gathering - Design occur until design is finished) - Operation & Maintenance	Initiation - Procurement - Material gathering - Design - Construction - Design - Construction (Repeating components Material gathering - Design occur until design is finished) - Operation & Maintenance	Initiation - Procurement - Material gathering - Design - Construction - Design - Construction (Repeating components Material gathering - Design occur until design is finished) - Operation & Maintenance	Not clear from interview

	Most important process remarks	1) The process of this circular project was completely centred around its materials The materials led to extra activities, and determined whether the construction could continue or not (and one should search for new materials) 2) It will be a challenge to arrange the logistics between different projects Ideally we want to construct a structure from components that are harvested from another project which is simultaneously being deconstructed	1) We need to pay more attention upfront to the end of service life and future plans 2) Collaboration between client and contractor needs to occur early on the process to provide them with the possibility to experiment and innovate in projects	1) Pay more attention upfront to the end of service life of the bridge 2) There is a lot of interaction between the materials and design 3) The availability of reusable materials seems to be the greatest threat	1) Collaboration is key in creating a successfull circular project 2) The initiation of the project is very important, since it creates support and dedication for the project	1) Our industry needs to transform to a system wherein we only use renewable and bio-based materials, also for larger projects 2) Dynamic process of searching for materials and redesigning	1) Certification and registration of reused materials is important to enable, so the materials are traceable 2) However, increased certification can make it harder to implement circularity, since certificating materials takes time and could be the cause for delay 3) There wasn't any circular practice during the construction itself 4) The client should be responsible for providing the contractor with reusable materials when a circular project is initiated 5) More openess between parties is beneficial
	Extra activities influencing the process	Gathering materials, quality assessment of materials for suitability	Transport of components, storage of components, preparation of components for application	Constantly checking if materials could be applied in the project, increased meetings, communication and coordination regarding applying these materials, searching, preparing and transporting the materials	Preparing the materials for application, searching for the right materials	Preparing the materials for application, searching for the right materials, redesign your structure	Preparing the materials for application, searching for the right materials

Appendix G: Overview regular case project interview data

Number	Question	Participant G	Participant H	Participant I	Participant J	Participant K
General						
1	Which company do you represent?	Municipality of Leiden	Ney & Partners	Dura Vermeer	PT Structural	Van der Zalm Metaalindustrie
2	What is your role in the company?	Projectmanager	Teamleader and partner	Manager	Projectleader	Projectleader and manager
3	Experience in the construction sector?	30 years	14 years	15 years	37 years	9 years
4	What is the circular economy according to you and what is your viewpoint about this?	The resources are not inexhaustible, so we need to contribute to sustainability and circularity in order to decrease burden on the environment	It is a broad and popular subject at the moment, but also relevant due to shortness of materials and energy	Reusing as much material as possible, and minimally using new materials This is a very important item to implement	The re-use of materials wherein we need to invest as little energy as possible to lose the least amount of materials Many things are already circular but I doubt if it is circular on purpose	Re-use of materials I agree that we need to reuse as much materials as possible or at least choose a sustainable alternative In the steel business this is easy, since all steel can easily be recycled or reused
5	What does the circular economy imply to the construction sector?	Policy for circularity in projects, resulting in circular demolition and circularity requirements in procurement	Circularity means designing in such a manner that it can be reused I'm not completely sure how realistic this is honestly Often, structures are made to be dismantled in the future, for the elements to be reused in future projects It is however unknown what has happened with the elements in their lifetime	Applying as little new materials as possible and materials that are released need to be reused in a good manner There are still a lot of hurdles to take in our sector Still, this is largely due to the way clients market and set requirements for new projects From the client-side, a lot can be improved	It will and should play a increasingly larger role in this sector We should develop a standard bridge which is applied everywhere, so we can replace and interchange components	This would be lengthening the life span of a structure by upgrading it, this is also financially more attractive than creating a new structure However, upgrading of structures is not always possible due to regulations
6	Are you currently working on any other project which is considered circular? If yes, what makes it circular?	Yes, a reused bridge coming from a different municipality	We participated in the Rijkswaterstaat innovation project for circular bridges with a concept for concrete reinforced with fibres I think this was a great initiative from Rijkswaterstaat to challenge parties to think and develop innovative projects	We are working on multiple projects wherein sustainability is a major topic of the project requirements	Not really, in the past however, we did calculate a detachable bridge which could be dissambled and moved elsewhere	Yes, we are currently working on a demountable bridge which can be dismantled and moved When creating guard walls, piling is often reused in other works
7	What aspect of circularity in the construction industry do you think is the most important?	I don't know which aspect of circularity is the most important, but I am a bit skeptical about circularity We have mixed ambitions in our city which do limit circularity at a certain point It would be nice if finances can be linked to circularity	Material usage	Trying not to score on financial incentives If sustainability and circularity is important in a project, we should be able to stand out on these topics in a procurement procedure Awareness about circularity is important, but at the start of a project we also need to think about how we are going to implement circularity in this project	Standardization of structures	Reusing materials with as little processes as possible upfront
Circular economy						
8	What was your role in this project?	Client	Architect and advisor	Contractor	Advisor for the structures	Subcontractor

9	Do you agree with the 5-component model for construction projects? Why or why not?	Yes The sequence of this project was a bit different, since we initiated a design competition for the design of the bridges before the project was procured to the contractor	Yes, but the seqeunce of components could be different, procurement and design are occasionally switched for example In this project there was a design competition for the design, situated between the initiative and the design component	I agree The sequence in general correct, but the municipality hosted, after the initiation, a design competititon for the design of the bridges As contractor we were involved in a later stage based on a Design & Construct contract	Yes, these components are in line with practice	I agree, but I also think that procurement and design are often switched
10	In which components were you involved in the project?	Initiation, construction, and operation & maintenance	Initiation, design, procurement, construction	Design, procurement, construction, operation & maintenance	Design, tender, construction, operation & maintenance	Design, construction
Circular economy in case study project						
Initiation						
11	Were the parties participating in the initiation of the project motivated to create a circular project?	n/a	n/a	n/a	n/a	n/a
12	During the initiation of this project, how important was the goal of creating a circular project?	Not important	n/a	Not important	I think the architect probably mentioned sustainability in its design since it is nowadays unusual to not adress this topic	n/a
13	When this project was initiated, all parties were motivated and contributed actively to the common goal of creating a circular project	n/a	n/a	n/a	n/a	No, but we did not have any influence on this since the design was already finished
Design						
14	The design of this project was created by making use of one or more of the six circular strategies mentioned	I think so, but I'm not sure	Design for efficiency is our goal as a company, so design for prevention was applied Design for reducing life cycle impact also, since low-maintenance materials were applied It is more efficient to create circular impact with larger projects than this relatively small project	Maybe not that deliberately, but design for future-proofness The bridges are placed in three seperate parts, making it possible to be dismantled and located somewhere else	I don't think these strategies were applied on purpose, but design for future proofness and design with secondary materials were applied in a certain way by choosing to construct the bridge in weatherproof steel But the project in general was design-driv	I don't know if it was done on purpose, but the reuse of materials was applied by using steel in this bridge, since steel can be fully recycled
15	This project was either designed for longevity, service/leasing, re-use in manufacture or material recovery	The project was designed for longetivity	n/a	n/a	The bridges have been designed for life expectancy of 50 years, but 100 years should be achievable as well	n/a
16	The first principle of the circulair economy and circular design, ''Design out waste and pollution'', has been integrated into the design of this project	n/a	n/a	n/a	n/a	n/a
Procurement						
17	The procurement models or procedures used were either a product-service system, public private partnership, cooperation model with parties on re-use and sharing, leasing model or a model containing a take-back system for suppliers	n/a	n/a	n/a	n/a	n/a

18	The submitted tender contributes to closed energy and material loops within supply chains, whilst minimizing, and in the best case avoiding, negative environmental impacts and waste creation across their whole life-cycle	n/a	n/a	n/a	n/a	n/a
19	The procurement procedure in the project was performance based and included tools like the life cycle approach, life cycle costs, and contained criteria for reuse of materials	n/a	No, but it was performance based due to a quality plan which aimed at esthetics and robustness	n/a	n/a	n/a
Construction						
20	What circularity measurements were taken during the construction of this project?	Not that I know of	Not that I know of	No	We executed some activities to lengthen the life span of the bridge, but that isn't noteworthy	No, there were some restrictions for CO2-emissions during the construction, but no measurements were taken
21	Have agreements been made with the supplier of materials for the recovery of materials after their lifespan?	No	No	No	No, the bridge has become property of the client	No
22	What measurements were taken to make the construction itself circular (or sustainable)? (Think of equipment, machinery, etc)	No	No	n/a	n/a	n/a
Operation & maintenance						
23	To what level can the project be dismantled for the harvest of future components?	I think it cannot be dismanteld to be constructed somewhere else	Some part of het superstructure can be dismantled and used again or recycled	The bridge can be dismantled into three decks and two supports, making it possible for the bridge to moved to another place It is also possible to recycle the materials In general, we did discuss when designing	It should be possible to dismantle the bridge entirely, making it possible to move the bridge to another location with the same span	The bridge could be cut into three segments and applied somewhere else In practice, this is probably not that simple
24	Are project components after its service life in this project reusable for new future projects?	Yes, but nothing special The steel, concrete and stones can be recycled	n/a	n/a	The bridge itself won't be directly reusable, but you could recycle the steel and create new steel	Not directly, but the steel can be recycled into new steel
25	The end-of-service life and possible future plans, considering the materials used, have been taken into account at the start of this project	As a requirement we asked for a bridge with a long lifespan So the materials have been chosen to accomodate this	No	No	No	Not that I know of I honestly don't think that this will become standard in the steel industry because steel is already easy to recycle

Project general							
26	Were there any differences or particularities in the project process when compared to the process of regular construction projects?	The design of the bridge was unique, making it part of a network of bridges So there was more attention paid to the future users of the bridge	The project was unique because of its context, being part of a family of small bridges in a crowded area, meaning that there was a participation aspect to it Atypical for the process was that the contractor took over the design responsibility of the superstructure, recreating the design to make it executable During this redesigning, the contractor and client were consulting us	We received a binding design from the architect, which we had to adapt to make it constructable In addition, we had to arrange a new subcontractor since the initial one went bankrupt	The project was unique because of the applied materials and the design Arc bridges are uncommon in The Netherlands due to soil conditions and the combination of stainless steel and weatherproof steel is also unique In addition, the process for us was also very different since our initial client for this project went bankrupt Luckily the contractor took over this role from the bankrupt company	This project was special for us, since we got this contract after the initial subcontractor went bankrupt In addition, the design was something special as well due to the unique combinations of applied materials
27	Were there any extra activities or steps that needed to be taken?	No	Initially we should only create the design, but eventually we were given a consultory role during the entire process	Yes, normally in a Design & Construct contract the esthetical design is not the number one priority, however in this project is was So we needed to tackle some issues resulting from the design	The construction of the bridge was a challenge to execute in the way the architect designed it Some adaptations to the design had to be made, and a scale model was created for the architect to see how the bridge would look like	No
28	Are circular construction projects, according to you, more or less expensive?	At first, more expensive	Depends on how circularity is translated into practice	I think it should be cheaper	At the start, these projects will be more expensive But eventually it will become cheaper	It depends on the type of project
29	What is the reason for these higher or lower costs?	Costs of investments At the start, it will be more expensive, but when materials become more scarce, the price will drop It is also more expensive because it is more complex	If circularity means constructing object larger than they should be to accomodate future use, it will be more expensive Initially it will be more expensive since technologies have not been progressed so far, but that will tilt in the future	Because you make smarter use of the resources available, making sure nothing will be discarded Right now this will take some time and energy upfront, but ultimately it will become cheaper since we will save upon the purchasing of materials	When bridges are standardized, there will be less engineering work to do In addition, we could reuse components and replace broken parts with parts that are on stock Due to a smaller stock of different components, there will be less costs of this stock	Monumental projects usually have a large number of requirements, making it more expensive Smaller objects are of course cheaper The materials and manhours are the cause for these larger costs
30	What may pose limitations towards circularity in construction projects?	Insights about the materials on functional level Circularity should become standard in our mindset	There are too few innovation projects Project requirements are often determined in a manner that there is no room left for innovation	The unfamiliarity of people and organisations about the implementation of circularity We need to stop thinking from a design, and start thinking from the available materials	The absence of standardized bridges Besides that, there needs to be a change in culture We need to accept that more things will become standardized and that there will be higher initial costs to facilitate a longer lifespan or re-usability of components	Insights about the materials themselves What are their properties and what is their previous use

Closing remarks						
31	Do you have the ambition to participate in (more) circular construction projects in the future, and why?	Yes, as well as from policymakers as the board	Absolutely	Of course I feel the urge to contribute to this topic Simultaniously however, I'm tempted to keep on following the same old procedures	Yes, but we do not have that much influence on projects, since we are an adivsing party which is involved when the design is already finished We will however raise circularity as topic with our clients	Of course If we can contribute to a better environment, we will do that Financially there is no incentive yet, but from the environmental viewpoint there is

General conclusions						
	Suggested sequence of components	Initiation, design competition, design, procurement, construction, operation & maintenance	Initiation, design competition, design, procurement, construction, operation & maintenance	Initiation, design competition, design, procurement, construction, operation & maintenance	Initiation, preliminary design, procurement, definitive design, construction, operation & maintenance	Initiation, design, procurement, construction, operation & maintenance
	Most important process remarks	1) Insights about the materials will provide more information about its possible future function or application	1) It is often unknown what has happened with a reused material More information on this would be beneficial 2) Innovation projects provides companies with the opportunity to innovate without any severe conseqeunces, hence these projects are beneficial for the further development of circularity in practice 3) Larger projects have a larger impact 4) Project requirements are often limiting the possibilities for innovation	1) The requirements of a project do often not allow for circularity 2) The financial incentive in a procurement procedure should be replaced by an incentive for circularity and sustainability 3) For circular projects we will need to think and design with the available materials instead of first designing and then start searching for materials 4) At the initiative of a project, we should already think about circularity	1) Standardization of bridges is the way to achieve circularity This results in less engineering work to do In addition, we could reuse components and replace broken parts with parts that are on stock Due to a smaller stock of different components, th	1) Insights about the materials themselves What are the properties and what was its previous use?
	Extra activities influencing the process	Design competition, the bridge being part of family of bridges	Civilian participation aspect to the design, consultory role of architect during the process	Binding design from architect, adaptation of design, search for a new subcontractor	Change in client, adaptation of the design	Suddenly involved into project

Appendix H: Overview of applied materials circular case project

Amount of applied materials and weights

Weight determination assumptions

For the determining the different weights of the materials applied in this project, the specific gravity (SG)of individual materials were used combined with the dimensions in order to determine its weight. The dimensions and amounts have been determined in project documents 13, 14, 15, 16, 17, 18 noted in Appendix Q. The SG applied per material are noted by the listed footnotes below which are referred to in the table:

1. Steel, SG = 7850 Kg/m³	Source:	Tosec (n.d.).
2. Concrete, SG = 2400 Kg/m³	Source:	Vastmans Frank (2020).
3. Steel, as weighted by Anton Constructiewerken	Source:	Anton Constructiewerken
4. Reinforced concrete girders, SG = 7,65 kN/m[1]	Source:	Beoordeling_te_handhaven_bestaande_kunstwerken.pdf
5. Reinforced rubber, SG = 1500 Kg/m³	Source:	Vilton (n.d.).
6. Wood quality D60, SG = 840 Kg/m³	Source:	Centrum Hout (2014).
7. Wood, European Oak, SG = 640 Kg/m³	Source:	Centrum Hout (2014).
8. Reinforced concrete, SG = 2500 Kg/m³	Source:	Vastmans Frank (2020).

Estimation of applied materials

Code	Description	Amount		Weight per unit		Total weight		Material source	Expected future use
1	**ACCESSIBILITY**								
2	**PILING**								
20	**Steel tubular piles**								
201010	Installment of steel tubular piles[1]	8	pcs			**45453,6**	**Kg**		
	Tubular pile Ø914mm, L= 16,8m	2	pcs	5947,2	Kg	11894,4	Kg	Reused	Recycle
	Tubular pile Ø914mm, L= 16,3m	2	pcs	5770,2	Kg	11540,4	Kg	Reused	Recycle
	Tubular pile Ø914mm, L= 15,8m	2	pcs	5593,2	Kg	11186,4	Kg	Reused	Recycle
	Tubular pile Ø914mm, L= 15,3m	2	pcs	5416,2	Kg	10832,4	Kg	Reused	Recycle
202020	Pouring concrete in tubular piles[2]	32	m³	2400	Kg	**76800**	**Kg**	New	Recycle
3	**STEEL WORK**								
30	**Substructure**								
301010	Installment of steel abutments[3]	2	pcs	3570,6	Kg	**7141,2**	**Kg**	Reused	Recycle
31	**Girders**								
311010	Concrete I-girders 1250/450mm[4]	6	pcs			**126092,58**	**Kg**		
	Steel reinforced concrete I-girder, L= 27,9m	2	pcs	21764,31	Kg	43528,62	Kg	Reused	Reuse
	Steel reinforced concrete I-girder, L= 25m	2	pcs	19502,07	Kg	39004,14	Kg	Reused	Reuse
	Steel reinforced concrete I-girder, L= 27,92m	2	pcs	21779,91	Kg	43559,82	Kg	Reused	Reuse
311020	Steel diamond plate beam support[3]	12	pcs	57	Kg	**684**	**Kg**	Reused	Recycle
311030	Girder pads[5]	12	pcs	6,62	Kg	**79,44**	**Kg**	New	Landfill
311040	Grouting[2]	0,44	m³	2400	Kg	**1056**	**Kg**	New	Recycle
32	**Superstructure**								
321010	Installment of steel support beams[3]	40	pcs			**4980**	**Kg**		
	Steel sheet 1200x50x4966mm	2	pcs	1896	Kg	3792	Kg	New	Recycle
	Steel sheet 535x20x4966mm	2	pcs	423	Kg	846	Kg	New	Recycle
	Steel sheet 535x15x1200mm	4	pcs	77	Kg	308	Kg	New	Recycle
	Steel sheet 45x10x290mm	32	pcs	1,0625	Kg	34	Kg	New	Recycle
321020	Installment of steel crossbeams[3]	29	pcs	682,8	Kg	**19801,2**	**Kg**		
	Applied new steel					4721,2	Kg	New	Recycle
	Applied reused steel					15080	Kg	Reused	Recycle
321030	Threaded rod M20, L=5000mm	348	pcs	10,5	Kg	**3654**	**Kg**	New	Recycle

4	**BRIDGE DECK**								
40	**Wooden deck**								
401010	Wooden girder, strength D60, 175x100x3000mm[6]	234	pcs	44,1	Kg	**10319,4**	**Kg**	Reused	Energy generation
401010	Wooden decking, strength D60, D60 35mm[6]	324	m²	29,4	Kg	**9525,6**	**Kg**	Reused	Energy generation
5	**RAILINGS**								
50	**Bench**								
501010	Wooden bench, strength D60, 35x440mm[6]	162	m1	12,94	Kg	**2096,28**	**Kg**	Reused	Energy generation
51	**Railing**								
511010	Steel railings[3]	270	pcs	9	Kg	**2430**	**Kg**	Reused	Recycle
511020	Threaded rod M12, L=1000mm	540	pcs	0,725	Kg	**391,5**	**Kg**	New	Recycle
511030	Wooden railway sleeper railing 150x70mm[7]	526	pcs			**5281,92**	**Kg**		
	Railway sleeper, oak, 150x70x2000mm	260	pcs	13,44	Kg	3494,4	Kg	Reused	Energy generation
	Railway sleeper, oak, 150x70x1000mm	266	pcs	6,72	Kg	1787,52	Kg	Reused	Energy generation
511040	Wooden railway sleeper top railing 250x140mm[7]	162	m1	22,4	Kg	**3628,8**	**Kg**	Reused	Energy generation
6	**FINISHING**								
60	**Baffle plates**								
601010	Reinforced concrete baffle plates 3000x1000x250mm[8]	8	st	1875	Kg	**15000**	**Kg**	New	Reuse

Constructed project Tweede leven brug		
WEIGHT REUSED MATERIALS	227733,38	Kg
WEIGHT NEW MATERIALS	106682,14	Kg
TOTAL WEIGHT	**334415,52**	**Kg**

Future material use after lifecycle Tweede leven brug		
Materials fit for landfill	**79,44**	**Kg**
Materials fit for energy generation	**30852**	**Kg**
Materials fit for recycling	**162392**	**Kg**
Materials fit for reuse	**141093**	**Kg**

Appendix I: Overview of applied materials regular case project

Amount of applied materials and weights

Weight determination assumptions

For the determining the different weights of the materials applied in this project, the specific gravity (SG)of individual materials were used combined with the dimensions in order to determine its weight. The weight of some applied materials have been received directly from the producer and thus are known. The dimensions and amounts have been determined in project documents 10, 11, 12, 24, 26, 27, 29 noted in Appendix Q. The SG applied per material and the known weights are noted by the listed footnotes below which are referred to in the table:

1. Steel, SG = 7850 Kg/m³ — Source: Tosec (n.d.).
2. Concrete, SG = 2400 Kg/m³ — Source: Vastmans Frank (2020).
3. Weatherproof steel, as weighted by Van der Zalm — Source: Van der Zalm, steel producer
3. Stainless steel, as weighted by Van der Zalm — Source: Van der Zalm, steel producer
3. Duplex stainless steel, as weighted by Van der Zalm — Source: Van der Zalm, steel producer
6. Wood Basralocus, quality D18, SG = 900 Kg/m³ — Source: Reggehout (n.d.).
7. Drainage mat, weight = 0,6 Kg/m² — Source: Emergo (2017).
8. Brick pavement waalformat, weight = 130 Kg/m² — Source: Wienerberger (n.d.).
9. Cast iron street lights, weight = 105 Kg/pc — Source: Ox-iron art (n.d.).
10. Iron pole cap, weight = 5Kg/pc — Source: Havenonderdelen (n.d.).

Estimation of applied materials

Code	Description	Amount		Weight per unit		Total weight		Material source	Expected future use
1	**ACCESSIBILITY**								
2	**PILING**								
20	**Steel tubular piles**								
201010	Installment of steel tubular piles[1]	12	pcs			**10523,08**	**Kg**		
	Tubular pile Ø324mm, L= 13m	2	pcs	810,43	Kg	1620,86	Kg	New	Reuse
	Tubular pile Ø324mm, L= 14,1m	4	pcs	879	Kg	3516	Kg	New	Reuse
	Tubular pile Ø324mm, L= 14m	2	pcs	872,77	Kg	1745,54	Kg	New	Reuse
	Tubular pile Ø324mm, L= 14,6m	4	pcs	910,17	Kg	3640,68	Kg	New	Reuse
3	**SUBSTRUCTURE**								
30	**Abutments**								
301010	Installment of concrete abutment west side[3]	2	pcs			**26340,5**	**Kg**		
	Concrete foundation floor	1,5	m³	2400	Kg	3600	Kg	New	Recycle
	Concrete abutment	7,5	m³	2400	Kg	18000	Kg	New	Recycle
	Steel rebar for concrete abutment west side	1	x	840,5	Kg	840,5	Kg	New	Recycle
	Masonry bricks waalbrick format 200x65x50mm	30	m²	130	Kg	3900	Kg	New	Recycle
301010	Installment of concrete abutment east side[3]	2	pcs			**15240,5**	**Kg**		
	Concrete foundation floor	1	m³	2400	Kg	2400	Kg	New	Recycle
	Concrete abutment	5	m³	2400	Kg	12000	Kg	New	Recycle
	Steel rebar for concrete abutment west side	1	x	840,5	Kg	840,5	Kg	New	Recycle
31	**Bridge support pillars**								
311010	Concrete support points	2	pcs			**13920**	**Kg**		
	Prefab concrete support beam 3,00x1,00x0,80m	2	pcs	5760	Kg	11520	Kg	New	Reuse
	Concrete mortar for assembly	1	m³	2400	Kg	2400	Kg	New	Recycle
4	**SUPERSTRUCTURE**								
40	**Steel bridge superstructure**								
400010	Steel bridge superstructure including pillars					**27569,2**	**Kg**		
	Weather-resistant steel bridge, including pillars	1	x	26620	Kg	26620	Kg	New	Recycle
	Stainless steel spheres	388	pcs	0,9	Kg	349,2	Kg	New	Recycle
	Duplex stainless steel pressure arch	2	pcs	300	Kg	600	Kg	New	Recycle
41	**Grouting**								
410010	Grouting of bearings	1	m³	2400	Kg	**2400**	**Kg**	New	Recycle

5	**BRIDGE DECK**								
50	**Pavement bridge deck**								
501010	Installing pavement on bridge deck	68	m²			**22773,2**	**Kg**		
	Drainage mat (1,5m² per 1m² pavement)	102	m²	0,6	Kg	61,2	Kg	New	Landfill
	Concrete mortar, thickness 85mm	5,78	m³	2400	Kg	13872	Kg	New	Recycle
	Pavement waalbrick format 200x65x50mm	68	m²	130	Kg	8840	Kg	New	Recycle
6	**EXTRA PROJECT ITEMS**								
60	**Lighting**								
601010	Cast iron street light Leiden	3	pcs	105	Kg	**315**	**Kg**	New	Recycle
61	**Canal structure**								
611010	Slackening structure	1	pcs			**3989**	**Kg**		
	Wooden beams, quality D18, 350x350x9000mm	4	pcs	992,25	Kg	3969	Kg	New	Energy generation
	Pole cap 250x250mm	4	pcs	5	Kg	20	Kg	New	Recycle

Constructed project Wisenniabrug		
WEIGHT REUSED MATERIALS	0	Kg
WEIGHT NEW MATERIALS	123070,48	Kg
TOTAL WEIGHT	**123070,48**	**Kg**

Future material use after lifecycle Wisenniabrug		
Materials fit for landfill	**61,2**	**Kg**
Materials fit for energy generation	**3969**	**Kg**
Materials fit for recycling	**96997,2**	**Kg**
Materials fit for reuse	**22043,08**	**Kg**

Appendix J: Calculation of circularity indicators circular case project

1.1 Secondary materials

$$S_x = \frac{\sum_i (m_i \times m_{si})}{\sum_i m_i} = \frac{334415.52 \times 69.74\%}{334415.52} = 69.74\%$$

S_x = 69,74%

m_i = Total weight = 334415,52 Kg

Mass of secondary input* = 233232,06 Kg

m_{si} = (Mass of secondary input)/(m_i) = 69,74%

* Mass of secondary consists of all applied secondary materials. The applied new steel is possibly coming from a recycled source since steel can easily be recycled into new steel. Since this is almost untraceable, the assumption of the average percentage steel from recycled sources of 40% is used as in this calculation (Björkman & Samuelsson, 2014).
Mass of secondary input = 45453,60 + 7141,2 + 126092,58 + 684 + 15080 + 10319,4 + 9525,6 + 2096,28 + 2430 + 5281,92 + 3628,8 + (4980 + 4721,2 + 3654 + 391,5)*0,4 = 233232,06 Kg

See Appendix H for specification of material weights

1.1.1 Reused secondary materials

$$H_x = \frac{\sum_i (m_i \times m_{s,hi})}{\sum_i m_i} = \frac{334415.52 \times 68.10\%}{334415.52} = 68.10\%$$

H_x = 68,10%

m_i = Total weight = 334415,52 Kg

Mass of reused input* = 227733,38 Kg

$m_{s,hi}$ = (Mass of reused input)/(m_i) = 68,10%

* Mass of reused input consists of all applied reused materials.
Mass of reused input = 45453,60 + 7141,2 + 126092,58 + 684 + 15080 + 10319,4 + 9525,6 + 2096,28 + 2430 + 5281,92 + 3628,8 = 227733,38 Kg

See Appendix H for specification of material weights

1.1.2 Recycled secondary materials

$$R_x = \frac{\sum_i (m_i \times m_{s,ri})}{\sum_i m_i} = \frac{334415.52 \times 1.64\%}{334415.52} = 1.64\%$$

R_x = 1,64%

m_i = Total weight = 334415,52 Kg

Mass of recycled input* = 5498,68 Kg

$m_{s,ri}$ = (Mass of recycled input)/(m_i) = 1,64%

* Mass of recycled input consists of all applied recycled materials. The applied new steel is possibly coming from a recycled source since steel can easily be recycled into new steel. Since this is almost untraceable, the assumption of the average percentage steel from recycled sources of 40% is used as in this calculation (Björkman & Samuelsson, 2014).
Mass of recycled input = (4980 + 4721,2 + 3654 + 391,5)*0,4 = 5498,68 Kg

See Appendix H for specification of material weights

1.2 Primary materials

$$V_x = \frac{\sum_i (m_i \times m_{vi})}{\sum_i m_i} = \frac{334415.52 \times 30.26\%}{334415.52} = 30.26\%$$

V_x = 30,26%

m_i = Total weight = 334415,52 Kg

Mass of primary input* = 101183,46 Kg

m_{vi} = (Mass of primary input)/(m_i) = 30,26%

See Appendix H for specification of material weights

* Mass of primary input consists of all applied new materials.
Mass of primary input = 76800+79,44+1056 + (4980 + 4721,2 + 3654 + 391,5)*0,6 + 15000 = 101183,46 Kg

1.2.1 Renewable primary materials

$$H_x = \frac{\sum_i (m_i \times m_h)}{\sum_i m_i} = \frac{334415.52 \times 0\%}{334415.52} = 0\%$$

H_x = 0,00%

m_i = Total weight = 334415,52 Kg

Mass of renewable primary input* = 0 Kg

m_h = (Mass of renewable primary input)/(m_i) = 0,00%

See Appendix H for specification of material weights

* Mass of renewable primary input consists of all renewable new materials, which is nothing. No renewable materials have been applied.

1.2.1a Sustainably produced renewable primary materials

$$N_x = \frac{\sum_i (m_i \times m_{ni})}{\sum_i m_i} = \frac{334415.52 \times 0\%}{334415.52} = 0\%$$

N_x = 0,00%

m_i = Total weight = 334415,52 Kg

Mass of sustainbly produced renewable primary input* = 0 Kg

m_{ni} = (Mass of sustainbly produced renewable primary input)/(m_i) = 0,00%

See Appendix H for specification of material weights

* Mass of sustainably produced renewable primary input consists of all sustainably produced renewable new materials, which is nothing. No renewable materials have been applied.

1.2.1b Unsustainably produced renewable primary materials

$$VN_x = \frac{\sum_i (m_i \times (m_{vi} - m_{ni}))}{\sum_i m_i} = \frac{334415.52 \times (0\% - 0\%)}{334415.52} = 0\%$$

VN_x = 0,00%

m_i = Total weight = 334415,52 Kg

Mass of sustainbly produced renewable primary input* = 0 Kg

m_{vi} = (Mass of renewable primary input) = 0,00%

m_{ni} = (Mass of sustainbly produced renewable primary input)/(m_i) = 0,00%

See Appendix H for specification of material weights

* Mass of sustainbly produced renewable primary input consists of all unsustainably produced renewable new materials, which is nothing. No renewable materials have been applied.

1.2.2 Non-renewable primary materials

$$NH_x = \frac{\sum_i (m_i \times m_{nh})}{\sum_i m_i} = \frac{334415.52 \times 30.26\%}{334415.52} = 30.26\%$$

NH_x = 30,26%

m_i = Total weight = 334415,52 Kg

Mass of non-renewable primary input* = 101183,5 Kg

m_{nh} = (Mass of non-renewable primary input)/(m_i) = 30,26%

See Appendix H for specification of material weights

* Mass of non-renewable primary input consists of all non-renewable new materials, which is all new materials combined.
Mass of non-renewable primary input = 76800 + 79,44 + 1056 + (4980 + 4721,2 + 3654 + 391,5)*0,6 + 15000 = 101183,46 Kg

1.3 Physically scarce materials

The indicator for physically scarce materials needs to be developed further with help of the ADP method for determining the physical scarcity. The integration of how to include the ADP-method into the Platform CB'23-method is still being investigated by Platform CB'23 (Platform CB'23, 2022). Therefore it has not been included in this circularity measurement.

1.4.1 Socio-economically non-scarce materials

$$NK_x = \frac{\sum_i (m_i \times m_{nk})}{\sum_i m_i} = \frac{334415.52 \times 74.70\%}{334415.52} = 74.70\%$$

NK_x = 74,70%

m_i = Total weight = 334415,52 Kg

Mass of socio-economically non-scarce input* = 249800,58 Kg

m_{nk} = (Mass of socio-economically non-scarce input)/(m_i) = 74,70%

See Appendix H for specification of material weights

* Mass of socio-economically non-scarce input consists of all socio-economically non-scarce materials applied, which is all materials except for steel and the girder pads.
Mass of socio-economically non-scarce input = 76800 + 126092,58 + 1056 + 10319,4 + 9525,6 + 2096,28 + 5281,92 + 3628,8 + 15000 = 249800,58 Kg

1.4.2 Socio-economically scarce materials

$$K_x = \frac{\sum_i (m_i \times m_k)}{\sum_i m_i} = \frac{334415.52 \times 25.30\%}{334415.52} = 25.30\%$$

K_x = 25,30%

m_i = Total weight = 334415,52 Kg

Mass of socio-economically scarce input* = 84614,94 Kg

m_k = (Mass of socio-econmically scarce input)/(m_i) = 25,30%

See Appendix H for specification of material weights

* Mass of socio-economically scarce input consists of all steel materials (use of Fluorite and Cokes) and girder pads (use of Natural rubber).
Mass of socio-economically scarce input = 45453,6 + 7141,2 + 684 + 79,44 + 4980 + 19801,2 + 3654 + 2430 + 391,5 = 84614,94 Kg

2.1 Output materials available for reusing

$$H_g = \frac{\sum_i (m_i \times m_{he})}{\sum_i m_i} = \frac{334415.52 \times 42.19\%}{334415.52} = 42.19\%$$

H_g = 42,19%

m_i = Total weight = 334415,52 Kg

Mass of reusable output* = 141092,6 Kg

m_{he} = (Mass of reusable output)/(m_i) = 42,19%

* Mass of reusable output consists of materials which could possibly be reused, which are according to the interviews, the concrete girders and the baffle plates.
Mass of reusable output = 126092,58 + 15000 = 141092,6 Kg

See Appendix H for specification of material weights

2.2 Output materials available for recycling

$$R_e = \frac{\sum_i (m_i \times m_{re})}{\sum_i m_i} \quad \frac{334415.52 \times 40.31\%}{334415.52} = 48.56\%$$

R_e = 48,56%

m_i = Total weight = 334415,52 Kg

Mass of recyclable output* = 162391,5 Kg

m_{re} = (Mass of recyclable output)/(m_i) = 48,56%

* Mass of recyclable output consists of materials which could possibly be recycled, which are the steel components and the poured concrete.
Mass of recyclable output = 45453,6 + 76800 + 7141,2 + 684 + 1056 + 4980 + 19801,2 + 3654 + 2430 + 391,5 = 162391,5 Kg

See Appendix H for specification of material weights

3.1 Output materials most likely used for energy generation

$$R_{ew} = \frac{\sum_i (m_i \times m_{ew})}{\sum_i m_i} = \frac{334415.52 \times 9.23\%}{334415.52} = 9.23\%$$

R_{ew} = 9,23%

m_i = Total weight = 334415,52 Kg

Mass of output to be burned* = 30852 Kg

m_{ew} = (Mass of output to be burned)/(m_i) = 9,23%

* Mass of output to be burned consists of materials which will possibly be used for energy generation, which are wooden components.
Mass of output to be burned = 10319,4 + 9525,6 + 2096,28 + 5281,92 + 3628,8 = 30852 Kg

See Appendix H for specification of material weights

3.2 Output materials most likely used as landfill

$$R_{st} = \frac{\sum_i (m_i \times m_{st})}{\sum_i m_i} = \frac{334415.52 \times 0.02\%}{334415.52} = 0.02\%$$

R_{st} = 0,02%

m_i = Total weight = 334415,52 Kg

Mass of output to be used as landfill* = 79,44 Kg

m_{st} = (Mass of output to be used as landfill)/(m_i) = 0,02%

* Mass of output to be used as landfill consists of materials which will possibly be used as landfill, which are the girder pads only.

See Appendix H for specification of material weights

Appendix K: Calculation of circularity indicators regular case project

1.1 Secondary materials

$$S_x = \frac{\sum_i (m_i \times m_{si})}{\sum_i m_i} = \frac{123070.48 \times 13.04\%}{123070.48} = 13.04\%$$

S_x = 13,04%

m_i = Total weight = 123070,48 Kg

Mass of secondary input* = 16043,31 Kg

m_{si} = (Mass of secondary input)/(m_i) = 13,04%

See Appendix I for specification of material weights

* Mass of secondary input consists of all applied secondary materials. The applied new steel is possibly coming from a recycled source since steel can easily be recycled into new steel. Since this is almost untraceable, the assumption of the average percentage steel from recycled sources of 40% is used as in this calculation (Björkman & Samuelsson, 2014).
Mass of secondary input = (10523,08 + 840,5 + 840,5 + 27569,2 + 315 + 20) * 0,4 = 16043,31 Kg.

1.1.1 Reused secondary materials

$$H_x = \frac{\sum_i (m_i \times m_{s,hi})}{\sum_i m_i} = \frac{123070.48 \times 0\%}{123070.48} = 0\%$$

H_x = 0,00%

m_i = Total weight = 123070,48 Kg

Mass of reused input* = 0 Kg

$m_{s,hi}$ = (Mass of reused input)/(m_i) = 0,00%

See Appendix I for specification of material weights

* Mass of reused input consists of all applied reused materials, which is nothing. No reused materials have been applied.

1.1.2 Recycled secondary materials

$$R_x = \frac{\sum_i (m_i \times m_{s,ri})}{\sum_i m_i} = \frac{123070.48 \times 13.04\%}{123070.48} = 13.04\%$$

R_x = 13,04%

m_i = Total weight = 123070,48 Kg

Mass of recycled input* = 16043,31 Kg

$m_{s,ri}$ = (Mass of recycled input)/(m_i) = 13,04%

See Appendix I for specification of material weights

* Mass of recycled input consists of all applied recycled materials. The applied new steel is possibly coming from a recycled source since steel can easily be recycled into new steel. Since this is almost untraceable, the assumption of the average percentage steel from recycled sources of 40% is used as in this calculation (Björkman & Samuelsson, 2014).
Mass of recycled input = (10523,08 + 840,5 + 840,5 + 27569,2 + 315 + 20) * 0,4 = 16043,31 Kg.

1.2 Primary materials

$$V_x = \frac{\sum_i (m_i \times m_{vi})}{\sum_i m_i} = \frac{123070.48 \times 100\%}{123070.48} = 100\%$$

V_x = 100,00%

m_i = Total weight = 123070,48 Kg

Mass of primary input* = 123070,48 Kg

m_{vi} = (Mass of primary input)/(m_i) = 100,00%

See Appendix I for specification of material weights

* Mass of primary input consists of all applied new materials. All applied materials were new in this case project.

1.2.1 Renewable primary materials

$$H_x = \frac{\sum_i (m_i \times m_h)}{\sum_i m_i} = \frac{123070.48 \times 3.22\%}{123070.48} = 3.22\%$$

H_x = 3,22%

m_i = Total weight = 123070,48 Kg

Mass of renewable primary input* = 3969 Kg

m_h = (Mass of renewable primary input)/(m_i) = 3,22%

* Mass of renewable primary input consists of all renewable new materials, which is the applied wood for the slackening structure. Mass of renewable primary input = slackening structure = 3969 Kg.

See Appendix I for specification of material weights

1.2.1a Sustainably produced renewable primary materials

$$N_x = \frac{\sum_i (m_i \times m_{ni})}{\sum_i m_i} = \frac{123070.48 \times 3.22\%}{123070.48} = 3.22\%$$

N_x = 3,22%

m_i = Total weight = 123070,48 Kg

Mass of sustainbly produced renewable primary input* = 3969 Kg

m_{ni} = (Mass of sustainbly produced renewable primary input)/(m_i) = 3,22%

* Mass of sustainably produced renewable primary input consists of all sustainably produced renewable new materials, which is the applied FSC certfied wood. Mass of sustainably produced renewable primary input = Wood of slackening structure = 3969 Kg.

See Appendix I for specification of material weights

1.2.1b Unsustainably produced renewable primary materials

$$VN_x = \frac{\sum_i (m_i \times (m_{vi} - m_{ni}))}{\sum_i m_i} = \frac{123070.48 \times (3.22\% - 3.22\%)}{123070.48} = 0\%$$

VN_x = 0,00%

m_i = Total weight = 123070,48 Kg

Mass of sustainbly produced renewable primary input* = 3969 Kg

m_{vi} = (Mass of renewable primary input) = 3,22%

m_{ni} = (Mass of sustainbly produced renewable primary input)/(m_i) = 3,22%

* Mass of sustainably produced renewable primary input consists of all sustainably produced renewable new materials, see indicator 1.2.1a for specifications.

See Appendix I for specification of material weights

1.2.2 Non-renewable primary materials

$$NH_x = \frac{\sum_i (m_i \times m_{nh})}{\sum_i m_i} = \frac{123070.48 \times 96.78\%}{123070.48} = 96.78\%$$

NH_x = 96,78%

m_i = Total weight = 123070,48 Kg

Mass of non-renewable primary input* = 119101,5 Kg

m_{nh} = (Mass of non-renewable primary input)/(m_i) = 96,78%

* Mass of non-renewable primary input consists of all non-renewable new materials, which is all new materials combined except for the wooden components. Mass of non-renewable primary input = 10523,08 + 26340,5 + 15240,5 + 13920 + 27569,2 + 2400 + 22773,2 + 315 = 119101,5 Kg.

See Appendix I for specification of material weights

1.3 Physically scarce materials

The indicator for physically scarce materials needs to be developed further with help of the ADP method for determining the physical scarcity. The integration of how to include the ADP-method into the Platform CB'23-method is still being investigated by Platform CB'23 (Platform CB'23, 2022).

1.4.1 Socio-economically non-scarce materials

$$NK_x = \frac{\sum_i (m_i \times m_{nk})}{\sum_i m_i} = \frac{123070.48 \times 67.41\%}{123070.48} = 67.41\%$$

NK_x = **67,41%**

m_i = Total weight = 123070,48 Kg

Mass of socio-econmically non-scarce input* = 82962,20 Kg

m_{nk} = (Mass of socio-econmically non-scarce input)/(m_i) = 67,41%

* Mass of socio-econmically non-scarce input consists of all socio-economically non-scarce materials applied, which is all materials except for the steel, stainless steel, Duplex stainless steel and cast iron components.

Mass of socio-econmically non-scarce input = 3600 + 18000 + 3900 + 2400 + 12000 + 11520 + 2400 + 2400 + 22773,2 + 3969 = 82962,2 Kg.

See Appendix I for specification of material weights

1.4.2 Socio-economically scarce materials

$$K_x = \frac{\sum_i (m_i \times m_k)}{\sum_i m_i} = \frac{123070.48 \times 32.59\%}{123070.48} = 32.59\%$$

K_x = **32,59%**

m_i = Total weight = 123070,48 Kg

Mass of socio-economically scarce input* = 40108,28 Kg

m_k = (Mass of socio-econmically scarce input)/(m_i) = 32,59%

* Mass of socio-economically scarce input consists of all steel, stainless steel and Duplex stainless steel components (use of Fluorite and Cokes) + Cast iron components (use of Phosphorus and Silicon).

Mass of socio-economically scarce input = 10523,08 + 840,5 + 840,5 +27569,2 + 315 + 20 = 40108,28 Kg.

See Appendix I for specification of material weights

2.1 Output materials available for reusing

$$H_g = \frac{\sum_i (m_i \times m_{he})}{\sum_i m_i} = \frac{123070.48 \times 17.91\%}{123070.48} = 17.91\%$$

H_g = **17,91%**

m_i = Total weight = 123070,48 Kg

Mass of reusable output* = 22043,08 Kg

m_{he} = (Mass of reusable output)/(m_i) = 17,91%

* Mass of reusable output consists of materials which could possibly be reused, which are, according to the interviews and logical reasoning, the steel piling and concrete support beams.

Mass of reusable output = 10523,08 + 11520 = 22043,08 Kg.

See Appendix I for specification of material weights

2.2 Output materials available for recycling

$$R_e = \frac{\sum_i (m_i \times m_{re})}{\sum_i m_i} = \frac{123070.48 \times 78.81\%}{123070.48} = 78.81\%$$

R_e = **78,81%**

m_i = Total weight = 123070,48 Kg

Mass of recyclable output* = 96997,2 Kg

m_{re} = (Mass of recyclable output)/(m_i) = 78,81%

* Mass of recyclable output consists of materials which could possibly be recycled, which are the steel, stainless steel, Duplex stainless steel and cast iron components and the poured concrete and mortar.

Mass of recyclable output = 26340,5 + 15240,5 + 2400 + 27569,2 + 2400 + 13872 + 8840 + 315 + 20 = 96997,2 Kg.

See Appendix I for specification of material weights

3.1	Output materials most likely used for energy generation

$$R_{ew} = \frac{\sum_i (m_i \times m_{ew})}{\sum_i m_i} = \frac{123070.48 \times 3.22\%}{123070.48} = 3.22\%$$

R_{ew} = 3,22%

m_i = Total weight = 123070,48 Kg

Mass of output to be burned* = 3969 Kg

m_{ew} = (Mass of output to be burned)/(m_i) = 3,22%

* Mass of output to be burned consists of materials which will possibly be used for energy generation, which are the wooden components.
Mass of output to be burned = Wood of slackening structure = 3969 Kg.

See Appendix I for specification of material weights

3.2	Output materials most likely used as landfill

$$R_{st} = \frac{\sum_i (m_i \times m_{st})}{\sum_i m_i} = \frac{123070.48 \times 0.05\%}{123070.48} = 0.05\%$$

R_{st} = 0,05%

m_i = Total weight = 123070,48 Kg

Mass of output to be used as landfill* = 61,2 Kg

m_{st} = (Mass of output to be used as landfill)/(m_i) = 0,05%

* Mass of output to be used as landfill consists of materials which will possibly be used as landfill, which are the drainage mats.
Mass of output to be used as landfill = Drainage mats = 61,2 Kg.

See Appendix I for specification of material weights

Appendix L: Construction costs overview circular case project

Estimated construction costs Tweede leven brug

Code	Description	Amount	Unit	Price per unit	Total
	DIRECT CONSTRUCTION COSTS				
1	**ACCESSIBILITY**				
10	**Scaffolding**				**€ 17.954,57**
100000	SUBCONTRACTING: Scaffolding for bridge work				€ [redacted]
	Transport scaffolding	[redacted]	EUR	€ [redacted]	€ [redacted]
	Scaffolding assembly	377	m²	€ [redacted]	€ [redacted]
	Rent scaffolding	12	Wks	€ [redacted]	€ [redacted]
	Scaffolding disassembly	377	m²	€ [redacted]	€ [redacted]
2	**PILING**				
20	**Piling foundation**				**€ 64.836,00**
200000	SUBCONTRACTING: Supply and application steel piling				€ [redacted]
	Supply and application steel tubular pile Ø914mm, average L= 16,05m	8	Pcs	€ [redacted]	€ [redacted]
	Inspection and certification steel piling	1	Pcs	€ [redacted]	€ [redacted]
200010	Torch steel piling at desired height				€ [redacted]
	Welder	16	Hr	€ [redacted]	€ [redacted]
	Telescopic crane	4	Hr	€ [redacted]	€ [redacted]
200020	Remove ground from steel piling				€ [redacted]
	Vacuum excavation of steel piling	8	Pcs	€ [redacted]	€ [redacted]
200030	Supply and applying concrete in steel piling				€ [redacted]
	Carpenter	16	Hr	€ [redacted]	€ [redacted]
	Telescopic crane	8	Hr	€ [redacted]	€ [redacted]
	Concrete mixture C30/37	32	m³	€ [redacted]	€ [redacted]
3	**BRIDGE STRUCTURE**				
30	**Substructure**				**€ 28.322,30**
300000	SUBCONTRACTING: Supply and applying steel abutments				€ [redacted]
	Supply of steel material	7141,2	Kg	€ [redacted]	€ [redacted]
	Transport to treatment location	[redacted]	EUR	€ [redacted]	€ [redacted]
	Preparing steel for treatment	24	Hr	€ [redacted]	€ [redacted]
	Treatment (sawing, composing, welding)	200	Hr	€ [redacted]	€ [redacted]
	Transport	[redacted]	EUR	€ [redacted]	€ [redacted]
	Assembly	108	Hr	€ [redacted]	€ [redacted]
	General costs subcontractor	[redacted]	EUR	€ [redacted]	€ [redacted]
31	**Girders**				**€ 70.375,13**
310000	SUBCONTRACTING: Repair of concrete girders				€ 22.700,99
	Measurement and determination of girder face ends	[redacted]	EUR	€ [redacted]	€ [redacted]
	Sawing girders	[redacted]	EUR	€ [redacted]	€ [redacted]
	Hydrojet girders	1	Pcs	€ [redacted]	€ [redacted]
	Disposal of debris	1485	Kg	€ [redacted]	€ [redacted]
	Sand blast exposed steel reinforcement	[redacted]	EUR	€ [redacted]	€ [redacted]
	Supply and application of primer to steel reinforcements	12	Pcs	€ [redacted]	€ [redacted]
	Supply and application of formwork	12	Pcs	€ [redacted]	€ [redacted]
	Supply of concrete mortar	1056	Kg	€ [redacted]	€ [redacted]
	Applying concrete mortar	12	Pcs	€ [redacted]	€ [redacted]
	Demoulding and finishing girder face ends	12	Pcs	€ [redacted]	€ [redacted]
	Applying girder face ends with sealing layer	12	Pcs	€ [redacted]	€ [redacted]
	Finishing openings Dywidag	42	Pcs	€ [redacted]	€ [redacted]
310010	Loading and supplying concrete girders				€ [redacted]

	Supply of concrete girders (already in possession)	6	Pcs	€ -	€ -
	Carpenter	32	Hr	€ [redacted]	€ [redacted]
	Telescopic crane 300 ton	16	Hr	€ [redacted]	€ [redacted]
	Truck	16	Hr	€ [redacted]	€ [redacted]
310020	Bracing of concrete girders				€ [redacted]
	Bracing of concrete girders on structure	[redacted]	EUR	€ [redacted]	€ [redacted]
310030	SUBCONTRACTING: Supply and applying steel beam supports				€ [redacted]
	Supply of steel diamond plate material	684	Kg	€ [redacted]	€ [redacted]
	Treatment of steel (sawing, composing, welding)	96	Hr	€ [redacted]	€ [redacted]
	Transport	1	Pcs	€ [redacted]	€ [redacted]
	Assembly	24	Hr	€ [redacted]	€ [redacted]
	General costs subcontractor	[redacted]	EUR	€ [redacted]	€ [redacted]
310040	Supply and applying girder pads				€ [redacted]
	Supply of girder pads	12	Pcs	€ [redacted]	€ [redacted]
	Carpenter	6	Hr	€ [redacted]	€ [redacted]
310050	Installment of concrete girders				€ [redacted]
	Carpenter	64	Hr	€ [redacted]	€ [redacted]
	Telescopic crane 300 ton	16	Hr	€ [redacted]	€ [redacted]
310060	Supply and applying concrete mortar for grouting girder				€ [redacted]
	Carpenter	40	Hr	€ [redacted]	€ [redacted]
	Concrete mortar	0,44	m³	€ [redacted]	€ [redacted]
32	**Superstructure**				**€ 113.183,22**
320000	SUBCONTRACTING: Supply and application of steel crossbeams				€ [redacted]
	Supply of steel material	19801,2	Kg	€ [redacted]	€ [redacted]
	Disassembly of initial steel material	87	Hr	€ [redacted]	€ [redacted]
	Preparing steel for treatment	72,5	Hr	€ [redacted]	€ [redacted]
	Treatment of steel (sawing, composing, welding)	406	Hr	€ [redacted]	€ [redacted]
	Threaded rod M20, L=5000mm	348	Pcs	€ [redacted]	€ [redacted]
	Bracing	1	Pcs	€ [redacted]	€ [redacted]
	Transport	2	Pcs	€ [redacted]	€ [redacted]
	Assembly	261	Hr	€ [redacted]	€ [redacted]
	General costs subcontractor	[redacted]	EUR	€ [redacted]	€ [redacted]
320010	Drilling holes in concrete girders				€ [redacted]
	Drilling holes in concrete girders for assembly	348	Pcs	€ [redacted]	€ [redacted]
320020	Supply and applying grouting between girders and head plate				€ [redacted]
	Carpenter	184	Hr	€ [redacted]	€ [redacted]
	Formwork	58	Pcs	€ [redacted]	€ [redacted]
	Concrete mortar	58	Pcs	€ [redacted]	€ [redacted]
320030	SUBCONTRACTING: Supply and applying steel support beams				€ [redacted]
	Steel material	4980	Kg	€ [redacted]	€ [redacted]
	Treatment of steel (sawing, composing, welding)	64	Hr	€ [redacted]	€ [redacted]
	Transport	[redacted]	EUR	€ [redacted]	€ [redacted]
	Assembly	108	Hr	€ [redacted]	€ [redacted]
	General costs subcontractor	[redacted]	EUR	€ [redacted]	€ [redacted]
4	**BRIDGE DECK**				
40	**Wooden deck**				**€ 142.862,63**
400000	SUBCONTRACTING: Supply and application wooden girders				€ [redacted]
	Harvest of wood	[redacted]	EUR	€ [redacted]	€ [redacted]
	Supply of wood	17,52	m³	€ [redacted]	€ [redacted]

	Transport	17,52	m³	€ [redacted]	€ [redacted]
	Cleaning the wood	17,52	m³	€ [redacted]	€ [redacted]
	Sorting, sawing, shortening and planing the wood	17,52	m³	€ [redacted]	€ [redacted]
	General costs subcontractor	[redacted]	EUR	€ [redacted]	€ [redacted]
400010	SUBCONTRACTING: Supply and application wooden bridge deck				€ [redacted]
	Harvest of wood	[redacted]	EUR	€ [redacted]	€ [redacted]
	Supply of wood (already in possession)	30	m³	€ -	€ -
	Transport	30	m³	€ [redacted]	€ [redacted]
	Cleaning the wood	30	m³	€ [redacted]	€ [redacted]
	Sorting, sawing, shortening and planing the wood	30	m³	€ [redacted]	€ [redacted]
	General costs subcontractor	[redacted]	EUR	€ [redacted]	€ [redacted]
5	**RAILING**				
50	**Bench**				**€ 35.873,80**
500000	SUBCONTRACTING: Supply and application wooden bench Oak				€ [redacted]
	Harvest of wood	[redacted]	EUR	€ [redacted]	€ [redacted]
	Supply of wood	3,645	m³	€ [redacted]	€ [redacted]
	Transport	3,645	m³	€ [redacted]	€ [redacted]
	Cleaning the wood	3,645	m³	€ [redacted]	€ [redacted]
	Sorting, sawing, shortening and planing the wood	3,645	m³	€ [redacted]	€ [redacted]
	Check bevels	3,645	m³	€ [redacted]	€ [redacted]
	General costs subcontractor	[redacted]	EUR	€ [redacted]	€ [redacted]
500010	SUBCONTRACTING: Supply and application wooden bench wagon wood				€ [redacted]
	Harvest of wood	[redacted]	EUR	€ [redacted]	€ [redacted]
	Supply of wood	4,617	m³	€ [redacted]	€ [redacted]
	Transport	4,617	m³	€ [redacted]	€ [redacted]
	Cleaning the wood	4,617	m³	€ [redacted]	€ [redacted]
	Sorting, sawing, shortening and planing the wood	4,617	m³	€ [redacted]	€ [redacted]
	Check bevels	4,617	m³	€ [redacted]	€ [redacted]
	General costs subcontractor	[redacted]	EUR	€ [redacted]	€ [redacted]
51	**Railing**				**€ 111.778,73**
510000	SUBCONTRACTING: Supply and application steel railing				€ [redacted]
	Supply of steel material	2430	Kg	€ [redacted]	€ [redacted]
	Treatment of steel (sawing, composing, welding)	200	Hr	€ [redacted]	€ [redacted]
	Threaded rod M12, L=1000mm	540	Pcs	€ [redacted]	€ [redacted]
	Transport	[redacted]	EUR	€ [redacted]	€ [redacted]
	Assembly	135	Hr	€ [redacted]	€ [redacted]
	General costs subcontractor	[redacted]	EUR	€ [redacted]	€ [redacted]
510010	SUBCONTRACTING: Supply and application wooden railing				€ [redacted]
	Harvest of wood	[redacted]	EUR	€ [redacted]	€ [redacted]
	Supply of wooden railway sleepers	14,88	m³	€ [redacted]	€ [redacted]
	Transport	14,88	m³	€ [redacted]	€ [redacted]
	Cleaning the wood	14,88	m³	€ [redacted]	€ [redacted]
	Sorting, sawing, shortening and planing the wood	14,88	m³	€ [redacted]	€ [redacted]
	General costs subcontractor	[redacted]	EUR	€ [redacted]	€ [redacted]
510020	SUBCONTRACTING: Supply and application wooden top railing				€ [redacted]
	Harvest of wood	[redacted]	EUR	€ [redacted]	€ [redacted]
	Supply of wooden railway sleepers	7,69	m³	€ [redacted]	€ [redacted]
	Transport	7,69	m³	€ [redacted]	€ [redacted]
	Cleaning the wood	7,69	m³	€ [redacted]	€ [redacted]
	Sorting, sawing, shortening and planing the wood	7,69	m³	€ [redacted]	€ [redacted]
	Chisel costs and setting up machine	[redacted]	EUR	€ [redacted]	€ [redacted]
	General costs subcontractor	[redacted]	EUR	€ [redacted]	€ [redacted]

6	**FINISHING**				
60	**Baffle plates**				€ 5.496,00
600000	Supply and application concrete baffle plates				€ [redacted]
	Carpenter	16	Hr	€ [redacted]	€ [redacted]
	Mobile crane	8	Hr	€ [redacted]	€ [redacted]
	Supply concrete baffle plates 3000x1000x250mm	8	Pcs	€ [redacted]	€ [redacted]
				TOTAL INCURRED DIRECT COSTS =	**€ 590.682,39**
INDIRECT CONSTRUCTION COSTS					
90	**Construction site costs**				
900	**Construction site**				€ [redacted]
900000	General construction site costs	[redacted]	EUR	€ [redacted]	€ [redacted]
91	**Non-recurring costs**				
910	General costs subcontracting				€ [redacted]
910000	Project preparation for construction subcontractor				€ [redacted]
	Detailed calculation and drawings	[redacted]	Hr	€ [redacted]	€ [redacted]
	Work preparation and project management	[redacted]	Hr	€ [redacted]	€ [redacted]
	Welding plan and welding engineer	[redacted]	Hr	€ [redacted]	€ [redacted]
	Execution	[redacted]	Hr	€ [redacted]	€ [redacted]
	Project team costs, steel disassembly, transport	[redacted]	EUR	€ [redacted]	€ [redacted]
	Extra activities subcontractor	[redacted]	EUR	€ [redacted]	€ [redacted]
92	**Operating costs**				
920	Operating personell				€ [redacted]
920000	Executive, technical, administrative (UTA) employees Dura Vermeer				€ [redacted]
	Paver	10	Hr	€ [redacted]	€ [redacted]
	Purchaser	3,16	Hr	€ [redacted]	€ [redacted]
	Project planner	477,71	Hr	€ [redacted]	€ [redacted]
	Project manager	417,75	Hr	€ [redacted]	€ [redacted]
	Foreman	683,84	Hr	€ [redacted]	€ [redacted]
	Surveyors	119,98	Hr	€ [redacted]	€ [redacted]
	Social return staff	18,04	Hr	€ [redacted]	€ [redacted]
	Telescopic crane	2	Hr	€ [redacted]	€ [redacted]
93	**Overhead costs**				
930	General costs				€ [redacted]
930000	General costs	[redacted]	EUR	€ [redacted]	€ [redacted]
				TOTAL INCURRED INDIRECT COSTS =	**€ 349.293,09**

Assumptions construction costs Tweede leven brug

Wherever possible, the costs will be split into incurred manhours, materials and equipment. This specification of costs elements also applied to subcontracted compents. Manhours, materials, equipment, and contracts with subcontractors are often lumped together in the incurred costs overview. To breakdown the lump sum in manhours, materials and equipment, the accepted contracts with the subcontracters have been analyzed. Whenever a subcontracted cost component is not further specified than a lump sum, the issued contract did not provide the cost breakdown. This resulted in contacting the subcontractor for the specification of costs. In some cases, the subcontractor did not want to cooperate in disclosing their price breakdown of the lump sum.

General
The construction costs have been determined with help of the overview of construction costs. This document is an internal documents in which the actual costs for the contractor itself are being tracked. There are unfortunately a couple of cost components that were initially in this document, but were deemed obsolete in a later stage. These are: - Soil work in preparation for prefab retaining wall; - Supply and application of prefab retaining wall; - Supply and application of lighting.

Harvesting of wood
The harvest of wood to be reused in the circular project was executed by the subcontractor for a lump sum of € 130,000.00, without any specifications of activities. Since this cost item is linked to the wooden materials, it has been added to cost items in which reused wood was applied. Based on the amount of wood applied in relation to the total amount of reused wood, the lump sum of € 130,000.00 was divided over the cost items.

General costs subcontractors
The subcontractors responsible for supplying and applying the wood and the steel materials issued general costs for their activities. Usually, the general costs for suppliers and subcontractors is included in their unit price, price of equipment or hourly wages of their applied workforce in the project. Both contractors invoiced their general costs seperately from the activites described in the issued contract. Therefore, the general costs have been equally distributed over the relevant cost items, based on the ratio costs of cost item to the total costs of the subcontractor.

Maintenance costs
Costs of large maintenance items are largely dependent on the amount of wear and tear. It is difficult to approximate the abrasion over a period of 10 or more years. In addition, once the large maintenance will be executed, a whole different price level is dominating the expenditures on maintenance. Hence, this price level is also hard to determine. The activities within this maintenance cost overview have been deteremined by consultation with experts which are responsible of providing a maintenance plan.

Appendix M: Construction costs overview regular case project

Incurred construction costs Wisenniabrug

Code	Description	Estimated amount	unit	Factor	Incurred amount	unit	Price per unit	Total	Cost type
	DIRECT CONSTRUCTION COSTS								
1	**ACCESSIBILITY**								
10	**Lighting**							**€ 10.828,25**	
100000	SUBCONTRACTOR: Delivery, installation, moving street lighting							€ [redacted]	
	Subcontracting street lighting	[redacted]	EUR	0,93	[redacted]	EUR	€ [redacted]	€ [redacted]	8010
2	**PILING**								
20	**Piling foundation**							**€ 18.339,63**	
200000	SUBCONTRACTING: Supply and application steel piling							€ [redacted]	
	Subcontracting steel piling Ø324mm, average L= 14,07	[redacted]	EUR	0,76	[redacted]	EUR	€ [redacted]	€ [redacted]	8040
3	**BRIDGE STRUCTURE**								
30	**Substructure**							**€ 66.398,69**	
300	**Preparatory work abutment Oude Herengracht**							**€ [redacted]**	
300000	Removal of pavement and excavation of retaining wall foundation							€ [redacted]	
	Laborer	8	Hr	2,32	18,59	Hr	€ [redacted]	€ [redacted]	2010
	Small track excavator	8	Hr	2,32	18,59	Hr	€ [redacted]	€ [redacted]	2010
	Mobile excavator	1	Hr	2,32	2,32	Hr	€ [redacted]	€ [redacted]	2010
300010	SUBCONTRACTOR: Drilling retaining wall							€ [redacted]	
	Subcontracting drilling	3	Pcs	6,73	20,20	Pcs	€ [redacted]	€ [redacted]	8020
300020	Complement to ground level + laying PVC pipe							€ [redacted]	
	Laborer	4	Hr	2,32	9,30	Hr	€ [redacted]	€ [redacted]	2010
	Small track excavator	4	Hr	2,32	9,30	Hr	€ [redacted]	€ [redacted]	2010
	Mobile excavator	1	Hr	2,32	2,32	Hr	€ [redacted]	€ [redacted]	2010
	PVC pipe Ø400mm	3	Pcs	1,46	4,37	Pcs	€ [redacted]	€ [redacted]	7080
	Grouting	[redacted]	EUR	1,46	[redacted]	EUR	€ [redacted]	€ [redacted]	7080
300030	Excavate until abutment base							€ [redacted]	
	Laborer	4	Hr	2,32	9,30	Hr	€ [redacted]	€ [redacted]	2010
	Small track excavator	4	Hr	2,32	9,30	Hr	€ [redacted]	€ [redacted]	2010
	Mobile excavator	1	Hr	2,32	2,32	Hr	€ [redacted]	€ [redacted]	2010
	Truck	4	Hr	2,32	9,30	Hr	€ [redacted]	€ [redacted]	2010
	Landfill costs	[redacted]	EUR	2,20	[redacted]	EUR	€ [redacted]	€ [redacted]	2010
300040	Complement to ground level							€ [redacted]	
	Laborer	4	Hr	2,32	9,30	Hr	€ [redacted]	€ [redacted]	2010
	Small track excavator	4	Hr	2,32	9,30	Hr	€ [redacted]	€ [redacted]	2010
	Mobile excavator	1	Hr	2,32	2,32	Hr	€ [redacted]	€ [redacted]	2010
	Truck	4	Hr	2,32	9,30	Hr	€ [redacted]	€ [redacted]	2010
	Supply of sand	[redacted]	EUR	2,20	[redacted]	EUR	€ [redacted]	€ [redacted]	2010
300050	Restore pavement							€ [redacted]	
	Paver	16	Hr	0,94	15,02	Hr	€ [redacted]	€ [redacted]	8030
	Pavement various	[redacted]	EUR	1,77	[redacted]	EUR	€ [redacted]	€ [redacted]	7040
301	**Abutment Houtmarkt prepratory work**							**€ [redacted]**	
301000	Excavation on behalf of load-bearing posts							€ [redacted]	
	Laborer	4	Hr	2,32	9,30	Hr	€ [redacted]	€ [redacted]	2010
	Small track excavator	4	Hr	2,32	9,30	Hr	€ [redacted]	€ [redacted]	2010
	PVC pipe Ø400mm	2	Pcs	1,46	2,91	Pcs	€ [redacted]	€ [redacted]	7080
301010	Complement soil load-bearing posts							€ [redacted]	
	Laborer	4	Hr	2,32	9,30	Hr	€ [redacted]	€ [redacted]	2010
	Small track excavator	4	Hr	2,32	9,30	Hr	€ [redacted]	€ [redacted]	2010
	Truck	4	Hr	2,32	9,30	Hr	€ [redacted]	€ [redacted]	2010
	Supply of sand	[redacted]	EUR	2,20	[redacted]	EUR	€ [redacted]	€ [redacted]	2010
302	**Abutment Oude Herengracht**							**€ [redacted]**	
302000	Demolition masonry							€ [redacted]	
	Subcontracting drilling	[redacted]	EUR	6,73	[redacted]	EUR	€ [redacted]	€ [redacted]	8020
	Laborer	1	Hr	2,32	2,32	Hr	€ [redacted]	€ [redacted]	2010
	Small track excavator	1	Hr	2,32	2,32	Hr	€ [redacted]	€ [redacted]	2010
	Attachment escavator	1	Day	2,32	2,32	Day	€ [redacted]	€ [redacted]	2010
	Truck	4	Hr	2,32	9,30	Hr	€ [redacted]	€ [redacted]	2010
302010	Pouring concrete skid 2,50x1,00x0,75m							€ [redacted]	

	Carpenter	48	Hr	1,76	84,49	Hr	€ [redacted]	€ [redacted]	1010
	Concrete pump	1	Hr	1,05	1,05	Hr	€ [redacted]	€ [redacted]	1030
	Formwork	[redacted]	EUR	0,95	[redacted]	EUR	€ [redacted]	€ [redacted]	7050
	Subcontracting braiding steel	400	Kg	1,57	627,20	Kg	€ [redacted]	€ [redacted]	7010
	Concrete mortar	2	m³	1,32	2,64	m³	€ [redacted]	€ [redacted]	7020
	Small truck load	7	m³	1,32	9,24	m³	€ [redacted]	€ [redacted]	7020
302020	Adaptations masonry							€ [redacted]	
	Bricklayer	32	Hr	1,51	48,39	Hr	€ [redacted]	€ [redacted]	8050
	Masonry various	[redacted]	EUR	0,96	[redacted]	EUR	€ [redacted]	€ [redacted]	7060
302030	SUBCONTRACTING: Application of sealing layer							€ [redacted]	
	Subcontracting sealing layer	[redacted]	EUR	0,07	[redacted]	EUR	€ [redacted]	€ [redacted]	8060
303	**Abutment Houtmarkt**							€ [redacted]	
303000	Supply and application prefab concrete support beam							€ [redacted]	
	Carpenter	8	Hr	1,76	14,08	Hr	€ [redacted]	€ [redacted]	1010
	Crane	4	Hr	0,24	0,96	Hr	€ [redacted]	€ [redacted]	1020
	Concrete support beam 2,50x1,25x0,75 m	4,8	m³	0,82	3,94	m³	€ [redacted]	€ [redacted]	7030
303010	Pouring concrete in recesses							€ [redacted]	
	Carpenter	4	Hr	1,76	7,04	Hr	€ [redacted]	€ [redacted]	1010
	Concrete mortar	1	m³	1,32	1,32	m³	€ [redacted]	€ [redacted]	7020
	Crane	3	Hr	0,24	0,72	Hr	€ [redacted]	€ [redacted]	1020
303020	Pouring concrete beams 0,40/0,75x0,50x7,00m							€ [redacted]	
	Carpenter	120	Hr	1,76	211,23	Hr	€ [redacted]	€ [redacted]	1010
	Crane	4	Hr	0,24	0,96	Hr	€ [redacted]	€ [redacted]	1020
	Formwork	[redacted]	EUR	0,95	[redacted]	EUR	€ [redacted]	€ [redacted]	7050
	Subcontracting braiding steel	400	Kg	1,57	627,20	Kg	€ [redacted]	€ [redacted]	7010
	Concrete mortar	3	m³	1,32	3,96	m³	€ [redacted]	€ [redacted]	7020
	Small truck load	6	m³	1,32	7,92	m³	€ [redacted]	€ [redacted]	7020
303030	Placing prefab concrete floor plate							€ [redacted]	
	Carpenter	4	Hr	1,76	7,04	Hr	€ [redacted]	€ [redacted]	1010
	Crane	3	Hr	0,24	0,72	Hr	€ [redacted]	€ [redacted]	1020
	Concrete floor plate 250mm thick	1	m³	0,82	0,82	m³	€ [redacted]	€ [redacted]	7030
303040	Application masonry							€ [redacted]	
	Bricklayer	96	Hr	1,51	145,17	Hr	€ [redacted]	€ [redacted]	8050
	Masonry various	[redacted]	EUR	0,96	[redacted]	EUR	€ [redacted]	€ [redacted]	7060
	Brick 200x65x50mm	30	m²	0,96	28,87	m²	€ [redacted]	€ [redacted]	7060
303050	SUBCONTRACTING: Application of sealing layer							€ [redacted]	
	Subcontracting sealing layer	[redacted]	EUR	0,07	[redacted]	EUR	€ [redacted]	€ [redacted]	8060
304	**Pillars**							€ [redacted]	
304000	Supply and application prefab concrete support beam							€ [redacted]	
	Carpenter	32	Hr	1,76	56,33	Hr	€ [redacted]	€ [redacted]	1010
	Sunday allowance personnel	16	Hr	1,76	28,16	Hr	€ [redacted]	€ [redacted]	1010
	Crane	8	Hr	0,24	1,92	Hr	€ [redacted]	€ [redacted]	1020
	Sunday allowance crane	8	Hr	0,24	1,92	Hr	€ [redacted]	€ [redacted]	1020
	Concrete support beam 3,00x0,80x1,00 m	4,8	m³	0,82	3,94	m³	€ [redacted]	€ [redacted]	7030
304010	Pouring concrete in recesses							€ [redacted]	
	Carpenter	8	Hr	1,76	14,08	Hr	€ 47,00	€ [redacted]	1010
	Concrete mortar	1	m³	1,32	1,32	m³	€ 85,00	€ [redacted]	7020
31	**Superstructure**							**€ 163.773,08**	
310000	SUBCONTRACTING Supply and application steel bridge							€ [redacted]	
	Machining steel plates	170	Hr	1	170	Hr	€ 85,00	€ [redacted]	8070
	Sawing steel components	35	Hr	1	35	Hr	€ 50,00	€ [redacted]	
	Cutting steel components	105	Hr	1	105	Hr	€ 85,00	€ [redacted]	
	Welding of components	1675	Hr	1	1675	Hr	€ 60,00	€ [redacted]	
	Polish stainless steel components	40	Hr	1	40	Hr	€ 50,00	€ [redacted]	
	Stainless steel	[redacted]	EUR	1	[redacted]	EUR	€ 1,00	€ [redacted]	
	General costs subcontractor	[redacted]	EUR	1	[redacted]	EUR	€ 1,00	€ [redacted]	
310010	SUBCONTRACTING: Grouting of bearings							€ [redacted]	
	Subcontracting grouting	[redacted]	EUR	0,07	[redacted]	EUR	€ [redacted]	€ [redacted]	8060

4	**BRIDGE DECK**										
40	**Pavement bridge deck**								€	19.545,73	
400000	Supply and application drainage mat								€	[redacted]	
	Paver	40	Hr	0,94	37,55	Hr	€	[redacted]	€	[redacted]	8030
	Drainage mat 120x30mm	78,75	m²	1,77	139,19	m²	€	[redacted]	€	[redacted]	7040
400010	Supply and application sand-cement stabilization 85mm thick								€	[redacted]	
	Paver	40	Hr	0,94	37,55	Hr	€	[redacted]	€	[redacted]	8030
	Pavement various	[redacted]	EUR	1,77	[redacted]	EUR	€	[redacted]	€	[redacted]	7040
	Truck	16	Hr	2,32	37,19	Hr	€	[redacted]	€	[redacted]	2010
	Sand-cement	[redacted]	EUR	2,20	[redacted]	EUR	€	[redacted]	€	[redacted]	2010
400020	Supply and application brick pavement								€	[redacted]	
	Paver	112	Hr	0,94	105,15	Hr	€	[redacted]	€	[redacted]	8030
	Pavement various	[redacted]	EUR	1,77	[redacted]	EUR	€	[redacted]	€	[redacted]	7040
	Concrete brick 200x65x50mm	70	m²	1,77	123,72	m²	€	[redacted]	€	[redacted]	7040
400030	Grouting pavement								€	[redacted]	
	Epoxy mortar	4	Kg	1,77	7,07	Kg	€	[redacted]	€	[redacted]	7040
	Craftsman	16	Hr	0,94	15,02	Hr	€	[redacted]	€	[redacted]	8030
6	**FINISHING**										
60	**Slackening structure**								€	5.929,33	
600000	SUBCONTRACTING: Slackening structure poles								€	[redacted]	
	Supply of wooden poles 350x350x9000mm	[redacted]	EUR	0,17	[redacted]	EUR	€	[redacted]	€	[redacted]	
	Supply and removal of equipment	[redacted]	EUR	1,00	[redacted]	EUR	€	[redacted]	€	[redacted]	8080
	Construction crew (crane, two laborers, pontoon)	[redacted]	EUR	1,00	[redacted]	EUR	€	[redacted]	€	[redacted]	
	Post caps 250x250mm	4	Pcs	1,00	4	Pcs	€	[redacted]	€	[redacted]	
								TOTAL INCURRED DIRECT COSTS =	**€**	**284.814,71**	

	INDIRECT CONSTRUCTION COSTS										
90	**Construction site costs**										
900	**Traffic measures**								€	[redacted]	
900000	Driving lane closure								€	[redacted]	
	Traffic controller	160	Hr	0,84	134,27	Hr	€	[redacted]	€	[redacted]	8240
	Traffic measure various	[redacted]	EUR	0,28	[redacted]	EUR	€	[redacted]	€	[redacted]	8240
900010	Detour, including road block								€	[redacted]	
	Traffic controller	40	Hr	0,84	33,57	Hr	€	[redacted]	€	[redacted]	8240
	Sunday allowance traffic controller	40	Hr	0,84	33,57	Hr	€	[redacted]	€	[redacted]	8240
	Traffic measure various	[redacted]	EUR	0,28	[redacted]	EUR	€	[redacted]	€	[redacted]	8240
901	**Construction site**								€	[redacted]	
901000	Construction site								€	[redacted]	
	Construction site / job area various	[redacted]	EUR	1,11	[redacted]	EUR	€	[redacted]	€	[redacted]	9000
91	**Non-recurring costs**										
910	Testing costs								€	[redacted]	
910000	Test load bridges	[redacted]	EUR	0,17	[redacted]	EUR	€	[redacted]	€	[redacted]	9010
911	Tender								€	[redacted]	
911000	Tender costs	[redacted]	EUR	0,18	[redacted]	EUR	€	1,00	€	[redacted]	9200
911010	Most Economically Advantageous Tender (MEAT) criteria costs	[redacted]	EUR	0,066	[redacted]	EUR	€	1,00	€	[redacted]	9800
912	Legal costs								€	[redacted]	
912000	Document duties								€	[redacted]	9400
	Bank guarantee	[redacted]	EUR	0,039	[redacted]	EUR	€	[redacted]	€	[redacted]	
	Permit fees	[redacted]	EUR	0,039	[redacted]	EUR	€	[redacted]	€	[redacted]	
913	Provisional sums								€	[redacted]	
913000	Provisional sum bridge landings	[redacted]	EUR	0,052	[redacted]	EUR	€	[redacted]	€	[redacted]	9503

92	**Operating costs**										
920	Operating personell								€	[redacted]	
920000	Executive, technical, administrative (UTA) employees								€	[redacted]	9300
	Design staff	160	Hr	0,20	31,26	Hr	€	[redacted]	€	[redacted]	
	Engineering staff	256	Hr	0,20	50,02	Hr	€	[redacted]	€	[redacted]	
	Construction engineering staff	160	Hr	0,20	31,26	Hr	€	[redacted]	€	[redacted]	
	Project manager	1500	Hr	0,20	293,07	Hr	€	[redacted]	€	[redacted]	
	Project planner	120	Hr	0,20	23,45	Hr	€	[redacted]	€	[redacted]	
	Process manager	150	Hr	0,20	29,31	Hr	€	[redacted]	€	[redacted]	
	Area manager	250	Hr	0,20	48,84	Hr	€	[redacted]	€	[redacted]	
	Foreman	4864	Hr	0,20	950,32	Hr	€	[redacted]	€	[redacted]	
	Surveyors	250	Hr	0,20	48,84	Hr	€	[redacted]	€	[redacted]	
	KAM coordinator	62,5	Hr	0,20	12,21	Hr	€	[redacted]	€	[redacted]	
93	**Overhead costs**										
930	General costs								€	[redacted]	
930000	General costs	[redacted]	EUR	0,13	[redacted]	EUR	€	[redacted]	€	[redacted]	AK
94	**Profit and risk**										
940	Profit and risk								€	[redacted]	
940000	Profit and risk	[redacted]	EUR	0,13	[redacted]	EUR	€	[redacted]	€	[redacted]	WRR
95	**Time bound costs**										
950	Subcription charges								€	[redacted]	
950000	Subscription charges	[redacted]	EUR	0,17	[redacted]	EUR	€	[redacted]	€	[redacted]	CONTR
					TOTAL INCURRED INDIRECT COSTS =				**€**	**210.477,09**	

Assumptions construction costs Wisenniabrug

Wherever possible, the costs will be split into incurred manhours, materials and equipment. This specification of costs elements also applied to subcontracted compents. Manhours, materials, equipment, and contracts with subcontractors are often lumped together in the incurred costs overview. To breakdown the lump sum in manhours, materials and equipment, the accepted contracts with the subcontracters have been analyzed. Whenever a subcontracted cost component is not further specified than a lump sum, the issued contract did not provide the cost breakdown. This resulted in contacting the subcontractor for the specification of costs. In some cases, the subcontractor did not want to cooperate in disclosing their price breakdown of the lump sum.

The Wisenniabrug was part of a larger project, the Singelparkbruggen, wherein multiple bridges were built, there has been little categorization of the actual costs. Manhours, materials, equipment, and contracts with subcontractors have been lumped together in the incurred costs overview. To find the specific incurred costs for the Wisenniabrug, a number of assumptions have been made. These assumptions are noted below, categorized per cost item.

General
Manhours of the entire project are lumped together, hence there is no division in manhours to the different bridges. Therefore the work estimation of the Wisenniabrug will be combined with the incurred costs overview. First the total incurred manhours are determined from the incurred cost overview, using the average hourly costs of laborers. Subsequently, a factor is determined which quantifies the transformation from estimated manhours to actual manhours. Ultimately this factor is used to multiply with the estimated manhours in order to generate an approximation of the actual manhours spend on the Wisenniabrug

1010 Manhours		
Total MCC budget 1010	€	[redacted]
Estimated costs 1010 Wisenniabrug	€	[redacted]
Estimated total hours 1010 entire project		[redacted]
Hours 1010 Wisenniabrug		[redacted]
1010 Ratio based on hours(Wisenniabrug/total)		0,17
Incurred costs 1010	€	[redacted]
Incurred costs 1010 Wisenniabrug	**€**	[redacted]
Average costs per hour by estimation	€	[redacted]
Incurred manhours Wisenniabrug		[redacted]
Factor estimated hours to incurred hours		**1,76**
Factor estimated costs to incurred costs		**1,65**

1020 Cranes		
Total MCC budget 1020	€	[redacted]
Estimated costs 1020 Wisenniabrug	€	[redacted]
Estimated total hours 1020 entire project		[redacted]
Hours 1020 Wisenniabrug		[redacted]
1020 Ratio based on hours(Wisenniabrug/total)		0,18
Incurred costs 1020	€	[redacted]
Incurred costs 1020 Wisenniabrug	**€**	[redacted]
Average costs per hour by estimation	€	[redacted]
Incurred Crane hours Wisenniabrug		[redacted]
Factor estimated hours to incurred hours		**0,24**
Factor estimated costs to incurred costs		**0,20**

1030 Concrete pumps		
Total MCC budget 1030	€	[redacted]
Estimated costs 1030 Wisenniabrug	€	[redacted]
Estimated total days 1030 entire project		[redacted]
Days 1030 Wisenniabrug		[redacted]
1030 Ratio (Wisenniabrug/total)		0,11
Incurred costs 1030	€	[redacted]
Incurred costs 1030 Wisenniabrug	**€**	[redacted]
Average costs per day by estimation	€	[redacted]
Incurred Concrete pump days Wisenniabrug		[redacted]
Factor estimated days to incurred days		**1,05**
Factor estimated costs to incurred costs		**1,05**

2010 General ground work		
Total MCC budget 2010	€	[redacted]
Estimated costs 2010 Wisenniabrug	€	[redacted]
Estimated total hours 2010 entire project		[redacted]
Hours 2010 Wisenniabrug		[redacted]
2010 Ratio (Wisenniabrug/total)		0,19
Incurred costs 2010	€	[redacted]
Incurred costs 2010 Wisenniabrug	**€**	[redacted]
Average costs per hour by estimation	€	[redacted]
Incurred hours of ground work Wisenniabrug		[redacted]
Factor estimated hours to incurred hours		**2,32**
Factor estimated costs to incurred costs		**2,20**

7010 Steel braided reinforcement (Subcontracted)		
Total MCC budget 7010	€	[redacted]
Estimated costs 7010 Wisenniabrug	€	[redacted]
Estimated total Kgs 7010 entire project		[redacted]
Kgs 7010 Wisenniabrug		[redacted]
7010 Ratio (Wisenniabrug/total)		0,07
Incurred costs 7010	€	[redacted]
Incurred costs 7010 Wisenniabrug	**€**	[redacted]
Average costs per Kg by estimation	€	[redacted]
Incurred Kgs Wisenniabrug		[redacted]
Factor estimated Kgs to incurred Kgs		**1,57**
Factor estimated costs to incurred costs		**2,30**

7020 Concrete mortar		
Total MCC budget 7020	€	[redacted]
Estimated costs 7020 Wisenniabrug	€	[redacted]
Estimated total m³ 7020 entire project		[redacted]
m³ 7020 Wisenniabrug		[redacted]
7020 Ratio (Wisenniabrug/total)		0,13
Incurred costs 7020	€	[redacted]
Incurred costs 7020 Wisenniabrug	**€**	[redacted]
Average costs per m³ by estimation	€	[redacted]
Incurred m³ Wisenniabrug		[redacted]
Factor estimated m³ to incurred m³		**1,32**
Factor estimated costs to incurred costs		**2,08**

7030 Prefab concrete		
Total MCC budget 7030	€	[redacted]
Estimated costs 7030 Wisenniabrug	€	[redacted]
Estimated total m³ 7030 entire project		[redacted]
m³ 7030 Wisenniabrug		[redacted]
7030 Ratio (Wisenniabrug/total)		1,00
Incurred costs 7030	€	[redacted]
Incurred costs 7030 Wisenniabrug	**€**	[redacted]
Average costs per m³ by estimation	€	[redacted]
Incurred m³ Wisenniabrug		[redacted]
Factor estimated m³ to incurred m³		**0,82**
Factor estimated costs to incurred costs		**0,82**

7040 Pavement various		
Total MCC budget 7040	€	[redacted]
Estimated costs 7040 Wisenniabrug	€	[redacted]
Estimated total costs 7040	€	[redacted]
7040 Ratio (Wisenniabrug/total)		0,37
Incurred costs 7040	€	[redacted]
Incurred costs 7040 Wisenniabrug	**€**	[redacted]
Factor estimated costs to incurred costs		**1,77**
Due to the many differences in units of measurement used or the presence of provisional sums, only a factor for transforming estimated costs to incurred costs has been determined.		

7050 Formwork		
Total MCC budget 7050	€	[redacted]
Estimated costs 7050 Wisenniabrug	€	[redacted]
Estimated total costs 7050	€	[redacted]
7050 Ratio (Wisenniabrug/total)		0,056
Incurred costs 7050	€	[redacted]
Incurred costs 7050 Wisenniabrug	**€**	[redacted]
Factor estimated costs to incurred costs		**0,95**
Due to the many differences in units of measurement used or the presence of provisional sums, only a factor for transforming estimated costs to incurred costs has been determined.		

7060 Masonry		
Total MCC budget 7060	€	[redacted]
Estimated costs 7060 Wisenniabrug		[redacted]
Estimated total costs 7060	€	[redacted]
7060 Ratio (Wisenniabrug/total)		0,52
Incurred costs 7060	€	[redacted]
Incurred costs 7060 Wisenniabrug	**€**	[redacted]
Factor estimated costs to incurred costs		**0,96**
Due to the many differences in units of measurement used or the presence of provisional sums, only a factor for transforming estimated costs to incurred costs has been determined.		

7080 Small supplies		
Total MCC budget 7080	€	[redacted]
Estimated costs 7080 Wisenniabrug	€	[redacted]
Estimated total costs 7080	€	[redacted]
7080 Ratio (Wisenniabrug/total)		0,051
Incurred costs 7080	€	[redacted]
Incurred costs 7080 Wisenniabrug	**€**	[redacted]
Factor estimated costs to incurred costs		**1,46**
Due to the many differences in units of measurement used or the presence of provisional sums, only a factor for transforming estimated costs to incurred costs has been determined.		

8010 Street lighting (Subcontracted)		
Total MCC budget 8010	€	[redacted]
Estimated costs 8010 Wisenniabrug	€	[redacted]
Estimated total pcs 8010 entire project		[redacted]
Pcs 8010 Wisenniabrug		[redacted]
8010 Ratio (Wisenniabrug/total)		0,25
Incurred costs 8010	€	[redacted]
Incurred costs 8010 Wisenniabrug	**€**	[redacted]
Average costs per m³ by estimation	€	[redacted]
Incurred pcs Wisenniabrug		[redacted]
Factor estimated pcs to incurred pcs		**0,92**
Factor estimated costs to incurred costs		**0,93**

8020 Drilling, cutting, demolishing (Subcontracted)		
Total MCC budget 8020	€	[redacted]
Estimated costs 8020 Wisenniabrug	€	[redacted]
Estimated total costs 8020	€	[redacted]
8020 Ratio (Wisenniabrug/total)		0,20
Incurred costs 8020	€	[redacted]
Incurred costs 8020 Wisenniabrug	**€**	[redacted]
Factor estimated costs to incurred costs		**6,73**
Due to the many differences in units of measurement used or the presence of provisional sums, only a factor for transforming estimated costs to incurred costs has been determined.		

8030 Paver (Subcontracted)		
Total MCC budget 8030	€	[redacted]
Estimated costs 8030 Wisenniabrug	€	[redacted]
Estimated total hours 8030 entire project		[redacted]
Hours 8030 Wisenniabrug		[redacted]
8030 Ratio (Wisenniabrug/total)		0,30
Incurred costs 8030	€	[redacted]
Incurred costs 8030 Wisenniabrug	**€**	[redacted]
Average costs per hour by estimation	€	[redacted]
Incurred hours Wisenniabrug		[redacted]
Factor estimated hours to incurred hours		**0,94**
Factor estimated costs to incurred costs		**1,13**

8040 Steel piling (Subcontracted)		
Total MCC budget 8040	€	[redacted]
Estimated costs 8040 Wisenniabrug	€	[redacted]
Estimated total pcs 8040 entire project		[redacted]
Pcs 8040 Wisenniabrug		[redacted]
8040 Ratio (Wisenniabrug/total)		0,14
Incurred costs 8040	€	[redacted]
Incurred costs 8040 Wisenniabrug	**€**	[redacted]
Average costs per m^1 by estimation	€	[redacted]
Incurred m Wisenniabrug		[redacted]
Factor estimated m^1 to incurred m^1		**1,72**
Factor estimated costs to incurred costs		**0,76**

8050 Bricklayer (Subcontracted)		
Total MCC budget 8050	€	[redacted]
Estimated costs 8050 Wisenniabrug	€	[redacted]
Estimated total hours 8050 entire project		[redacted]
Hours 8050 Wisenniabrug		[redacted]
8050 Ratio (Wisenniabrug/total)		0,56
Incurred costs 8050	€	[redacted]
Incurred costs 8050 Wisenniabrug	**€**	[redacted]
Average costs per hour by estimation	€	[redacted]
Incurred hours Wisenniabrug		[redacted]
Factor estimated hours to incurred hours		**1,51**
Factor estimated costs to incurred costs		**1,58**

8060 Preservation, concrete coating (Subcontracted)		
Total MCC budget 8060	€	[redacted]
Estimated costs 8060 Wisenniabrug	€	[redacted]
Estimated total costs 8060	€	[redacted]
8060 Ratio (Wisenniabrug/total)		0,13
Incurred costs 8060	€	[redacted]
Incurred costs 8070 Wisenniabrug	**€**	[redacted]
Factor estimated costs to incurred costs		**0,07**
Due to the many differences in units of measurement used or the presence of provisional sums, only a factor for transforming estimated costs to incurred costs has been determined.		

8070 Steel construction (Subcontracted)		
Total MCC budget 8070	€	[redacted]
Estimated costs 8070 Wisenniabrug	€	[redacted]
Estimated total costs 8070	€	[redacted]
8070 Ratio (Wisenniabrug/total)		0,14
Incurred costs 8070	€	[redacted]
Incurred costs 8070 Wisenniabrug	**€**	[redacted]
Factor estimated costs to incurred costs		**0,06**
Due to the many differences in units of measurement used or the presence of provisional sums, only a factor for transforming estimated costs to incurred costs has been determined.		

8080 Slackening structure (Subcontracted)		
Total MCC budget 8080	€	[redacted]
Estimated costs 8080 Wisenniabrug	€	[redacted]
Estimated total costs 8080	€	[redacted]
8080 Ratio (Wisenniabrug/total)		0,22
Incurred costs 8080	€	[redacted]
Incurred costs 8080 Wisenniabrug	**€**	[redacted]
Factor estimated costs to incurred costs		**0,48**
Due to the many differences in units of measurement used or the presence of provisional sums, only a factor for transforming estimated costs to incurred costs has been determined.		

8240 Traffic control (Subcontracted)		
Total MCC budget 8240	€	[redacted]
Estimated costs 8240 Wisenniabrug	€	[redacted]
Estimated total hours 8240 entire project		[redacted]
Hours 8240 Wisenniabrug		[redacted]
8240 Ratio (Wisenniabrug/total)		0,21
Incurred costs 8240	€	[redacted]
Incurred costs 8240 Wisenniabrug	**€**	[redacted]
Average costs per hour by estimation	€	[redacted]
Incurred hours Wisenniabrug		[redacted]
Factor estimated hours to incurred hours		**0,84**
Factor estimated costs to incurred costs		**0,28**

9000 Construction site		
Total MCC budget 9000	€	[redacted]
Estimated costs 9000 Wisenniabrug	€	[redacted]
Estimated total costs 9000	€	[redacted]
9000 Ratio (Wisenniabrug/total)		0,15
Incurred costs 9000	€	[redacted]
Incurred costs 9000 Wisenniabrug	**€**	[redacted]
Factor estimated costs to incurred costs		**1,11**
Due to the many differences in units of measurement used or the presence of provisional sums, only a factor for transforming estimated costs to incurred costs has been determined.		

Indirect construction costs - General assumption		
In general, the indirect costs have been estimated and specified for the project in its entirety, unlike the direct costs of the Wisenniabrug. The indirect costs have therefore been first transformed into the estimated indirect costs for the Wisenniabrug, based on the contracted price offer, by multiplying the ratio (estimation direct costs Wisenniabrug)/(estimation direct costs entire project) with the indirect costs of the Wisenniabrug. Secondly, a factor has been determined based on the MCC incurred costs to transform the estimated indirect construction costs to the incurred indirect construction costs of the Wisenniabrug.		
Total estimated direct costs complete project	€	[redacted]
Total estimated direct costs Wisenniabrug	€	[redacted]
Factor entire project to Wisenniabrug		**0,13**

9010 Testing costs		
Factor entire project to Wisenniabrug		0,13
Total estimated costs on indirect cost item	n/a	
Total incurred costs on indirect cost item	€	[redacted]
Factor total estimated costs to incurred costs	n/a	
Factor estimated to incurred costs Wisenniabrug		**0,17**
There were no costs estimated for this post. Since there are six bridges in the entire project, the incurred costs are shared equally among the bridges, hence one-sixth of the incurred costs for the Wisenniabrug.		

9100 Construction signs		
Factor entire project to Wisenniabrug		0,13
Total estimated costs on indirect cost item	€	[redacted]
Total incurred costs on indirect cost item	€	[redacted]
Factor total estimated costs to incurred costs		0,92
Factor estimated to incurred costs Wisenniabrug		**0,12**

9200 Tender costs		
Factor entire project to Wisenniabrug		0,13
Total estimated costs on indirect cost item	€	[redacted]
Total incurred costs on indirect cost item	€	[redacted]
Factor total estimated costs to incurred costs		1,30
Factor estimated to incurred costs Wisenniabrug		**0,18**

9300 Executive, technical, administrative staff costs		
Factor entire project to Wisenniabrug		0,13
Total estimated costs on indirect cost item	€	[redacted]
Total incurred costs on indirect cost item	€	[redacted]
Factor total estimated costs to incurred costs		1,45
Factor estimated to incurred costs Wisenniabrug		**0,20**

9400 Document duties		
Factor entire project to Wisenniabrug		0,13
Total estimated costs on indirect cost item	€	[redacted]
Total incurred costs on indirect cost item	€	[redacted]
Factor total estimated costs to incurred costs		0,29
Factor estimated to incurred costs Wisenniabrug		**0,039**

9503 Provisional sum bridge landings		
Factor entire project to Wisenniabrug		0,13
Total estimated costs on indirect cost item	€	[redacted]
Total incurred costs on indirect cost item	€	[redacted]
Factor total estimated costs to incurred costs		0,39
Factor estimated to incurred costs Wisenniabrug		**0,052**

800 Most Economically Advantageous Tender (MEAT) criteria costs		
Factor entire project to Wisenniabrug		0,13
Total estimated costs on indirect cost item	€	[redacted]
Total incurred costs on indirect cost item	€	[redacted]
Factor total estimated costs to incurred costs		0,49
Factor estimated to incurred costs Wisenniabrug		**0,066**

AK General costs		
Factor entire project to Wisenniabrug		0,13
Total estimated costs on indirect cost item	€	[redacted]
Total incurred costs on indirect cost item	€	[redacted]
Factor total estimated costs to incurred costs		0,96
Factor estimated to incurred costs Wisenniabrug		**0,13**

CONTR Subscription charges		
Factor entire project to Wisenniabrug		0,13
Total estimated costs on indirect cost item	n/a	
Total incurred costs on indirect cost item	€	[redacted]
Factor total estimated costs to incurred costs	n/a	
Factor estimated to incurred costs Wisenniabrug		**0,17**
There were no costs estimated for this post. Since there are six bridges in the entire project, the incurred costs are shared equally among the bridges, hence one-sixth of the incurred costs for the Wisenniabrug.		

WRR Profit and risks		
Factor entire project to Wisenniabrug		0,13
Total estimated costs on indirect cost item	€	[redacted]
Total incurred costs on indirect cost item	€	[redacted]
Factor total estimated costs to incurred costs		1,00
Factor estimated to incurred costs Wisenniabrug		**0,13**

Maintenance costs
Costs of large maintenance items are largely dependent on the amount of wear and tear. It is difficult to approximate the abrasion over a period of 10 or more years. In addition, once the large maintenance will be executed, a whole different price level is dominating the expenditures on maintenance. Hence, this price level is also hard to determine.

Appendix N: Construction costs per project component circular case project

Initiation

The costs of the inititaion consist mainly of transactional costs, which are excluded from the scope of this research.

Gathering materials

Steel materials	€	28.732,70	Gathering of reusable steel for different uses.
Steel for abutments	€	[redacted]	
Steel diamond plates	€	[redacted]	
Steel for crossbeams	€	[redacted]	
Steel for support beams	€	[redacted]	
Steel for railing	€	[redacted]	
Concrete girders	€	7.872,00	Gathering of reusable concrete girders
Wooden materials	€	130.000,00	Gathering of reusable wood, as one cost item, for different uses.
Steel piling	€	-	Price of gathering steel piling could not be determined due to the lack of further cost specifications of subcontractor.
TOTAL COSTS GATHERING MATERIALS=	€	166.604,70	

Design

Operating costs	€	[redacted]	
Purchaser	€	[redacted]	These manhours can be fully accounted to the design.
Project planner	€	[redacted]	These manhours can be fully accounted to the design.
Project manager	€	[redacted]	50% of these manhours can be accounted to the design.
Project prepation subcontractor	€	[redacted]	
Detailed calculation and drawings	€	[redacted]	These costs can be fully accounted to the construction.
Work preparation, project management	€	[redacted]	These costs can be fully accounted to the construction.
Welding plan and welding engineer	€	[redacted]	These costs can be fully accounted to the construction.
Project team cost	€	[redacted]	These costs can be fully accounted to the construction.
TOTAL COSTS DESIGN=	€	112 243,00	

Construction

Direct costs	€	404.808,51	Direct construction costs except for the material gathering items
Construction site costs	€	40.873,00	All construction site costs are accounted to the construction.
Operating costs	€	[redacted]	
Project manager	€	[redacted]	50% of these manhours can be accounted to the design.
Foreman	€	[redacted]	These manhours can be fully accounted to the design.
Surveyors	€	[redacted]	These manhours can be fully accounted to the design.
Paver	€	[redacted]	These manhours can be fully accounted to the design.
Social return staff	€	[redacted]	These manhours can be fully accounted to the design.
Telescopic crane	€	[redacted]	These manhours can be fully accounted to the design.
Non-recurring costs	€	[redacted]	
General costs [redacted]	€	[redacted]	These general costs can be fully accounted to the construction.
General costs [redacted]	€	[redacted]	These general costs can be fully accounted to the construction.
Non-recurring costs subcontractor	€	[redacted]	
Project execution	€	[redacted]	These costs can be fully accounted to the construction.
Extra incurred activities	€	[redacted]	These costs can be fully accounted to the construction.
TOTAL COSTS CONSTRUCTION=	€	573.730,07	

Operation & maintenance

Inspections	€	1.250,00	Noted price is the yearly price
Large maintenance	TBA		Cannot be accurately determined in advance
TOTAL COSTS OPERATION AND MAINTENANCE=	€	1.250,00	

Appendix O: Construction costs per project component regular case project

Initiation
The costs of the inititaion consist mainly of transactional costs, which are excluded from the scope of this research. In addition, this data is inaccessible since there is no access to the data of the client, who initiated the project.

Design competition
Data on this components is not accessible since these costs have been made by a third party before the contractor, Dura Vermeer, was involved in this project.

Procurement			
Tender costs	€	[redacted]	The tender costs are fully accounted to the procurement procedure.
TOTAL COSTS DESIGN=	**€**	[redacted]	

Design			
Operating costs	€	[redacted]	
Design staff	€	[redacted]	These manhours can be fully accounted to the design.
Engineering staff	€	[redacted]	These manhours can be fully accounted to the design.
Construction staff	€	[redacted]	These manhours can be fully accounted to the design.
Project manager	€	[redacted]	50% of these manhours can be accounted to the design.
Project planner	€	[redacted]	These manhours can be fully accounted to the design.
Process manager	€	[redacted]	These manhours can be fully accounted to the design.
Time bound costs	€	[redacted]	Contributions will be accounted to the design.
TOTAL COSTS DESIGN=	**€**	**26.122,61**	

Construction			
Direct costs	€	**307.684,60**	All direct construction costs are accounted to the construction.
Construction site costs	€	[redacted]	All construction site costs are accounted to the construction.
Operating costs	€	[redacted]	
Project manager	€	[redacted]	50% of these manhours can be accounted to the design.
Area manager	€	[redacted]	These manhours can be fully accounted to the design.
Foreman	€	[redacted]	These manhours can be fully accounted to the design.
Surveyors	€	[redacted]	These manhours can be fully accounted to the design.
KAM coordinator	€	[redacted]	These manhours can be fully accounted to the design.
Non-recurring costs	€	[redacted]	
Testing costs	€	[redacted]	These costs can be fully accounted to the construction
Legal costs	€	[redacted]	These costs can be fully accounted to the construction
Provisional sums	€	[redacted]	These costs can be fully accounted to the construction
TOTAL COSTS CONSTRUCTION=	**€**	**411.172,48**	

Operation & maintenance			
Inspections	€	**1.250,00**	Noted price is the yearly price
Preventive maintenance	€	**1.000,00**	Noted price is the yearly price
Large maintenance	TBA		Cannot be accurately determined in advance
TOTAL COSTS OPERATION AND MAINTENANCE=	**€**	**2.250,00**	

Appendix P: Validation protocol

Validation protocol

The validation protocol will be executed in the form of an interview. During this interview, the interviewer will constantly present its findings to the interviewees. Their reaction on the findings is constantly verified, by execution of semi-structured interview. The questions in this document function as the main questions of the interview. Often, the interviewer will ask follow-up questions, based on the answers given.

This study was initiated with the goal of identifying the differences between regular construction projects and circular construction projects on project process and construction costs. The reach this objective, the research was set out to answer the main research question:

What are the effects of the implementation of circularity on the project process and costs in infrastructural construction projects?

In order to answer this research question, a multiple case study was conducted wherein two projects were compared to one another on circularity, project process and construction costs. The two case studies are:

1. Circular case project: Tweede leven brug
    - Location: Almere, Floriade expo site;
    - Pedestrian and bicycle bridge;
    - Pilot project aimed at circularity by construction with only applying reused materials.
2. Regular case project: Wisenniabrug
    - Location: Leiden, city centre;
    - Pedestrian and bicycle bridge;
    - Part of a larger project, Singelparkbruggen.

Questions for validating the results

1. What is your function within this organization?

2. Do you have any experiences with circular projects?

3. Circularity is still not widely applied in construction projects. From the literature study was concluded that this threshold to implementing circularity for a lot of parties in the construction sector is due to three barriers which come together in a construction project: The cultural, technological and market barrier. The cultural barrier lies at its participants and the cultural shift that is needed to accept circularity in projects. The technological barrier is aimed at the technological aspects of implementation of circularity. The market barriers aims at the financial limitations towards circularity. Do you encounter this in practice as well?

4. Literature suggests that as a solution to lifting the beforementioned barriers is the execution of case studies. Do you agree to this?

5. The regular case study was executed with zero intent to execute it in a circular manner. Is this also relevant to other projects in practice?

6. The analysis of the case studies showed a difference between the process of a circular construction project and a regular construction project. The input from the interviews and the available project data resulted in the introduction of a new project component, which is Gathering of materials. During the project, this component constantly interchanges with the Design component until the design is finished. Do you see the need and added value of this project component for circular projects?

7. Looking at the costs of both case projects projected on the process components, it can be noticed that the costs are differently distributed among the components. The circular project distributes its costs more evenly among the components, however, the construction component is still the most expensive one. Do you agree to the costs distribution of the regular case project and what are your thoughts about the distribution of the circular case?

8. From the results seems that the majority of the direct construction costs, when circularity is applied, is more expensive than when applied in a regular project. The main factor for this seems to be the activities to gather and process the materials. Is this in line with your expectations? Is this also recognizable in regular projects?

9. From the results seems that the indirect construction costs is percentagewise more expensive than a lot between circularity being more or less expensive. The main factor for this seems to be the activities to process the materials. Is this in line with your expectations? Is this also recognizable in regular projects?

Appendix Q: Data collection logbook

D	Date accessed	Analysis topic	File name	Description	Used for
1	29-8-2022	Regular project construction costs	Project prognose per bewakingspost per kostensoort Singelparkbruggen pdf	Incurred construction costs of Wisenniabrug project	Identification of the actual construction costs of the Wisenniabrug project
2	29-8-2022	Regular project construction costs	Open begroting Singelparkbruggen	Cost estimation of Wisenniabrug project	Identification of the expected construction costs of the Wisenniabrug project
3	30-8-2022	Circular project construction costs	Prijsaanbieding Weerwater C V WP5005 KW05_v4 0 pdf	Price offer to client + price structure	Identification of the expected construction costs of the Tweede leven brug project
4	30-8-2022	Circular project construction costs	Besteksraming KW5 pdf	Cost estimation of Tweede leven brug project	Identification of the expected construction costs of the Tweede leven brug project
5	30-8-2022	Circular project construction costs	Raming Brug circulair Floriade KW05[redacted] pdf	Price offer from [redacted] to Dura Vermeer	Identification of the offered price and the price structure of the subcontractor to Dura Vermeer
6	5-9-2022	Regular project construction costs	Beheer- en onderhoudsplan Singelparkbruggen pdf	Operation and maintenance plan for the Wisenniabrug, including expected costs	Identification of the expected operation and maintenance costs
7	5-9-2022	Regular project construction costs	Inschatting onderhoudskosten[redacted] pdf	Cost estimation for the operation and maintenance costs	Identification of the expected operation and maintenance costs
8	5-9-2022	Regular project construction costs	Inschrijvingsbiljet Singelparkbruggen pdf	Price offer to the client for constructing the Singelparkbruggen	Identification of the expected construction costs of the Wisenniabrug project
9	9-9-2022	Regular project amounts of materials	Hoeveelheden RVS bollen1	Amount of stainless steel spheres applied	Determining the amounts of materials applied
10	9-9-2022	Regular project amounts of materials	Hoeveelheden tbv inkoop	Amounts of different materials applied	Determining the amounts of materials applied
11	9-9-2022	Regular project amounts of materials	Buigstaten overzicht-singelparkbruggen	Amounts of steel reinforcement applied	Determining the amounts of materials applied
12	9-9-2022	Regular project amounts of materials	overzicht betonmmortel	Amounts of concrete grouting applied	Determining the amounts of materials applied
13	15-9-2022	Circularity assessment	TEK_3001_KW05_UO_Palenplan_V3 0 pdf	Technical drawings of the bridge	Determining the amounts of materials applied
14	15-9-2022	Circularity assessment	TEK_3002_KW05_UO_Steunpunten en oplegblokken_V3 0 pdf	Technical drawings of the bridge	Determining the amounts of materials applied
15	15-9-2022	Circularity assessment	TEK_3003_Kw05_UO_Dwarsdrager_Wind verbanden en houten dek_V3 0 pdf	Technical drawings of the bridge	Determining the amounts of materials applied
16	15-9-2022	Circularity assessment	TEK_3004_Kw05_UO_Prefab I liggers pdf	Technical drawings of the bridge	Determining the amounts of materials applied
17	15-9-2022	Circularity assessment	TEK_3006_KW05_UO_Leuning_V1 0 pdf	Technical drawings of the bridge	Determining the amounts of materials applied
18	27-9-2022	Circularity assessment	Beoordeling_te_handhaven_bestaande_kunstwerken pdf	Technical assessment of the used bridge components	Determining the amounts of materials applied
19	27-9-2022	Circular project construction costs	IPFLOR 5005 WBG V1 (1)	Internal incurred cost overview	Identification of the actual construction costs of the Tweede leven brug project
20	28-9-2022	Circular project construction costs	IPFLOR KW05 kosten uitdraai totaal	Incurred construction costs of Tweede leven brug project	Identification of the actual construction costs of the Tweede leven brug project
21	28-9-2022	Circular project construction costs	bielzen liggers def	Price specification from [redacted] to Dura Vermeer	Identification of the actual construction costs of the Tweede leven brug project
22	28-9-2022	Circular project construction costs	onderbouwing prijs van [redacted]	Price specification from [redacted] to Dura Vermeer	Identification of the actual construction costs of the Tweede leven brug project
23	29-9-2022	Regular project construction costs	[redacted] [redacted] opdracht docx	Subcontracted cost specifications	Specifying the activities and related costs of the subcontractors involved in the Wisenniabrug
24	29-9-2022	Regular project construction costs	[redacted] [redacted] opdracht docx	Subcontracted cost specifications	Specifying the activities and related costs of the subcontractors involved in the Wisenniabrug
25	30-9-2022	Regular project construction costs	[redacted] [redacted] opdracht docx	Subcontracted cost specifications	Specifying the activities and related costs of the subcontractors involved in the Wisenniabrug
26	30-9-2022	Regular project construction costs	[redacted] [redacted] opdracht pdf	Subcontracted cost specifications	Specifying the activities and related costs of the subcontractors involved in the Wisenniabrug

27	30-9-2022	Regular project construction costs	[redacted] [redacted] opdracht pdf	Subcontracted cost specifications	Specifying the activities and related costs of the subcontractors involved in the Wisenniabrug
28	30-9-2022	Regular project construction costs	[redacted] [redacted] opdracht pdf	Subcontracted cost specifications	Specifying the activities and related costs of the subcontractors involved in the Wisenniabrug
29	30-9-2022	Regular project construction costs	[redacted] opdracht pdf	Subcontracted cost specifications	Specifying the activities and related costs of the subcontractors involved in the Wisenniabrug
30	30-9-2022	Regular project construction costs	[redacted] opdracht pdf	Subcontracted cost specifications	Specifying the activities and related costs of the subcontractors involved in the Wisenniabrug
31	1-10-2022	Regular project construction costs	[redacted] opdracht docx	Subcontracted cost specifications	Specifying the activities and related costs of the subcontractors involved in the Wisenniabrug
32	1-10-2022	Circular and regular project construction costs	kosten per uur UTA+uitvoerend personeel	Personel costs per hour	Specifying the costs of the personel involved in both case projects