Eindhoven University of Technology

Exploration for a successful transition to a circular civil engineering sector

Investigating the barriers faced when wanting to implement the circular economy in the civil engineering sector

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“Glance at the sun. See the moon and the stars. Gaze at the beauty of earth’s greenings. Now, think”

MICHEAL BRAUNGART

Preface

This thesis is written to conclude my master Construction Management and Engineering at the Eindhoven University of Technology. After more than six years studying and some other activities the end is now near. During these years I have had the opportunity to learn and listen to many people who are all passionate for their own subject. For me this passion has proven to be sustainability and that is why I have also chosen to write my thesis about the circular economy in the civil engineering sector. A lot of questions still remain unanswered, but I hope this thesis will contribute in its own way to a more sustainable and circular sector.

I would like to thank everybody that have helped me spark my passion, listened to my rather long monologues about waste and discussed with me about how we could preserve this planet in our own way. In particularly I would like to thank my supervisors from the TU/e, Qi Han for her formal and informal conversations and Bob van Thiel for his critical questions.

This thesis was written in collaboration with Witteveen+Bos, I would like to thank those involved for sharing their knowledge, the people from the Breda office for their warmth, Rob for always being available for me and Michel for his excitement and perseverance.

Furthermore, I would like to thank my family and friends for keeping up with the uncountable times I said "I am not a researcher", sending me all those interesting documents and helping me through this rollercoaster called 'graduation'.

Finally, I wish you, as a reader, a good time while reading and learning from this thesis. And I hope that if you haven't found you passion yet, you will find it soon. Because passion is the motor that drives us.

Annelieke Steens

Eindhoven, April 2018

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Summary

In 2016, the Dutch government started with a nation-wide program to implement the circular economy in several sectors within the country (Dutch Ministry of Infrastructure and the Environment & Dutch Ministry of Economic Affairs, 2016). This program mentions five sectors which will be prioritized, amongst which is the construction sector. A sub-sector of the construction sector is the civil engineering sector which concerns all wet and dry infrastructure in the Netherlands (EIB, 2018). Since the sector is known for its long life spans, it is important to start the implementation of the circular economy as soon as possible since the changes can have big effects in the future. However, these long life-spans do make the implementation harder since thinking ahead 50 or even 100 years is difficult for every sector.

This research is conducted to investigate which barriers can be identified that stand in the way of implementing the circular economy in the civil engineering sector. To identify which enablers can resolve these barriers and to investigate what the first steps are towards a more circular sector. The research question is stated as follows: "What are the first steps needed for a successful implementation of the circular economy in the civil engineering sector?".

To gain knowledge on the subjects of the circular economy and its relationship to the civil engineering sector, an elaborate literature review has been performed. From this, several difficulties were identified why it is challenging to implement the circular economy in the civil engineering sector. First, the constructions that are developed by the sector are fundamental for the Dutch economy. The roads, bridges, locks, rails and tunnels are of vital importance to the transportation of products and goods used every day. For this reason, governmental organizations such as Rijkswaterstaat find it really important to cause minimal hindrance for their users and to keep the infrastructure as safe as possible (RWS2, 2019). This does make it more difficult to implement new materials or techniques that are in line with the circular economy in the sector since they need to undergo many tests before they can be used in practice. Secondly the process within the sector is often seen as long and standardized (Dijcker et al., 2018). These two characteristics are seen as contradictory to the view of the circular economy where every project is considered to be unique and flexible, where changes within the design should be possible when new innovations emerge. Furthermore, the civil engineering sector can be described as a profit driven sector which can cause the implementation of the circular economy to move at a slower pace, because initial investments or a change in organization or operation are often required to be able to answer to the circular demands (Adams et al., 2017). These changes are often related to costs and require a purpose driven mindset.

The first step of the research was to identify which barriers are present that uphold the implementation of the circular economy in the sector. To gather the data on the barriers, the Grounded Theory Approach was used. Two core arguments for using this method were the lack of available scientific literature on the subject and the method helps to minimize the interference of possible preferences within the sector. By reading several governmental papers and scientific articles, and by interviewing six experts in the field, 28 different barriers have been identified and organized into seven categories. To explore which barriers can be considered as the most urgent and significant challenges to overcome to reach a circular civil engineering sector, these 28 barriers where presented to several experts working in the sector in the form of a questionnaire. The results of the survey was analyzed by using the Fuzzy Delphi Method to reach for consensus between the different experts involved. The experts were divided into three different stakeholder groups, respectively the contractors, the engineers and the governmental stakeholders, and were asked how important they considered the individual barriers and the barrier categories. The results of the questionnaire were investigated in

detail and afterwards a triangulation was performed to identify the differences of opinion between the three stakeholders.

Surprising was that the government considered the technological category as very important, but did not rate the individual barriers in these categories as important. The contractors and engineering firms considered the policy and regulatory category as the most important category, which was in line with their highest rated barriers. In general, all stakeholders considered four barriers as being the most important ones to overcome. These barriers where described in more detail and the related difficulties they posed to implementing the circular economy was elaborated on. Afterwards, several enablers were identified in a discussion with an expert in the field and by using the data collected by the Grounded Theory Approach. The top four barriers concerned the standardization within the sector, the lack of holistic approach, the inexperience with reutilization of materials and the long life-span of the constructions within the sector.

The findings of the methods have led to several recommendations and actions for the civil engineering sector to improve the implementation of the circular economy. The first steps that need to be taken to successfully implement the circular economy in the civil engineering sector consists of four actions:

1. To make the overall process of the civil engineering sector more circular, one of the first actions should be to better integrate the deconstruction and reutilization phase. A better integration could highly benefit the circular economy since this would mean that demands could be set and this phase could be added more easily to contracts too.
2. The circular economy within the civil engineering sector could highly benefit from the implementation of a material database and storage bank to optimally provide the market the materials that they seek. Such a database and storage bank should be rolled out nationwide for it to work.
3. The third action concerns the restructuring of the maintenance sector. This change, from geographic location towards a focus on material or type of construction can improve the knowledge on certain subjects, will improve the level of expertise on the subjects and will enable more innovation. This will mean that governmental parties on different levels would have to improve their collaboration and knowledge sharing.
4. Developing the rules and regulations that relate to the norms and warranty terms in a positive way so that these do not stand in the way of innovation is an action that should be investigated further to find out that possibilities are available.

Finally, all these enablers cannot happen without collaboration between the different stakeholders, both inside and outside the sector. Furthermore, it requires the awareness of the fact that a circular economy is not achieved when the focus lies merely on developing a construction with the longest life-span but designing something that is flexible and adaptive so that it can respond to changes. Awareness, collaboration, and knowledge sharing should be at the basis of the implementation of the circular economy in every sector. By changing its mindset together with implementing the four identified actions, the civil engineering sector can take the first steps towards a circular future.

Samenvatting

In 2016 heeft de Nederlandse overheid een landelijk programma opgezet om de circulaire economie binnen verschillende sectoren te implementeren (Dutch Ministry of Infrastructure and the Environment & Dutch Ministry of Economic Affairs, 2016). Dit programma benoemt vijf sectoren met een hoge prioriteit, waaronder de bouwsector. Een onderdeel van de bouwsector is de Grond-, Weg- en Waterbouw (GWW) die zich voornamelijk bezighoudt met de natte en droge infrastructuur binnen het land (EIB, 2018). Omdat de sector bekend staat om zijn lange levensduur, is het belangrijk om zo snel mogelijk met de implementatie van de circulaire economie te beginnen, omdat de veranderingen in de toekomst grote gevolgen kunnen hebben. Deze lange levensduurspannen maken de implementatie echter moeilijker omdat het vooruitdenken van 50 of zelfs 100 jaar erg moeilijk is.

Dit onderzoek is uitgevoerd met als doel om de eerste stappen te identificeren om de circulaire economie te implementeren binnen de GWW. Er is onderzocht wat op dit moment de belangrijkste barrières zijn op weg naar een circulaire GWW en hoe deze barrières overkomen kunnen worden voor een snellere en soepelere transitie. De onderzoeksvraag is geformuleerd als volgt: “Wat zijn de eerste stappen die ondernomen moeten worden voor een succesvolle implementatie van de circulaire economie binnen de GWW?”

Om meer kennis te vergaren over de onderwerpen ‘circulaire economie’ en ‘GWW’ is er allereerst een uitgebreid literatuuronderzoek uitgevoerd. Dit onderzoek resulteerde in meerdere kenmerken van de GWW die het moeilijk maken om de circulaire economie te implementeren in de sector. Allereerst is deze sector zeer belangrijk voor de Nederlandse economie. De wegen, bruggen, spoorwegen, sluizen en tunnels zijn van levensbelang voor het transporteren van goederen en producten van en naar bedrijven, winkels en huishoudens. Overheidsinstanties zoals Rijkswaterstaat maken zich dus hard om zo min mogelijk hinder te veroorzaken voor gebruikers en om onze infrastructuur zo veilig mogelijk te houden (RWS2, 2019). Deze factoren maken het wel moeilijk om nieuwe innovaties of producten te introduceren aangezien deze lange periodes van onderzoek moeten ondergaan voordat ze gebruikt mogen worden in de praktijk. Daarnaast worden de processen binnen de sector vaak gezien als lang en gestandaardiseerd (Dijcker et al., 2018). Echter is deze manier van werken niet voordelig wanneer men een transitie naar een circulaire economie wil bereiken. Voor een circulaire economie is het belangrijk om projecten als uniek te beschouwen om flexibel te blijven en het mogelijk te maken om nieuwe technieken of producten te gebruiken. Tot slot kwam er in de literatuurstudie naar voren dat de sector erg gericht is op het maken van winst (Adams et al., 2017). Winst maken is natuurlijk noodzakelijk voor een gezonde sector, maar de implementatie van de circulaire economie vereist ook investeringen of verandering in proces of organisatie. Daarin kan een winst gerichte visie een belemmering in zijn.

Om te ontdekken welke eerste stappen gezet moeten worden om een circulaire GWW te bewerkstelligen, is het in eerste instantie belangrijk om de barrières te identificeren die deze sector tegenkomt. Omdat het een redelijk nieuw onderwerp is binnen de sector, is het belangrijk om op een zo neutraal mogelijke manier een zo breed mogelijk scala aan barrières te verzamelen. De Gefundeerde Theorie (Engels: Grounded Theory) is hier een goede manier voor. Door middel van het lezen van verschillende overheidsdocumenten, wetenschappelijke artikelen en het uitvoeren van zes interviews met experts zijn de barrières opgesteld. De uiteindelijke uitkomst is een lijst van 28 barrières, verdeeld in zeven verschillende categorieën. Hierna is er onderzoek gedaan naar welke van de barrières op dit moment als belangrijkst worden ervaren door mensen die werken in de sector. Door middel van een online vragenlijst hebben de respondenten aangegeven hoe belangrijk zij deze 28 barrières en zeven categorieën vonden. De resultaten van de vragenlijst zijn geanalyseerd aan de

hand van de Fuzzy Delphi Methode. Deze belanghebbenden waren opgedeeld in drie verschillende groepen, respectievelijk de aannemers, de ingenieurs en de overheidsinstanties.

Tussen deze drie groepen waren duidelijke verschillen in mening te vinden. Overheden vonden de technologische categorie erg belangrijk maar hebben de individuele barrières in deze categorie niet hoog gescoord. De aannemers en ingenieurs vonden de categorie die ging over de wet en regelgeving erg belangrijk, wat wel in overeenstemming was met de hoogst gescoorde barrières van hen. Gelukkig waren alle belanghebbenden wel in overeenstemming met de top vier belangrijkste barrières. Deze top vier barrières is onderzocht om te kijken of hier een oplossingen voor gevonden kon worden zodat de eerste stappen naar een circulaire GWW gezet kunnen worden. De oplossingen zijn gedefinieerd aan de hand van de resultaten die gevonden waren tijdens de Gefundeerde Theorie en een discussie met een expert in het vakgebied. De top vier barrières betreffen de standaardisatie in de sector, het gebrek aan een holistische denkwijze, het gebrek aan ervaring met het hergebruik van materialen en de lange levensduur van de constructies binnen de sector.

De bevindingen van de methoden hebben geleid tot verschillende aanbevelingen en acties voor de GWW om de implementatie van de circulaire economie te verbeteren. Deze aanbevelingen kunnen gevat worden in vier acties die de sector kan ondernemen:

1. Om het gehele proces van de GWW meer circulair te maken, zou een van de eerste acties moeten zijn om de deconstructie- en hergebruikfase beter te integreren. Een betere integratie zou de circulaire economie ten goede komen omdat dit zou betekenen dat er eisen gesteld kunnen worden op basis van deze fase. Circulaire eisen zouden op deze manier gemakkelijker in contracten verwerkt kunnen worden en uitgevoerd in een later stadia van het project.
2. De circulaire economie binnen de GWW-sector kan veel baat hebben bij de implementatie van een materiaaldatabank en opslagbank om de materialen die gezocht worden optimaal te kunnen leveren aan de markt. Een dergelijke nationale database en opslagbank zorgt ervoor dat informatie over beschikbaarheid en kwaliteit van deze materialen toegankelijk is voor iedereen in de sector.
3. De derde actie betreft de herstructurering van de onderhoudspartijen. Deze verandering, van geografische locatie naar een focus op materiaal of type constructie, kan de kennis over bepaalde onderwerpen verbeteren, het niveau van expertise over de onderwerpen verhogen en meer innovatie mogelijk maken. Dit betekent dat regeringspartijen op verschillende niveaus hun samenwerking en kennisuitwisseling zouden moeten verbeteren.
4. Om innovatie in en hergebruik van materialen sneller naar de praktijk te brengen moet er gekeken worden naar de regels en voorschriften die de normen en garantievoorwaarden bepalen van de materialen die gebruikt mogen in constructies. Omdat het bepalen van deze regels en voorschriften niet bij de verantwoordelijkheden van de besproken stakeholders behoren, moet deze actie nader onderzocht worden om te identificeren welke mogelijkheden beschikbaar zijn.

Tot slot kunnen al deze acties niet tot stand komen zonder samenwerking tussen de verschillende belanghebbenden, binnen en buiten de sector. Daarnaast moet de sector goed in gedachte houden dat een circulaire economie niet werkt op een maximale levensduur, maar de focus zou veel meer moeten liggen op het ontwerpen van flexibele en adaptieve constructies die aansluiten bij de functie vraag van nu en in de toekomst. Bewustwording, samenwerking en kennisuitwisseling moeten de basis vormen voor de implementatie van de circulaire economie in iedere sector. Door het uitvoeren van de voorgestelde acties en een verandering van mindset kan de GWW een stapje dichterbij de visie van een circulaire sector komen.

Abstract

The circular economy (CE) is a topic that has gained much interest in several sectors within the Dutch economy. Partly because of the environmental benefits related to the concept, but it is proven that the concept also has positive economical and societal benefits (EMF, 2015).

At present, there is no overview of the effects related to the implementation of the circular economy within the civil engineering sector. This paper aims to address these issues and to positively contribute to this implementation by attacking the most important barriers and discussing their enablers.

The barriers have been structured by using the Grounded Theory Approach which led to 28 different barriers in seven different categories. For the retrieval of these barriers, governmental papers and scientific articles have been read, furthermore, six interviews have been performed with experts in the field. The most important barriers have been identified and rated by using the Fuzzy Delphi Method which helps at finding a consensus within the different stakeholder groups.

The four most important barriers have been identified and enablers are investigated for a better implementation of the circular economy within the civil engineering sector. This has led to the first steps that the sector has to undertake to become more circular: including the deconstruction and reutilization phase in the projects process, setting up a material database and storage bank, restructuring the maintenance sector, enhancing collaboration between the different stakeholders, and by improving the approval rate of reused and niche materials. By focusing on these steps the sector can start the progress to become more circular in their practices.

List of Abbreviations

CD	Competitive Dialogue
CE	Circular Economy
CRS	Customer Requirement Specification
DBFMO	Design, Built, Finance, Manage, Operate
D&C	Design and Construct
EMVI	Economisch Meest Voordelige Inschrijving (Dutch)
EU	European Union
FDM	Fuzzy Delphi Method
GPP	Green Public Procurement
GTA	Grounded Theory Approach
MEAT	Most Economic Advantageous Tender
RCC	Rapid Circular Contracting
RWS	Rijkswaterstaat (Dutch)
TFN	Triangular Fuzzy Number

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“Le changement du monde n’est pas seulement creation, progress, il est d’abord et toujours decomposition, crise”

ALAIN TOURAINE

1. INTRODUCTION

The introduction describes the motivation behind this thesis and the problem definition. This will lead to the research questions, the scope and limitations of the research. The chapter will end with an explanation of the methods used and provides a reading guide.

1.1. Research importance

The linear economy has been taken for granted since the industrialization of the economy many years ago (Yuan, Bi, & Moriguichi, 2018). This economic growth resulted in a take-make-dispose pattern and consumption-driven society, with the result that terms such as 'sustainability' and 'waste-efficiency' did not get much attention. This way of thinking and working has kept the economy turning for many decades. However, people now tend to see that this way of working cannot keep up for much longer while resources are running out.

In 2012, we already needed 1,6 earths to provide for the natural resources we consume (WWF, 2016). Unfortunately, we do not have more than one earth to provide our resources. This asks for a new way of thinking about waste, resources and business models as a whole (EMF, 2015).

A possible new way of thinking that keeps in mind (the lack of) resources and waste, is considering the economy as a closed loop rather than a linear process, which involves reusing and recycling rather than throwing products away after one use. This is called the circular economy (CE). The concept of the circular economy has been presented in several articles and documents and has been gaining more attention over recent years (Geissdoerfer, Savaget, Bocken, & Hultink, 2017; Kirchherr, Reike, & Hekkert, 2017).

Not only in education and research this topic has gained interest, but awareness on the concept of the circular economy is also growing on the political agenda. The United Nations has set up the Sustainable Development Goals in 2015 to preserve the planet. One of these goals, goal 12, focusses on responsible consumption and production (United Nations, 2018). This goal does not state the circular economy literally but does imply to use natural resources and waste more efficiently (United Nations, n.d.). Other goals, such as goal 7 (Affordable and clean energy), goal 11 (Sustainable cities and communities) and goal 13 (Climate action) also relate to the concept of the Circular Economy (United Nations, 2018).

At the end of 2015, the European Commission came with an action plan for the transition to a more circular economy (European Commission, 2015). In this report the EU states that "the circular economy will boost the EU's competitiveness by protecting businesses against scarcity of resources and volatile prices, helping to create new business opportunities and innovative, more efficient ways of producing and consuming. It will create local jobs at all skills levels and opportunities for social integration and cohesion. At the same time, it will save energy and help avoid the irreversible damages caused by using up resources at a rate that exceeds the Earth's capacity to renew them in terms of climate and biodiversity, air, soil and water pollution." (European Commission, 2015).

Hereafter, the Dutch Government came with her first action plan for the implementation of CE in the Dutch economy (Dutch Ministry of Infrastructure and the Environment & Dutch Ministry of Economic Affairs, 2016). This action plan focusses on five priority sectors in which the Dutch Government believes immediate action is required. One of these sectors is the construction sector which has led to an agenda that focusses solely on the transition of the built environment towards a circular economy (Dutch Ministry of Infrastructure and the Environment, 2018). The definition of CE in this agenda is stated as follows:

"Circular construction means the development, use and reuse of buildings, areas and infrastructure, without unnecessary exhaustion of natural resources, contamination of the built environment and damage to the ecosystem. Building in a way that is economically sound and contributes to the wellbeing of human- and animal life. Here and there, now and later."
(Freely translated from *Transitieagenda Circulaire Economie*, 2018)

The construction sector contains a lot of heavy materials such as concrete and steel, these materials have a great burden on the planet. When (re)using these materials in a more efficient way, this could have a positive impact on the earth and the economy. However, creating a circular economy is not a destiny, it is a long-term approach with constantly shifting goals, technical challenges and policy changes, this goal is not reached in the blink of an eye.

This graduation report will contribute to this process. It will focus on one of the sectors within the built environment to see where the current barriers are when wanting to implement the circular economy and will discuss how to possibly overcome these barriers.

1.2. Problem definition and objective

Shifting to a circular economy is innovative and interesting, but most of all: it is necessary if we want to preserve our earth's wellbeing. Resources are running low and the construction sector is a big contributor to this scarcity and the amount of waste generated on earth (Dutch Ministry of Infrastructure and the Environment, 2018a; WWF, 2016). However, implementing a concept such as the circular economy, especially in the construction sector, goes hand in hand with quite a lot of obstacles. The construction sector is a conventional sector which is aimed at competition, is characterized by the generation of profit and has short-term relationships (Pomponi & Moncaster, 2017; Pots, 2018). These components make it difficult to change this sector.

In the civil engineering sector, a sub-sector of the construction sector which mostly concerns the wet and dry infrastructure within the built environment, the implementation of CE is even more complicated. In the sector each project is unique, the constructions have long lifespans and alterations can occur during the life cycle (Dijcker, Crielaard, & Schepers, 2018). Furthermore, the civil engineering sector is facing quite some problems in finding contractors since current projects in the sector are affiliated with high risks and contractors have low profit margins (Cobouw, 2019). Asking for a circular project in this situation will only scare the contractors more. All of this adds complexity to the whole process of implementing the CE in this sector. There is not a single solution, which asks for innovation and courage, and this is something the people in the sector are currently not willing to take. The objective of this research focusses on finding all these obstacles and analyzing how to overcome the biggest barriers that prevent a circular civil engineering sector. The goal of this research is identifying, structuring, rating and enabling the most relevant features of the circular potential of the sector.

1.3. Scope, limitations and delimitations

This research will dig deeper into the barriers and enablers related to the implementation of the circular economy in the civil engineering sector, because the civil engineering sector has different and more specific characteristics than the construction sector in general. The scope of this research will thus be the civil engineering sector in the Netherlands. In particular, it will focus on projects that relate to the roads in the Netherlands. Projects related to the waterways and the railways are not included in this research because they are significantly different in terms of time, design and stakeholders. The focus will be on the construction and/or renovation of (high)ways, roads, bridges and tunnels. This also gives the first limitation because most literature concerning the CE is focused on the construction sector as a whole and not specifically for the civil engineering sector. This lack of available data can have an impact on the amount of barriers and enablers that will be found.

Because the concept of the circular economy is still an emerging concept, new articles about the circular economy appear every week. And because of the time limit of the research not every new article can be considered and, of course, not everybody that works in the civil engineering sector could be interviewed to ask their opinion on this topic. The goal of the researcher was to gather the broadest amount of data for the analysis in the available time.

1.4. Research questions

The previously made statements about the problem definition and the research scope have led to the following research question:

What are the first steps needed for a successful implementation of the CE in the civil engineering sector?

Main question

To answer the main research question it is important to perform an analysis on the current stage of the circular economy within the civil engineering sector, its awareness on the topic and the possible benefits of a circular civil engineering sector. This leads to the following sub-question:

What are the benefits of a circular civil engineering sector and where does the concept of the CE currently stand in the sector?

Sub-question 1

To be able to further implement the CE into the sector, it is important to know what the process within the sector looks like and its unique characteristics. This to be able to better understand the hurdles to overcome. The second sub-question is an informative question and is stated as follows:

What is a civil project, out of which phases does a civil project consist and what is the relationship between the CE and these phases?

Sub-question 2

When it is analyzed what the characteristics are of this specific sector, it can be investigated if these characteristics cause problems when wanting to implement the circular economy. Also, general barriers concerning the implementation will be looked into to see if they also cause a problem in the civil engineering sector. These findings are based upon the third sub-question which is described as follows:

What barriers arise when wanting to implement a circular vision in civil projects?

Sub-question 3

The last step in this research will be to find out whether these barriers could be overcome and what would then be the enablers that are related to that. The last sub-question will thus be:

What are possible enablers to the most important barriers?

Sub-question 4

1.5. Research design and reading guide

This master thesis has started with the research importance and problem definition at the beginning of **chapter 1** which resulted in the research questions and their associated limitations. Hereafter, the report will be structured according to three phases: the theoretical research, the qualitative research and quantitative research. The research model can be found in Figure 1.

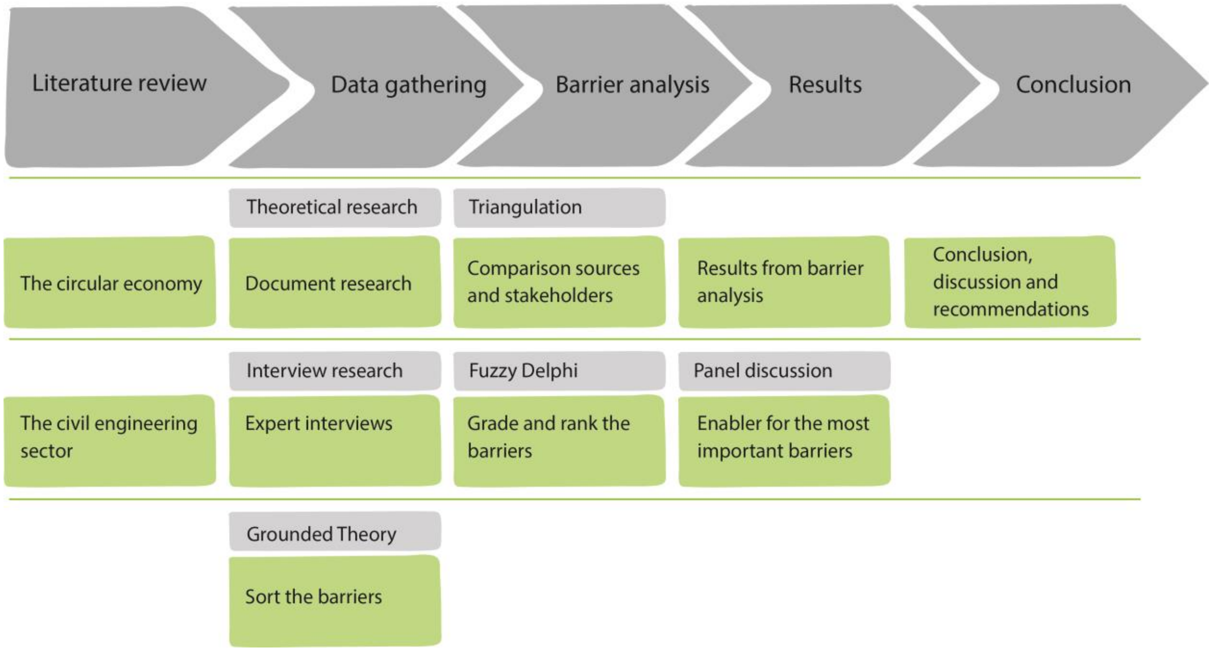


Figure 1 - Research model

The theoretical research is carried out through literature research. Firstly, to gain insight into the topic of the circular economy and its relationship to civil engineering, many articles have been read to improve knowledge on these topics. Also, it is investigated which steps have already been taken towards a more circular sector and which barriers can already be defined from these first steps. This review is performed to answer sub-questions 1 and 2 and can be found in **chapter 2**.

In the next chapter, **chapter 3**, the methodology of the research will be explained. In this thesis, the Grounded Theory Approach and the Fuzzy Delphi Method will be used to perform the analysis. Also following both analysis methods, a triangulation of results is conducted to identify differences and similarities.

The information gathered in the literature review forms a basis for **chapter 4**. The qualitative research has the goal to identify the barriers that are currently making it challenging to implement the circular economy in the civil engineering sector. The next chapter will thus answer sub-question 3. To gather the data, a document study that complements the literature review of chapter 2 and expert interviews have been performed. The document study provides a collection of both academic and non-academic data. The interviews are conducted with experts in the field of the circular economy within the civil engineering sector. All the data gathered will be analyzed based upon the Grounded Theory Approach that will result in an elaborate list of barriers that the sector is currently facing when wanting to implement the circular economy and their related enablers.

The quantitative research performed at the end of **chapter 4** consists of a survey. The survey is distributed to people working in the sector and has as goal to identify which of the categorized barriers are considered to be most important in the implementation process. This analysis will answer sub-question 4 and is performed with the Fuzzy Delphi Method.

Finally, in **chapter 5**, the most important barriers stated by the sector will be discussed, their related enablers will be analyzed and a small perspective into the future will be described.

This thesis will end in **chapter 6** with a summary of the research and stating the conclusion, which will summarize the answers to the research questions. Finally, the societal and scientific relevance and future recommendations are discussed.

To enable an easier reading experience the Appendix of this report has been kept short. The most relevant data has been kept in the Appendix but other information has been moved to a Supplement. This Supplement can be requested by emailing the researcher.

2. LITERATURE REVIEW

When implementing circular requirements, it is important to first understand the concept of the circular economy, its position in the civil engineering sector and the possible consequences for this sector. The literature research will provide insight in these topics and will emphasise on the possible barriers regarding the implementation of the circular economy in the civil engineering sector.

"Waste is actually a very bad revenue model. Because why would you make something that has no value or even costs money to get rid of it? Waste is basically stupid."

BILL MCDONOUGH

2.1. The circular economy

The circular economy is a concept that has gained a lot of popularity in recent years. The growth of published articles and related documents reflect this (Geissdoerfer et al., 2017). Not only is CE becoming a trending topic amongst scholars, but several governmental institutions have also adopted the CE-view. Institutions such as the European Commission and the United Nations have several policies focused on resource efficiency (European Commission, 2015; United Nations, 2018). However, CE is not solely an environmental strategy but also concerns the economy and society which makes it an interesting subject in multiple sectors (Yuan et al., 2018). The concept of CE will be explained in the next paragraphs.

2.1.1. The linear economy vs. the circular economy

Most processes in the current economy are linear in nature. For example, a factory would use natural resources to make products. These products would be sold to a client who will use the products until they have become useless, which leads to the final step, discarding the product. Such a process is common in the linear economy (EMF, 2015).

The circular economy is focused on connecting the final and first step of this linear process by reusing materials within the product or products as a whole, to minimize the production of waste. In this way, materials and natural resources can be used more efficiently in the production process. There are different levels of reusability which varies between reusing with the same function and no changes (high level), to incineration of the product to recover energy (low level) (Potting, Hekkert, Worrell, & Hanemaaijer, 2017). In Figure 2 the different levels are explained. These levels regard the circular economy, however, in the current situation a more unsustainable step is often undertaken where products end up in a landfill and will not even be incinerated (EMF, 2015).

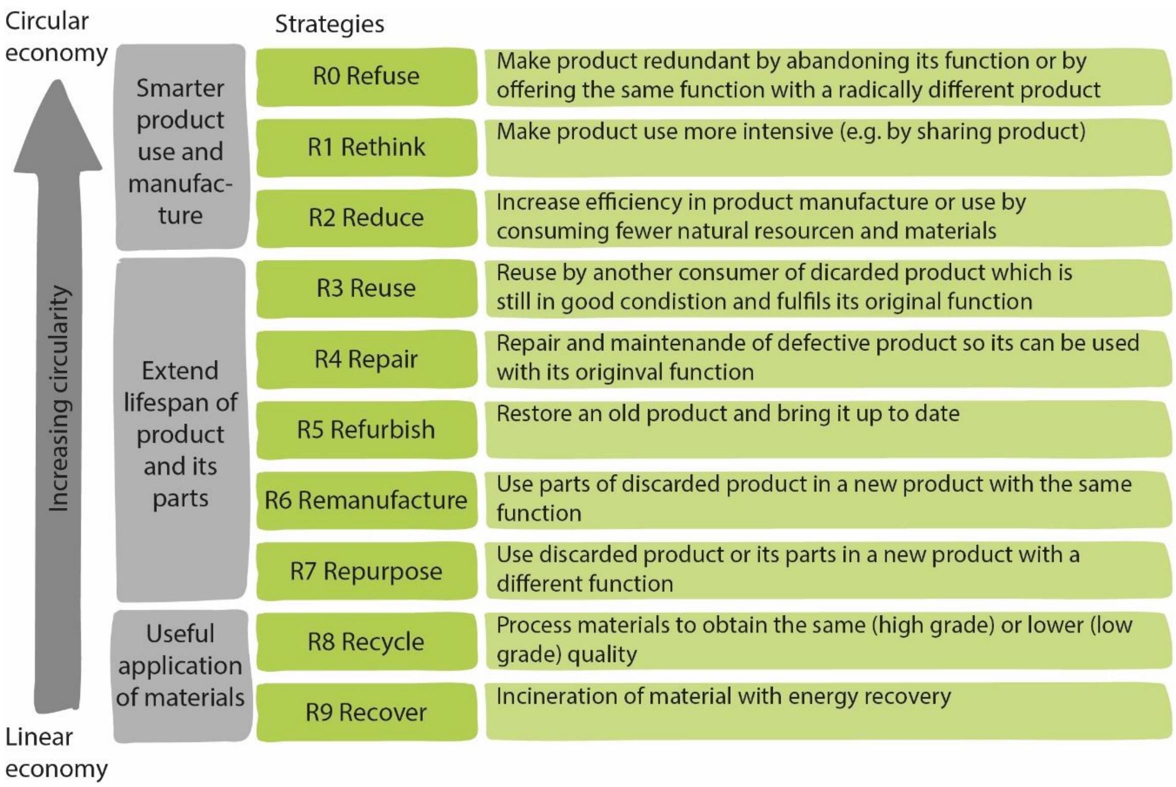


Figure 2 - R-levels of circularity (own image, adapted from Kircherr et al. (2017))

An institution that commits a lot of effort trying to enable a general vision on the concept of the circular economy is the Ellen MacArthur Foundation. The Ellen MacArthur Foundation has stated its definition of the circular economy as follows:

"The circular economy refers to an industrial economy that is restorative by intention; aims to rely on renewable energy; minimizes, tracks, and eliminates the use of toxic chemicals; and eradicates waste through careful design."
(EMF, 2015)

This definition and general vision comes with five core principles of the circular economy (EMF, 2015):

1. Design out waste
The core principle of the circular economy is that there is no more waste. All products should be easily dismantled and designed with the intention to fit, in one way or another, in a biological or technical cycle. So that materials can be reused with a minimal of energy used and a maximal value remained.

2. Build resilience through diversity
EMF (2015) states that "Diverse systems with many connections and scales are more resilient in the face of external shocks than systems built simply for efficiency" which means that flexibility and customizability are of high importance as products can be applied in a more comprehensive way.

3. Rely on energy from renewable sources
A key component of the circular economy is to reduce the current resource consuming society. A system should always investigate the amount of energy involved, in resources and labor, but also the way it was generated.

4. Think in 'systems'
To be able to see a construction or a product in parts rather than a whole, it makes it easier to identify the parts as elements with a mutual relationship. This insight can make re-utilization more obvious.

5. Waste is food
To reduce waste, one should investigate the option to reintroduce materials back in the system, for a technical nutrient, this is called 'upcycling'. This method will have big effects on the level of restoration of the system.

2.1.2. Benefits of implementing CE

The circular economy concerns the environment in the first place because it is mainly focused on using the resources that our planet possesses as efficient as possible (EMF, 2015) and attacks other problems such as water pollution, the loss of biodiversity and excessive land use (Geissdoerfer et al., 2017). Several studies have shown that the implementation of the CE in several sectors has led to a significant decrease in waste that was 'lost' (Adams, Thorpe, Osmani, & Thomback, 2017).

A circular approach is not only an environmental strategy but also concerns the economy. It makes processes more efficient, which has the potential to create competitive advantages for companies and reduces costs and production time (Geissdoerfer et al., 2017). While in the past industries considered investing in environmental goals as a trade-off between sustainability and industrial competitiveness, this view has been debunked in the past (Porter & Van der Linde, 1995). Evidence for the positive relationship between CE and a competitive advantage can be found in a case study by Yuan & Shi (2009), in which is investigated how CE measures would affect the environmental score and industrial competitiveness of a smeltery in China.

The Ellen MacArthur Foundation (2013) wants to shift towards a circular economy by pointing out ways to create value within this economic model. They developed four principles which are briefly discussed hereafter, and a visual representation can be found in Figure 3.

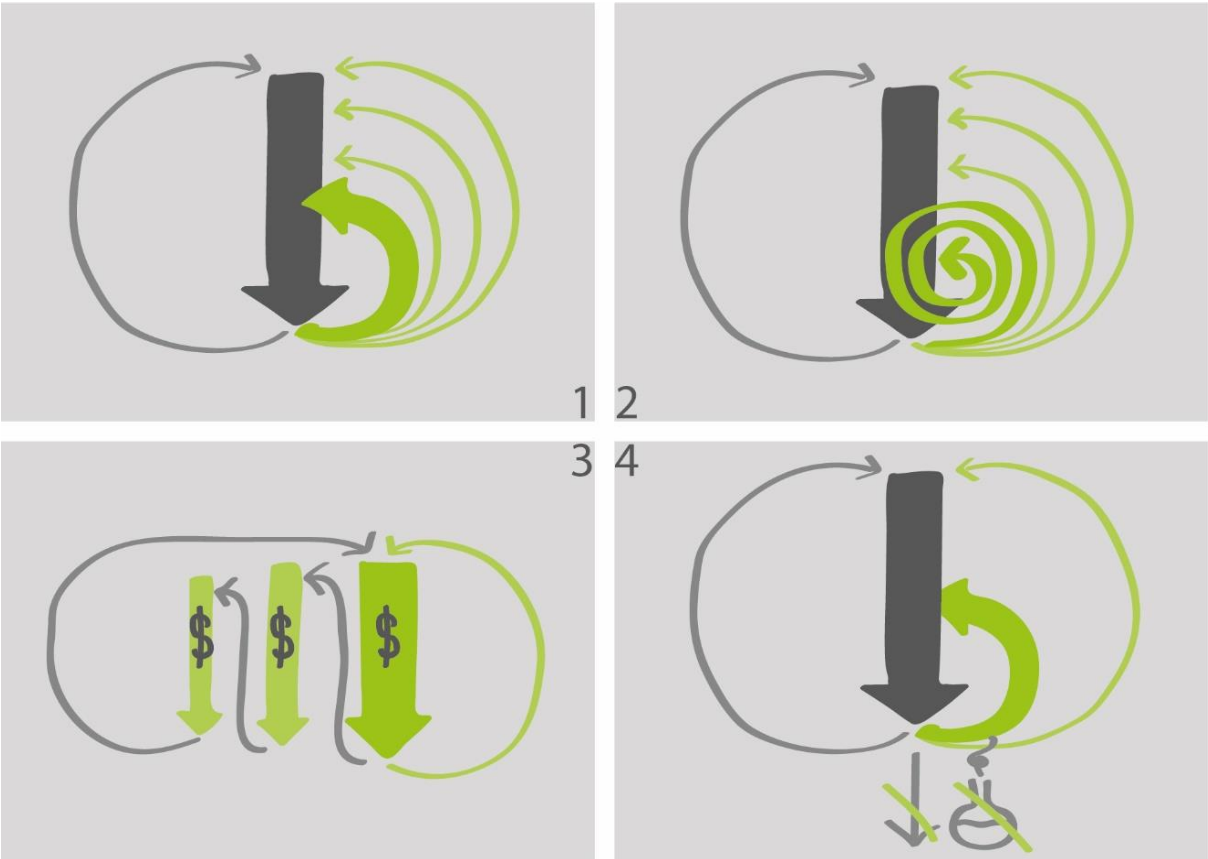


Figure 3 - Visual representation of the four principles of the EMF (own image, adapted from EMF (2015))

<u>1. Power of the inner circle</u>

The first principle is based upon the notion that when the circle is smaller, the savings are larger. These savings are costs such as labor and energy. Making bigger circles means more inefficiencies during the production process which makes the virgin material more difficult to extract and the end-of-life treatment costs higher.

<u>2. Power of circling longer</u>

A good way to enable a circular economy is to keep products, components, and materials in use for as long as possible. This principle can be realized by, for example, making the life-span of products longer or by using a more efficient re-utilization. This is a completely different mindset compared to the take-make-dispose mindset of the linear economy where products are to be thrown away after one use.

<u>3. Power of cascaded use and inbound material/product substitution</u>

Cascaded use of materials or products means reusing said material or product instead of throwing it away after a single use. Take for example wood. First, wood could be used as a structural product for houses, hereafter, it could be used as smaller pieces for wooden toys. If one is done playing with the toys, the wood could be cut into chipwood for insulation, paper, wooden board material, and many other purposes. This way of downcycling materials is a more economical way of production while embedded costs are lower and lesser virgin materials need to flow into the process. This principle asks for better collaboration and communication throughout all sectors of the economy.

4. Power of pure, non-toxic, or at least easier-to-separate inputs and designs

The last principle goes hand in hand with all three previously stated principles. Designing products while keeping in mind a way to decompose the materials and preserving purity and quality, would make recycling much easier. This thus means that products and materials have a higher level of reusability which will lead to lower costs.

To adopt these principles, new business models are required (Jonker, Kothman, Faber, & Montenegro Navarro, 2018). There are many ways to include circularity in business models, one of these examples is considering a product as-a-service rather than owning it. Examples of this are Philips not selling lamps but selling lumen and the 'pay-per-use' construction of the furniture of Gispen (Gispen, n.d.; Philips Lighting B.V., 2017). The big difference between these examples and the civil engineering sector is its difference in life-cycle. The mentioned products last for 5 to 20 years, but constructions in the civil engineering sector have a life-cycle closer to 50 or even 100 years (Dijcker et al., 2018). While new business models have been explored in other sectors, Adams et al. (2017) state that "they lack research and application in the construction sector" and Rijkswaterstaat (2015) does not see these business models as the ultimate viable solution for long-life structures.

Lastly, when implementing a circular economy there are many ways that this could be a benefit for the society itself. The accompanied advantages, such as enhanced efficiency and a reduction of costs and production time, can help solve societal challenges such as poverty trap and social vulnerability (Geissdoerfer et al., 2017). Also in terms of carbon emission reduction and job opportunities, the circular economy benefits the society as a whole. A report, commissioned by the Club of Rome, states that a circular economy could benefit the society by cutting 2/3 of CO_2 emissions and gaining around 200.000 jobs, this addition of jobs could cut one-third of the current unemployment rates in the Netherlands (Wijkman & Skånberg, 2015). Furthermore, expectations are also that the GDP of the Netherlands will increase with a minimum of 1,4% (TNO, 2013).

2.2. What is the civil engineering sector?

Within the construction sector, there are many sub-sectors that focus on specific areas. One of these sub-sectors is the civil engineering sector which focusses on the various ground and (water)road works such as railways, bridges, tunnels, and roads (CapAnalysis, 2002).

The civil engineering sector procures most projects publicly, which means that any company can compete for the project. The companies within this sector are much more specialized compared to the building and utility sector where more 'general' contractors can be found (CapAnalysis, 2002). Furthermore, most projects derive from a governmental request (EIB, 2018). Noteworthy for the civil engineering sector is that not only the constructions themselves have a long life-span, but the planning process before the construction is realized also takes up more time than, for example, offices or buildings (Dijcker et al., 2018; Dutch Ministry of Infrastructure and the Environment, 2018).

2.2.1. The most important stakeholders

Within the different phases that a project goes through, different stakeholders are involved. There are three main stakeholders in the sector: the client that commissions the project, the contractor of that project, and the engineering and consultancy firms that help with this process. Regarding the client, as stated before, most projects within the sector are procured by the government, the percentage of governmental procured projects was 49% in 2001 (CapAnalysis, 2002) and PIANOo, (n.d.-b) even states on his website that more than 80% of the projects in the civil engineering sector is procured by governmental organisations. The government consists of municipalities, provinces, water authorities, Prorail, and Rijkswaterstaat. Other clients could be companies, contractors or individuals (CapAnalysis, 2002). The accepter of the project is most likely the contractor that will construct the project.

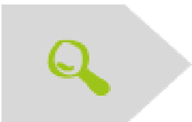
Engineering firms can support on both sides of the project: at the side of the client and at the side of the accepter.

Next to these main stakeholders there are the stakeholders affiliated to an individual project. These are people or companies that can influence the goal of the project. Examples of these stakeholders are: people living nearby the project, organizations regarding nature preservation, the operator of the construction or users of the construction.

2.2.2. The different phases in the civil engineering sector

Between the initiative of a new project until the demolition of the construction after usage, many steps will be undertaken by many stakeholders. Originally, the construction process is a linear process from initiative until the utilization of the construction, this process is described in ‘Leidraad voor Systems Engineering binnen de GWW-sector’ (Werkgroep Leidraad Systems Engineering, 2013). This process however, is not in line with the circular vision. This is why Twynstra Gudde recommended adding an additional step, depicted as ‘Deconstruction and Reuse in Figure 4, to the process which could help focus more attention to the disassembly and re-utilization of materials (de Vries, van Schijndel, van Bezu, & Blekemolen, 2018). Although deconstruction of buildings or other constructions is already performed for many years, this step is not entirely integrated in the process and is mostly not considered when drawing up contracts (de Vries et al., 2018) These two descriptions combined form the construction process in the civil engineering sector that will be used for this research, an overview can be found in Figure 4. The following paragraphs will elaborate more on the different phases and their input, output, stakeholders, and activities.

Figure 4 - The construction process (own image)



Exploration

The manual of Werkgroep Leidraad Systems Engineering (2013) mentions that the first phase starts off with the fact that there is an intention to build a construction. When this intention is announced, the involved stakeholders will identified and documented, and the main goal of the project will be formulated. This goal is the basis of the Customer Requirements Specification (CRS) which will be set up in this phase. A CRS contains all the wishes that the stakeholders would like to see back in the realized project. Sometimes these wishes could end up being contradictory, for example, stakeholder Y could prefer a bridge and stakeholder Z a tunnel. When this happens, after negotiation on these wishes, general requirements for the system will be formulated. This process is shown on the left side in Figure 5.

Simultaneous to this process, several analyses will be performed such as environmental analysis, stakeholder analysis, and problem analysis to obtain a full picture of the situation. Furthermore, the client (e.g. Rijkswaterstaat) will set up some preconditions such as prize, scope, time and the type of contract, which is sometimes done with the cooperation of an engineering firm. The CRS will lead to the start of the System Requirements that will be used to further design the construction.

Concept phase

The concept phase encompasses the development of the design which will be formulated in the form of a System Specification. Leaving the exploration phase, the design and requirements will be of a high abstract level, in the concept phase the design will become more specific. Several parties will be asked to reach a higher level of engineering within the design. At this moment in the process, it is known that the 'connection between A and B' will consist of, let's say a bridge and it is time to further develop the design regarding, for example, load, dimensions, and control system. The design will be worked out in several levels of detail and, if necessary, more information will be gathered regarding noise-, air- and/or environmental pollution. These design specifications can affect the requirements already set in the exploration phase and new requirements will be added.

This will eventually lead to the final list of System Requirements which are formulated using the method of 'Functional Specification'. A few years ago, Rijkswaterstaat started to use this method, which provides an unambiguous way to write down the System Requirements. It is part of the method of Systems Engineering and is now widely used in the civil engineering sector (INCOSE, n.d.; Rijkswaterstaat, 2005). The method is most commonly used for integrated contracts such as Design & Construct contracts (Lever, 2006). By writing down requirements in a functional way, the goal of the system is defined, but not "the road" that leads to it. This provides contractors with more room to include their own ideas and knowledge in the design as they are earlier involved in the process. This stimulates innovation and allows Rijkswaterstaat to outsource more of its process. Rijkswaterstaat has set up three main principles following from this method for developing System Requirements (Rijkswaterstaat, 2018). This means that requirements must be:

1. **Robust**; This means that the interpretation of the requirement must be specific enough and clearly formulated so that no misunderstanding could occur. It is helpful, when making a requirement, to evaluate whether it is written down in a S.M.A.R.T. way. In this context, S.M.A.R.T. means Specific, Measurable, Assignable, Realistic and Time-related (Doran, 1981).
2. **Solution free**; The requirements need to be stated in an abstract way, this means that no solutions are to be stated in the requirement itself.
3. **Traceable**; Traceability enlarges the clarity of the requirement and prevents that too many requirements are to be set. Knowing where the requirement comes from, for example, policy documents, laws or the wish of a client, makes for better understanding and implementation of the requirement in the design.

The list of System Requirements has now been completed and will be the input for the System Specification, which provides a structured overview of the system. The system specification will contain: The requirements, consisting of both the wishes formulated in the exploration phase and other requirements related to laws or policies; the scope; and the created design choices, which is both influenced by and influences the requirements. Figure 5 provides an overview of the process thus far.

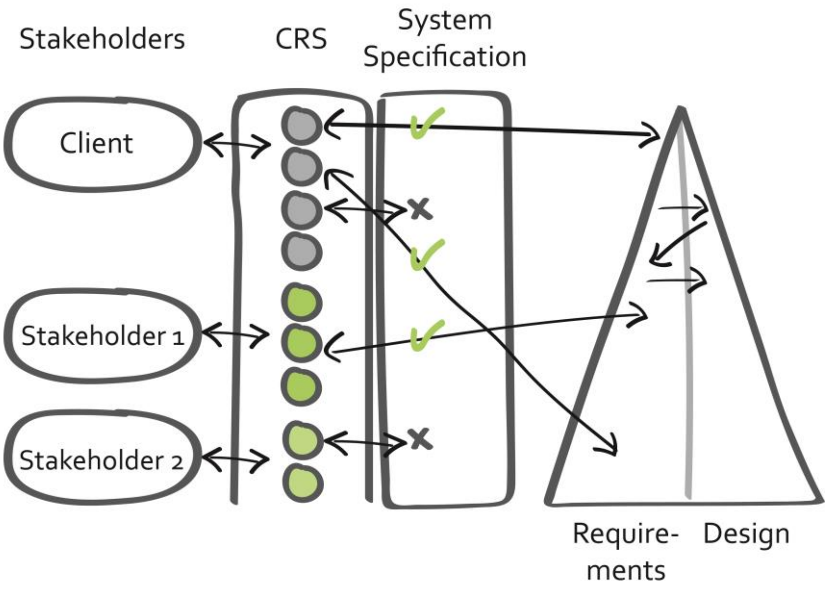


Figure 5 - From wish to system requirement (own image, adapted from Werkgroep Leidraad Systems Engineering (2013))

Development and contracting

When the System Specification has been written down, the procurement strategy and type of contract that is favorable will be selected. This happens in the development and contracting phase. To procure a project, it first needs to be clear which type of contract will be used. In the construction sector, four kinds of contracts are used (Chao-Duyvis, Koning, & Ubink, 2013). These are traditional contracts, building teams, integrated contracts, and alliances. Within the civil engineering sector, traditional and integrated contracts are mostly used and will be explained hereafter (PIANOo, n.d.-c).

<u>Traditional contract</u>

The traditional contract model is based on the traditional triangular relationship between client, contractor, and architect (Castelein, 2018). The contract is mostly based on the UAV-2012, a set of norms regarding the relationship between the three stakeholders (Chao-Duyvis et al., 2013). In this type of contract, the contractor is responsible for the realization of the project and the architect is responsible for the design. The client will have a contract with the architect to design the construction, when the design is ready, a contractor will be picked with whom a new contract will be set up. This has as result that there is little collaboration between the architect and contractor (Davis, Love, & Baccarini, 2008). This type of contract makes it easier to manage the process since in most cases the client is responsible for all decisions that are made, he is also responsible for the possible time- and cost-overrun. A disadvantage of the traditional contract is a higher risk of miscommunications due to the lack of collaboration. Furthermore, there is no input of the contractor on the design and the planning of the project, because he is appointed after the design phase (Castelein, 2018; Davis et al., 2008)

<u>Integrated contracts</u>

Integrated contracts, as the word might suggest, is a more integrated way of working in the construction sector. The collaboration is not in a triangular fashion, but the client signs a contract with one contractor, which will be responsible for the realization of all phases described in the contract (Castelein, 2018). The number of phases that are included, depends on the contract. This can vary between a Design & Construct (D&C) contract, where the contractor is responsible for the design of the construction and the realization, to Design, Build, Maintain, Operate & Remove (DBMOR) contracts, in which the contractor is not only responsible for the design and construction but for the whole process until the construction has to be removed (de Vries et al., 2018). It is thus the responsibility of the contractor to find an architect or sub-contractors to help with the entire process. One of the advantages of an integrated contract is the fact that the client only deals with one party, which makes the process more cost- and time efficient. Also, while all the parties are already initiated in the design phase, it can enhance the constructability and innovativeness of the design, and can reduce the project time. A disadvantage of these kind of contracts is the fact that the client has less involvement in the process (Castelein, 2018; Davis et al., 2008).

After the formulation of the contract, the project will be procured. In the procurement process, companies can enlist if they want to bid on this particular project. The necessary information such as the requirements regarding the project and the outcome of the analyses done will be distributed to the companies. Most procurement processes require a company to deliver a plan of work and the costs of the realization (RRBouw, 2012). Through several interview rounds and different levels of design detailing, one company will be picked according to its highest value on both criteria. In Dutch, this is called 'Economisch Meest Voordelige Inschrijving' (EMVI) and in English 'Most Economically Advantageous Tender (MEAT). The most used methods to procure a project in the civil engineering sector are public procurement and Competitive Dialogue.

Public procurement

In the civil engineering sector, almost 80% of the tenders is publicly procured (PIANOo, n.d.-a). A public procurement means that every contractor can subscribe for a tender. The project will be published publicly, thereafter every contractor, when he is interested, can subscribe to this project. The winning contractor is the one that complies most to the criteria set out by the client (Dutch Ministry of Economic Affairs and Climate Policy, 2016).

Competitive Dialogue

The method of Competitive Dialogue (CD) was initially developed for complex projects (Rijksoverheid, 2009). The method is introduced in 2004 and allows the client to enable a dialogue between him and a list of contractors already at an earlier stage. This is called an Early Contractor Involvement (ECI). Procurement methods, such as CD, that include ECI allow multiple contractors to get involved in the project before all System Requirements are set, which leads to better integration between the design team and the construction team and allows for more innovation throughout the process. Similar to integrated contracts, ECI has the benefits that it can reduce time, costs and efforts, and leaves room for an active role of the contractor which can result in creative solutions (Wondimu, Lohne, & Lædre, 2017). Not using ECI is often seen as inefficient because procedures are conducted sequentially (instead of interweaved) and because of the separation between design and construction (Wondimu et al., 2017).

Competitive Dialogue can be well combined with DBFM(OR) contracts (Dutch Ministry of Economic Affairs and Climate Policy, 2016; Wondimu, Klakegg, Lædre, & Ballard, 2018). This early dialogue between contractor and client "gives […] the opportunity to discuss, among other things, sustainability and renewable energy objectives" (Wondimu et al., 2017). After the dialogue, one or more contractors will be asked to compete in the tender (Dutch Ministry of Economic Affairs and Climate Policy, 2016).

The development and contracting phase ends with the contract being signed and the company continuing developing the design to bring it to an even higher level of detailing (Werkgroep Leidraad Systems Engineering, 2013).

Sub-development

When obtaining the project, a certain amount of detailing still must be done. Occasionally, the contractor introduces other sub-contractors to the project to help him with the final design, since there is a chance that the contractor does not have all expertise regarding some parts of the project. The project team will grow, and the project will be divided into smaller phases to make it more manageable. The output of this phase will be the final design that satisfies the System Requirements described in the contract, which will be validated by the stakeholders. This process is similar to the concept phase, however on a higher level of detail.

Execution

The execution phase will start after the project development has been accepted, now the project will be realized. The construction will be performed by the contractor and possible sub-contractors. The contractor is responsible for the validation of the project and needs to make sure everything is constructed according to the requirements that have been set. The constant validation throughout the project is critical as it enables the contractor to keep in line with the wishes of the client and the requirements that have been set. This phase continues until the project has been realized.

Utilization and Maintenance

The utilization and maintenance phase is where the construction will be used. Through utilization of the construction it slowly wears down thus maintenance could be necessary after a certain amount of time. Depending on the contract that is used for the construction, the maintenance can be done by the contractor, the client itself or another independent party.

Disassembly and Reuse

To be able to close the circle for a more circular view on the construction process, this final step is important since this provides the possibility to close the loop. This phase focusses on disassembling the construction so that parts can be reused in other constructions. The idea of Twynstra Gudde is that this phase could also be implemented in contracts (de Vries et al., 2018). The phase can already be taken into consideration in earlier stages of the project design.

2.3. Implementing CE in the civil engineering sector

In the past sub-chapters the concepts of the circular economy and the civil engineering sector have been discussed separately, this sub-chapter will dig further into the implementation of the circular economy within the civil engineering sector. To investigate this integration, a definition of CE is written to help the reader better understand the position of the concept within the sector. This definition is based upon the definitions of the Dutch Ministry of Infrastructure and the Environment (2018), and Van Oppen et al. (2018) and is described as follows:

The circular economy is an economic system that minimizes the waste of resources and maximizes the value retention of these resources without compromising the wellbeing of people and the planet. This *means that reusability of products and materials needs to be preserved and destruction of value needs to be prevented. With regard to here and now, there and later.*

2.3.1. The transition towards a circular economy in the civil engineering sector

The construction sector is a sector that has a large impact on the environment. The governmental paper 'Nederland circulair in 2050' (2016) states that the construction sector is responsible for the use of approximately 50% of raw materials in the Netherlands. However, the sector is doing a good job reusing their materials, more than 95% of materials are being downcycled to raise ground levels for roadworks. Unfortunately this is downcycling which is, as has been seen in the previous sub-chapter, not the highest level of circularity. Furthermore, the construction sector consumes 20% of the total national energy use. These numbers do not just apply to the construction of buildings and roads but also the consummation during the utilization and maintenance of constructions (CE Delft, 2015; Ellemmi, 2013). Therefore, implementing the circular economy in this sector could have a huge impact on waste production and energy usage in the Netherlands.

To implement the circular economy within the civil engineering sector in the Netherlands, one could look at several factors. In the coming paragraphs, two factors will be discussed upon, the process and procurement method.

As stated in paragraph 2.2.2, Twynstra Gudde has proposed the addition of an extra phase into the construction process which could be called 'deconstruction and reuse'. While currently little attention is paid to deconstruction rather than demolition, it might be a wise step to incorporate this step, so that it can be considered and planned for in an earlier stage of the process (Twynstra Gudde, 2018). The relationship of this final phase and the earlier steps in the process will be discussed hereafter, an overview of these relationships can be found in Figure 6.

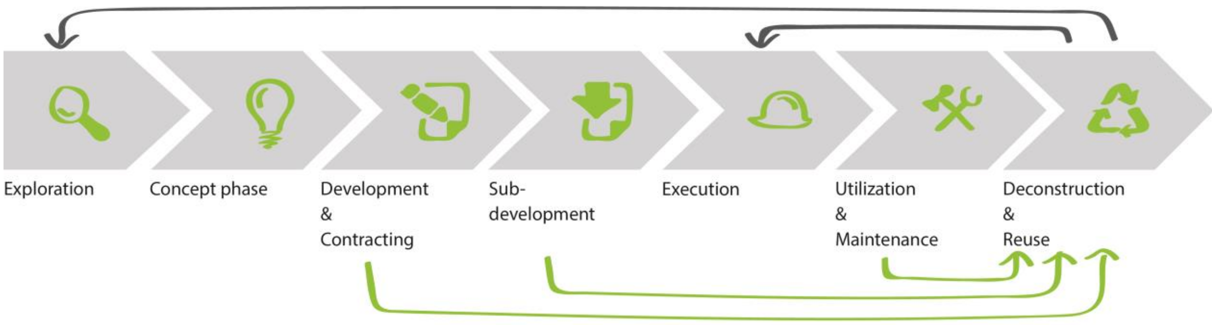


Figure 6 - Deconstruction and reuse and its relationships (own image)

To implement the circular economy in the construction process, one of the first steps is to make the process itself more circular. This means that at the beginning of the project, an initial consideration should be 'for my new project, can I reuse materials out of the old construction or are there other materials available in the vicinity?'. On top of this, when a project is initiated, it is important that a project is prepared for efficient deconstruction in the final phase. This requires considerations regarding the circular economy in all steps of the project. Within each process step, it is important to constantly consider how to contribute to the CE in the best way.

In the development and contracting phase this concerns the deliberation on how to implement the CE into the contract and the procurement. For example, one could add awarding criteria in the procurement regarding the CE so that the contractor who is planning to contribute the most to the CE is more likely to win the procurement (van Oppen et al., 2018). But one could also add specific requirements in the contract that every contractor needs to abide by. An important factor that could be inserted into the contracts is also how the project deals with the valuation, in both social and economic point of view (Jonker et al., 2018). This regards questions such as: 'what will be the value of the construction after deconstruction and how can this value come back to the initial investor?', 'how can this project socially contribute to the environment?' and 'who owns the materials in every stage of the project?'.

With every design phase (concept, development and sub-development), the design choices should be based upon the basis of flexibility, adaptability and reutilization (Adams et al., 2017). Furthermore, new innovations in the field of materials or other techniques should be considered to enable a fast transition towards a circular civil engineering sector.

When the project is constructed with a circular vision, one should not underestimate the utilization and maintenance phase. Because when the construction is not maintained while keeping in mind the end-of-life, there is a chance that the construction cannot be deconstructed in the way that is was intended (Dijcker et al., 2018). In order to enable this circular mindset in the entire process, the transfer of information is important (Pots, 2018). Mainly because it is impossible in the exploration phase to identify reutilization of material if no information is available on possible deconstruction in the area. Also between the different stakeholders, client, contractor and owner it is important to communicate to maximize the potential of CE appliances in the construction and utilization phases.

Van Oppen et al. (2018) state that the current procurement process in many sectors does not allow a good integration of the concept of the circular economy. When looking at the construction sector, a few innovations in the field of procurement methods can be found. Recently, a document was published by the European Commission to promote the circular economy within the procurement process, described as Green Public Procurement (GPP). This document implies that the European Union is actively trying to implement CE in the first stages of the construction process (European Commission, 2017). However, similar to other European documents on innovative contracts, GPP is more focused on systems with a shorter life-cycle. This creates problems when wanting to implement these principles in the civil engineering sector where projects have longer life-cycles. Another innovative method to boost circular procurement is Rapid Circular Contracting (RCC). Compared to other procurements methods RCC is focused on collaboration rather than a previously determined solution. This collaboration leads to mutual trust, innovation and more value creation (Wuestman & Bakker, n.d.). Furthermore, because the contractor will be picked on its 'program of ambitions' and not on a specific design, costs will be spared on multiple designs (by multiple contractors) (Wuestman & Bakker, n.d.). This because in the normal procurement method several contractors will be asked to make a preliminary design of the project and hereafter, one contractor will be picked as winner and will continue with its design. With RCC, the selection of the contractor is first and hereafter only one contractor, the winner, will design. This saves a lot of time (and money) for the contractors that do not win the tender.

2.3.2. Innovation, pilots and new techniques in the sector

In the field of the circular economy, some pilot projects have already been initiated in combination with several innovations in the field of material development and reutilization techniques. Pilots have come in many different forms within the civil engineering sector. One of the first projects of Rijkswaterstaat that mentioned the word 'circular economy' was highway A58. In this project one of the sub goals was to "contribute to a circular economy" (InnovA58, 2015). This is still quite vague but the first steps were made and Rijkswaterstaat has shown that it can become the launching customer that promotes the circular economy in the sector. In 2017, Rijkswaterstaat has set up the goal to use their 'power' as a purchaser in the sector to become a "booster of innovations" (Korlaar, Janssen, den Hartog, Rienstra, & de Haas van Dorsser, 2017). This is better shown in the project of the circular overpass nearby Kampen where the intention was to develop a fully circular overpass (Rijkswaterstaat, 2019a). The overpass, consisting of 40 concrete ‘LEGO-blocks’, can be taken apart and reused in other locations. It will be tested more in the coming future to further develop this initiative.

The last project that is worth mentioning approaches the concept of the circular economy in a totally different way. A contractor has taken up the challenge to become owner of the road it is developing. While such an approach has been done in other sectors with projects that have a shorter life-span, this was the first time this approach is taken in the civil-engineering sector. This concept, called an ‘as-a-service’ approach, means in this project that the contractor will become the owner of the materials and takes care of the road while the client, in this case the Province of Overijssel, pays the contractor for the availability of the road (Dura Vermeer, n.d.). This will stimulate the contractor to re-evaluate their approach on maintenance and use of materials (Dura Vermeer, 2019). There are still a lot of teething problems to overcome in the first phases of the project such as the calculation of the residual value of the materials. However, the project will help the sector in acquiring knowledge and experience with these kind of ‘as-a-service’ projects (Dura Vermeer, 2019).

In terms of innovation on materials and reutilization, new ideas are appearing in many sections of the sector. Innovations in the field of a better and more sustainable reutilization of asphalt are widely investigated with the cooperation of distributors, contractors, and Rijkswaterstaat (Rijkswaterstaat, 2019b). Not only in the field of traditional materials but also initiatives arise with materials that are currently almost unheard of in the sector. Such a new concept that has seen his first application in September 2018 was the PlasticRoad (PlasticRoad, n.d.). These modular pieces of road that are made from (recycled) plastic is one example of the possible solutions towards a more circular road design.

2.4. Barriers regarding implementing CE

The previous sub-chapter described the relations between the CE and the civil engineering sector. This sub-chapter will investigate the barriers that arise when wanting to implement the circular economy.

Firstly, to identify the barriers and their related enablers, it is important what both words mean. For this research the following definitions for barrier and enabler are used:

Barrier: an obstacle that prevents movement (Cambridge Dictionary, n.d.-a)

Enabler: something that makes it possible for a particular thing to happen or be done (Cambridge Dictionary, n.d.-b)

Unfortunately there is little to no research performed on the barriers towards implementation of the circular economy in the civil engineering sector. However, several barriers have been found in previous works for the implementation of the CE in general or other areas. From this, some barriers could be identified which also apply to this sector.

2.4.1. Circular strategies for materials and products

Environmental concerns are possibly the most important motive to encourage the implementation of the circular economy. But, because the environment has so many different perspectives to consider, it is not the easiest. Environmental goals could focus on the lowest energy consumption throughout the lifespan of a product, the amount of CO2 emitted for the production and many others. Due to the unclear definition of the circular economy within the civil engineering sector and the many different views of all stakeholders on the CE, it is difficult to define a clear environmental goal for civil projects (Adams et al., 2017). It is not always required to define an extensive list of all the environmental goals within a project, but it is recommended to do consider all the different possible impacts (Steinmann, Schipper, Hauck, & Huijbregts, 2016).

To consider these different impacts, it might be interesting to analyze the different sustainability goals set by the EU and the government to identify whether the circular goals set for the project work towards achieving them. It might also be possible that the circular goal set for a project does not align with the environmental goals set by the government. It is then up to the stakeholders to substantiate their choices and to explain why this is in their view nevertheless a good direction to follow.

Within the circular economy, waste is no longer seen as waste but as a resource (EMF, 2017). Waste management has never been seen as an important (and economic) factor within the civil engineering sector and therefore there is a lack of market mechanisms to meet the demand that would arise when implementing the circular economy (Adams et al., 2017). This barrier is in line with the fact that the recycling of products is currently not cheaper than the disposal of them (Doepel, 2015). Furthermore, documents also state that the labor related to the disassembly and assembly of the materials is higher and thus often financially unattractive, that circular replacements of materials are more expensive than the normal materials and that there is currently no market for reused materials (Doepel, 2015; EIB, 2018). The current sector is very reluctant in reusing materials due to warranty and insurance issues, and the general perception of no personal (financial) benefits to it (Adams et al., 2017; Mahpour, 2018). The result is that designers lack the motivation to actively think about re-utilization of products.

2.4.2. Making circularity measurable

Another barrier is the lack of methods to make circularity measurable (van Reijn, 2017). There have been many attempts to create a universal tool to calculate the amount of circularity (eg. EMF & Granta, 2015; Verberne, 2016) but no tool has currently been accepted as the standard. Not knowing how to validate a circular requirement at the end might result in not adding that requirement to the contract, which does not speed up the implementation of the circular economy.

The other technical barrier investigated is the design of the construction. The current stock of the civil engineering sector is not designed while keeping in mind the end-of-life of the product. This makes it challenging to identify which materials are present in a construction that can be reused. Also, the lack of consideration for dismantling in advance makes this process more difficult and costly (Adams et al., 2017). Having prior knowledge of constructions that are to be dismantled in the near future could provide CE opportunities when designing a construction in the vicinity. Materials from the old constructions could then be considered for re-utilization in the new construction.

2.4.3. Relationships in CE

With the introduction of integrated contracts in the construction sector, the relationship between client and contractor has gone through a shift. From the traditional relationship which is more opposed and cold, towards a warmer relationship where both client and contractor have a mutual goal (Adams et al., 2017). This new relationship is also more in line with the principles of CE. Not only in the construction sector but in all sectors that want to implement CE, research has proven that collaboration and mutual trust is key for enabling a circular economy (EMF, 2015).

Mohammadi & Slob (2018) are one of the many that state that the quality of the relationship between client and contractor is a critical success factor for reaching circular goals and results. This quality is based on prompt and accurate management with mutual responsibility. While the contractor is responsible for reaching the goals set out by the client, the client has its own responsibilities towards reaching his ambition. This principle makes both stakeholders wanting to make the best of the project. This not only concerns the contractor and the client, but also other stakeholders such as the company who will be responsible for the maintenance of the construction. This stakeholder is also included when collecting the requirements for the CRS but is often shown to be not flexible concerning materials or products chosen. When there is a good relationship between the stakeholders, all parties are more driven to reach their goals and innovate throughout the process (Pots, 2018).

2.4.4. Economic mindset and CE

An important barrier involves the behavior and state of mind of all stakeholders involved in the civil engineering sector. The economic revolution has shaped people into a worldview where financial profit was one of the most important motives to undertake something and that self-serving, competition and linear growth were the keys to success (Manshanden, 2016). This has led to many good things such as economic growth and less poverty. However, being at the edge of a new revolution, the informational revolution, the new generation of people tend to have a different definition for words such as freedom, power, and society. Where the older generation sees freedom as being independent and self-supporting, the new generation defines freedom as having access to networks and being able to develop yourself. Respectively, power was first seen as being on top of the hierarchy, it is now seen as the ability to share your products and knowledge (Manshanden, 2016). Finally, society was previously view as such that mankind was 'above' other species, whereas now we see ourselves more as being part of nature. This change in view has also led to a new, purpose-driven mindset where there is more focus on collaboration, adaptive growth, and a common interest. A visual representation of this transition can be found in Figure 7.

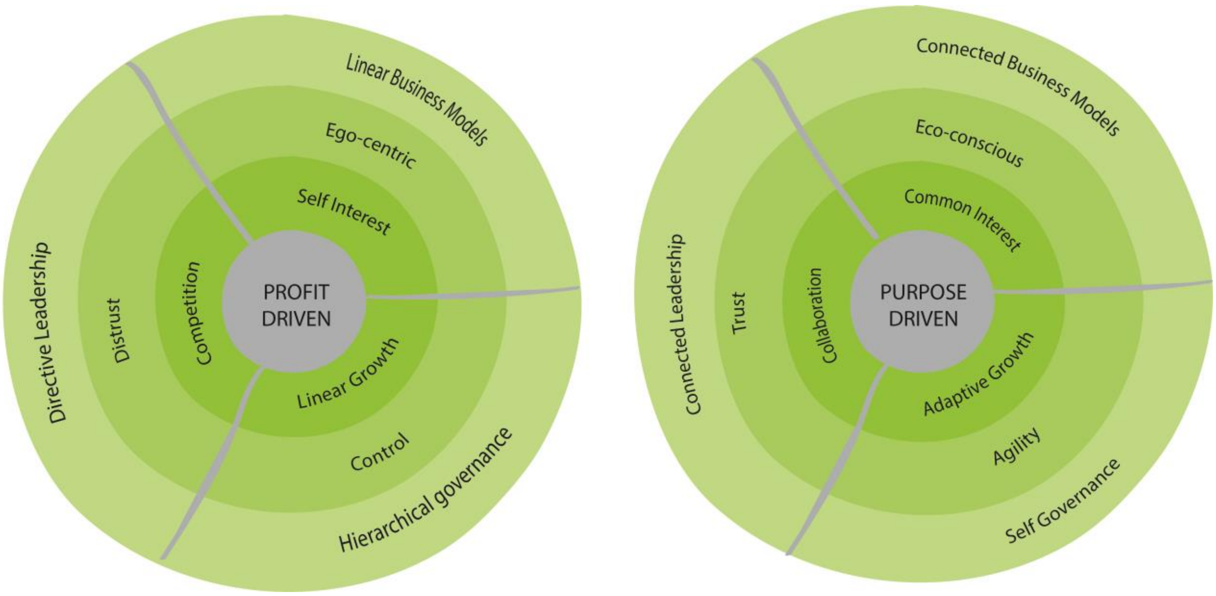


Figure 7 - Profit and purpose-driven societies (own image, adapted from Manshanden (2016))

Businesses now tend to try implementing this mindset into their business models. The current struggle however, is that these businesses try to change into a purpose-driven business from the outside in. Which means, that they are implementing a connected business model, but their main goal remains revolving around creating financial profit. Manshanden (2016) states that change needs to develop from the inside out in order to be successful. Hence, the transition begins with a change in awareness.

Within the civil engineering sector, this change in awareness has not yet been adopted. One of the reasons might be that the civil engineering sector is a traditional and fragmented sector which has more often inhibited the implementation of innovations (BIS, 2013). This traditional mindset can be traced back to the core capabilities that are often deeply rooted in the values of companies (Crespin-Mazet & Portier, 2010). Adams et al. (2017) also state that currently the "benefits of adopting the circular economy may not be shared equally across the supply chain" which leads to a lack of responsibility where nobody sees themselves as the launching customer.

Not only does the sector struggle with awareness, but there is also an underdeveloped commitment of individuals in this sector. Depending on the material, the behavior of people toward the utilization of materials is not always positive. Where reclaimed wood is very attractive for most people, they find it quite unattractive to implement reused steel in their homes (Pomponi & Moncaster, 2017). The analysis of Pomponi & Moncaster (2017) states that consumers' acceptance towards recycled products needs to improve because of the user preference for new materials. This change of mindset towards a more purpose-driven strategy could start by implementing more CE into the education curricula of relevant studies (Dutch Ministry of Infrastructure and the Environment, 2018). Education in the civil engineering sector itself is important too, such as feedback and feed-forward loops to inform and learn from each other (Pomponi & Moncaster, 2017). Also important is the change in design approach where an emphasis is set on material choice, a high level of flexibility and disassembly (Adams et al., 2017).

The profit-driven mindset enforces one of the highest ranked challenges within the construction sector for CE, the unclear financial case ((Adams et al., 2017). The sector is currently having trouble articulating the (social and economic) value aspects regarding the circular economy and how to measure the value throughout the process. Currently, the investment made by the initial investor is not economically interesting since no good calculations can be made about the value of the products at the end-of-life after such long life-spans in the sector. This results in the residual value not even being considered or, if it is calculated, not reaching the person that intentionally invested in the project (Adams et al., 2017). While costs and the related financial benefits are big factors when it comes to decision making in the construction sector, this challenge is a big incentive for contractors to hesitate with starting a project that has a CE ambition (Voogd, 2018).

This hurdle could be passed when the government would be willing to invest more in subsidies or other incentives to encourage CE. Many reports state that they would like to see the government stimulating the use of circular materials through subsidies, to function as a launching customer and to create a platform for development and innovation (Adams et al., 2017; Dutch Ministry of Infrastructure and the Environment, 2018a; EIB, 2018; Voogd, 2018). Genovese, Acquaye, Figueroa, & Lenny Koh (2017) state that there is a crucial role for the government to facilitate "some form of top-down […] support". However, in the Netherlands and often other countries, a government is not everlasting. This means that the government formation changes from time to time which results in short term plans and budgets which do not support the long term view of the CE very well. Ulubeyli & Kazanci (2018) therefore state that political stability can have an impact on the level of sustainability in the green construction industry and Hussain (2014) states that innovation and ingenuity can receive less attention in a country with less political stability.

2.4.5. Contracts and legislation

The final barrier is the legal dimension and concerns all legal aspects that might influence the implementation of CE in contracts. The first legal barrier that is worth mentioning is the type of contract or procurement method used. Researchers have investigated the hypothesis whether the type of contract and the type of procurement has an effect on the extent of circularity in the projects (e.g. Castelein, 2018; Pots, 2018). These hypotheses have been confirmed in their reports. The main conclusion of these reports is that when more steps are integrated in the contracts (so, DBFMO contracts) more aspects of the CE can be implemented (Castelein, 2018).

Participants in the research done by EIB (2018) mention a bottleneck that is also stated by others (eg. van Reijn, n.d.; Voogd, 2018) which are the laws and regulations that are focused on primary materials instead of the re-utilization of used materials. For example, currently, in the construction sector, a stamp of quality is only given to new products, not to products that are being reused (van Reijn, 2017). By not having a quality rating on the reused products, contractors are unable to provide any certainty on the quality and durability of constructions where reused materials are used. This results in a large barrier to the use of reusable materials in new constructions and makes it much more difficult (and expensive) to reuse materials from old constructions.

2.5. Conclusion

Within the literature research two sub-questions were analysed.

What are the benefits of a circular civil engineering sector and where does the concept of the CE currently stand in the sector?

Sub-question 1

To understand the benefits and disadvantages of a circular civil engineering sector, it is first important to understand what a circular civil engineering sector specifically entails. The meaning of the circular economy within the civil engineering sector in this report has been described as follows and is based on the definitions of the Dutch Ministry of Infrastructure and the Environment (2018) and Van Oppen et al. (2018).

The circular economy is an economic system that minimizes the waste of resources and maximizes the value retention of these resources without compromising the wellbeing of people and the planet. This means that reusability of products and materials needs to be preserved and destruction of value needs to be prevented. With regard to here and now, there and later.

Within the civil engineering sector, the concept of the circular economy is slowly gaining interest. However, it has more teething problems compared to other sectors due to the long life-spans of projects and the number of stakeholders involved. During the literature research it became evident that little scientific research has been conducted on the implementation of the circular economy within the civil engineering sector. Therefore, other sectors have also been investigated to identify what a circular economy means and what challenges the sector could expect during the transition. The transition might be more challenging because of the life-span, the segmentation in process and market, and other factors. This makes the implementation more difficult, but not impossible. The main benefit of creating a circular civil engineering is the amount of waste minimized and the use of resources that will be reduced. This will make this sector more future-proof.

The circular vision has seeped through to local governments and Rijkswaterstaat. In turn, more and more projects are procured while keeping in mind de circular economy. Rijkswaterstaat, as the biggest client within the sector, is trying to boost the implementation by challenging the market and setting up pilots. As launching customer they try to learn from them and quickly solve barriers and related challenges.

The second sub-question that is answered within the literature research is:

What is a civil project, out of which phases does a civil project consist and what is the relationship between the CE and these phases?

Sub-question 2

To better understand the barriers faced when implementing the circular economy in the civil engineering sector, it is important to understand the processes within the sector. The process of a civil project consists of seven steps which are:

1. Exploration;
2. Concept phase;
3. Development and contracting;
4. Sub-development;
5. Execution;
6. Utilization and maintenance;
7. And deconstruction and reuse.

In every phase of the process, the concept of the circular economy has its own implications. In the exploration phase it is important that the client is aware of the concept of the circular economy and defines his or her circular view which can be used throughout the process. This view can also be the basis on which the client describes the circular demands he wishes to see back in the project. Furthermore, collaboration and partnerships are amongst the most important aspects of the circular economy, the client should keep this in mind while deciding upon a type of contract. In this phase it is also interesting to think about the materials that could be reused in the vicinity or materials that could be reused of the old construction which is to be renovated. Because the concept of the circular economy could be differently implemented in every project it is important to consider all the options.

The concept phase is where the designing starts off in a very abstract level. This preliminary design should already include the incentive to design while keeping in mind the circular economy. Because new stakeholders will be added to the process such as the designers, it is important that these stakeholders are aware of, and in line with, the circular vision of the client. This phase contains the final CRS as output where the writers should keep in mind to maintain flexibility in the proposal so that the market can share their knowledge and expertise on the subject of the circular economy.

The focus of the development and contracting phase lies upon the procurement of the project. Within the procurement it is important that the client does not forget to integrate his circular vision in the awarding criteria of the project. These criteria can concern certain certificates that the contractor should possess, but could also concern the way they want to measure the amount of CE implemented or the organizational structure the contractor wants to use. When the project is granted to a contractor, it is key to write down in the contract the goals set out by the contractor himself. In the tender, the contractor would have written a document stating its own goals regarding the CE (if asked in the procurement), it is key that these promises find their way back into the contract.

The last phase before the execution of the project focusses on bringing the design up to the level of detail that is required to construct the project. While the contractor would have made designs for the tendering process it is important to constantly verify whether the circular design choices are still considered in the next level of design detailing. Lastly, a remark that is important in every phase of the process: because the urban environment changes constantly and new materials could be available after a certain amount of time, try to keep an open mind and review new technologies or innovations when they are introduced. These could provide new means to achieve the level of CE included in the project.

3. METHODOLOGY

The literature research was a good starting point to obtain useful knowledge of the circular economy and the civil engineering sector. However, little articles where found on how these two relate to each other. To gain more knowledge on this relationship and gather more data, several research methods will be used. The motivation behind the chosen methods and out of which step they consist will be elaborated on in this chapter.

"There can be no economy where there is no efficiency"

BENJAMIN DISRAELI

3.1. Method

To gain insight into the barriers that regard the implementation of the circular economy in the civil engineering sector, and the potential enablers to these barriers, two approaches were used. The research model will be described hereafter and can be found in Figure 8.

First, theoretical and qualitative research will be performed to obtain, in practice, which barriers arise when wanting to integrate the circular ambition in civil projects. The results will be an elaborate list of barriers that arise in civil projects and the enablers used to overcome these barriers. The Grounded Theory Approach (GTA) is used to structure the data, gathered from literature and interviews, and to categorize the barriers. When using the GTA, the research starts of this a large amount of data and through initial and focused coding each piece of information will be reviewed and compared to find commonalities and dissimilarities among the data to identify the relevant codes and categories. The enablers will be gathered, but only used at the end of the analysis, when the barriers have been ranked.

Second, because the data is gathered out of three different sources (interviews, governmental papers and articles), the differences and similarities will be investigated, this is described as the first triangulation in the research model.

Third, the eventual list will be sent out to be reviewed and graded by experts in the field. These experts will grade the identified barriers and the categories according to their perceived level of importance. The calculation of the ranked barriers and categories will be done according to the Fuzzy Delphi Method (FDM).

Lastly, another triangulation will be performed to analyze whether there are differences between the different branches in the sector that have filled in the survey. Hereafter the ranking of the barriers will be discussed and the enablers will be described of the highest ranked enablers. This will provide insight in how the barriers could be overcome and what the sector will look like.

A description of which methods have been selected to perform the analysis and why, will be described in the following sub-chapters. Hereafter, in chapter 4, a detailed description is provided on how the different steps of the research were conducted.

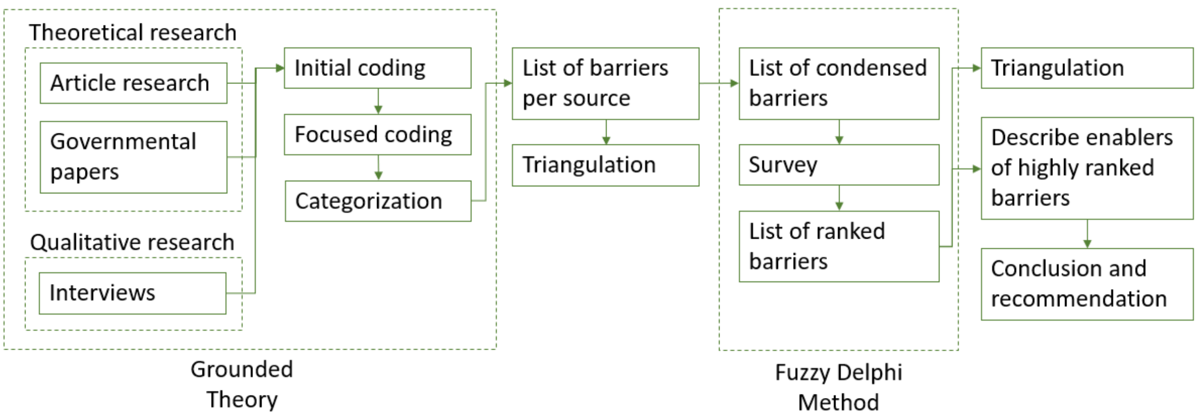


Figure 8 - Model of methods

3.2. Grounded Theory

The research to find the barriers and enablers within the civil engineering sector will be based upon the Grounded Theory Approach, which is originally derived from social sciences. This qualitative research method is useful to systematically analyze a wide range of data (Charmaz, 2014). It is key that a researcher that uses Grounded Theory for its analysis, starts off with a blank canvas. Through different rounds of information gathering, the researcher tries to make sense of the data and structure it according to his or her own interpretation (Saldaña, 2009). Because the goal in this thesis is to gather as much data on the challenges that the sector is facing regarding the implementation of the circular economy, this method is chosen. Furthermore, Grounded Theory is often used as an 'exploratory' method when little research has been conducted on the topic, which is the case for this subject (Charmaz, 2014).

The analysis began with the literature review which was aimed at getting to know the concepts of the circular economy and the processes within the civil engineering sector. This provided a glimpse of the possible barriers that have appeared in other sectors when wanting to implement the CE.

In the next sections, a lot of data was gathered by investigating the barriers of the literature review, by reading even more documents and articles on the subject, by performing several interviews with experts in the field and by attending sessions regarding the circular economy in the civil engineering sector. Grounded Theory helps focusing and organizing data and is therefore useful when more structure is required within the data (Charmaz, 2014). The first step of this method is to gather a large quantity of data from different stakeholders which will be converged and categorized by the researcher. Through several rounds of coding, memo-writing and comparing the data with information gathered from theory, the result will be a clear overview of the important barriers and enablers.

3.2.1. Data collection

As stated before, the goal of Grounded Theory is to gather a large amount of data concerning the topic chosen, all this data will be condensed and categorized through several steps of coding (Charmaz, 2014). The document research consisted of article research and the analysis of several governmental papers concerning the CE. These articles and papers concerned the research performed for the literature review in chapter 2 but more articles where read on top of this. For the articles a slightly broader scope was chosen, looking at not only the civil engineering sector, but also more general articles concerning the circular economy were read. The governmental papers concern documents written by the government themselves, such as the 'Transitieagenda', but also papers commissioned by the government have been read.

To gather a large quantity of data, six semi-structured interviews with different stakeholders were held on top of the elaborate document research. The experts interviewed are illustrated in Table 1 and an overview of the questions are attached in Appendix I. These stakeholders came from different levels within the sector to get a wide range of information on the barriers that are faced when wanting to implement the circular economy in the civil engineering sector. The stakeholders work in companies that are either affected by or affect this implementation. In most civil projects, there are three different parties included, see Figure 9. These are

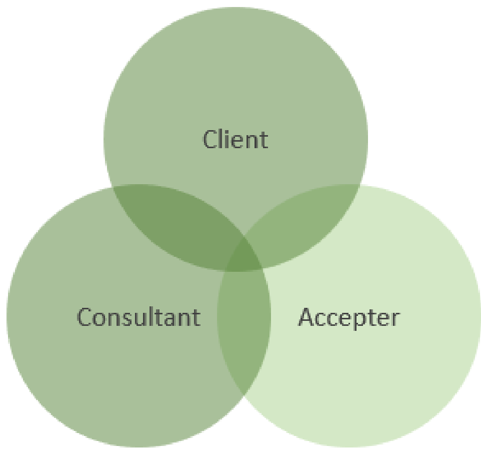


Figure 9 - Stakeholders in the sector

the client and the accepter of the project, which are in most civil projects the government and the contractor, and the engineering firms which consult and help with the project. An engineering firm could be asked to join the project by either the client or the contractor. Because of the slightly different focus of the research in the early stages of the graduation, no interviews were conducted with contractors. However, because engineering and consultancy firms do also work for contractors, it is believed that they can consider the possible barriers from both sides of the table.

Table 1 - Persons interviewed

Name	Company	Branche
Eric Wuestman	KplusV - Cirkelstad	Consultancy firm
Niels Ahsmann	KplusV	Consultancy firm
RWS1 [1]	Rijkswaterstaat	Government
RWS2 [1]	Rijkswaterstaat	Government
Jelmer Kooij	Witteveen+Bos	Engineering firm
Maarten Schäffner	Witteveen+Bos	Engineering firm

It is key to collect as much information as possible which means that the focus of the interviews is to let the interviewees talk as much as possible (Charmaz, 2014). The task of the interviewer is to asks the right questions and to keep the interviewee in the right direction. The main goal of the interviews is to ask the people who are working with the circular economy, what they are currently doing, if it is working and if not, what problems they face and what can be done about this. Following each interview, a summary will be written that specifically includes the mentioned barriers and enablers. These summaries are attached in Supplement I to VI. This data will be used for the coding framework. Through coding, the barriers and enablers will be categorized.

Furthermore, to gain more knowledge, the researcher has also attended two sessions related to the circular economy in the civil engineering sector. These sessions are described in memo's. Memo-writing is an important element of the Grounded Theory Approach. These conceptual memos are written by the researcher after every interview and when ideas are being developed about the coding and the process surrounding the coding. It is basically a conversation with yourself, a place to "dump your brain" about the data collected and the codes written (Saldaña, 2009). This can be ideas about similarities, comparisons of data and questions that come up during data collection and analysis (Sbaraini, Carter, Evans, & Blinkhorn, 2011). Because Grounded Theory is based upon the personal interpretations of the researcher, it is key that his or her thoughts are written down so that others can understand the steps taken. Memos can also be seen as data and can be used as input for the data collection (Saldaña, 2009). The memos can be found in Appendix II. In Figure 10, a small fragment of such a memo can be found. In this memo, it is stated what the first impressions of the interviews were and other things that came to mind.

Date	What
January 8th 2018	Interview Wuestman
Mr. Wuestman is even more optimistic than Mr. Schäffner, he highly motivates you to get into a positive vibe and you stop seeing barriers for the sector when in a conversation with him. However, he is so extremely positive that I'm unsure whether the transition will go as he envisioned, but it was interesting to brainstorm together on how the ideal world would look like. In contrast with Mr. Kooij, he does see appliances of the 'As a service' approach in the civil engineering sector. Next to that we discussed that the sector has be on the same page before innovative projects for	

Figure 10 - Screenshot of part of memo (source: Appendix II)

[1] Due to privacy reasons these names are not shown

3.2.2. Coding the barriers and possible enablers

As stated by Charmaz (2014), coding is an essential link between collecting data and establishing a grounded theory on the results. Coding happens in different stages. The coding starts off with the initial coding where the researcher formulates the primary thoughts that run through his or her mind when reading the raw data (Saldaña, 2009).

Hereafter, the focused coding follows several "highlights and several salient features" and the first thoughts about the categorizations comes to mind (Saldaña, 2009). The focused coding is formulated through interpretation of the data and discussion with the supervisors. The coding is performed staying as close to the data as possible, coding quickly and capturing actions or processes using mostly verbs ending in 'ing' (Charmaz, 2014).

The interviews, literature and governmental documents provided a lot of data and initial codes in their own way. Through comparing data with data, codes with codes and codes with theory, the coding developed from raw data to focused coding. How this process further enfolds will be elaborated upon in chapter 4.

3.2.3. Categorization

After the barriers and enablers have been properly categorized, through comparative research of related articles and personal insight, categories have been defined. Through the process, from the literature review, up until the interviews, the researcher has gained knowledge about the different relationships found in the barriers and the possible categories.

This, in combination with research into other articles that mention categories within the CE, enables a clear sortation of the different barriers and enablers. The seven categories and 3 different source types (interviews, literature and governmental documents) provide interesting information.

3.3. The survey and Fuzzy Delphi Method

A survey will be spread to grade the different barriers that are found in the first step of the research. In this way, the barriers can be graded on their level of priority to identify which are considered to be the most important barriers, seen from the point of view of the people working in the sector. To investigate the difference of opinions and their related importance between the branches within the sector, their opinions have been kept separate to investigate the differences.

The Delphi Technique is a good method to structure group opinions while keeping in mind these different opinions between different experts (Habibi, Jahantigh, & Sarafrazi, 2015). The regular Delphi method is traditionally used to collect judgments of experts for decision making and prediction (Di Zio & Maretti, 2014). This method however, asks the experts to evaluate their judgements in a multiple rounds (Kuo & Chen, 2008). The high number of rounds in the traditional Delphi method can be time consuming and have high costs related (Glumac, Han, Smeets, & Schaefer, 2011).

To get a grounded result without this condition of the traditional method, a Fuzzy method is introduced which keeps in mind the vagueness and ambiguity of the results (Kuo & Chen, 2008). Since different people can have different understandings of the word "very low", one of the verbal expressions such as the expressions that are used in this survey, limitations in terms of having an ambiguous data transmission arise. The Fuzzy method helps to reflect the human thinking style and creates more consensus within the panel by using Fuzzy triangular numbers (Habibi et al., 2015). An in-depth explanation on how this method works and out of which steps the method consist of will be further explained in the paragraph concerning the survey, sub-chapter 4.5.

3.4. Triangulation

The report contains different sources from which information is gathered. To prevent information from being seen as more important and false conclusions that could be drawn as a result, the sources have been kept separate during the Grounded Theory Approach. However, after all barriers and enablers have been coded, it is still interesting to find out whether there are differences or similarities that can be found between these three sources. In this report this is called the triangulation.

However very different, but still important, three different stakeholders are also investigated within the survey. Again, this partitioning is performed to analyze the importance of the different barriers from different points of view and to prevent barriers from not believing to be important enough. Since the survey considers three different views from the sector: the governmental view, the view from the engineering firms and from the side of the contractors, another triangulation will be performed to discover the similarities and differences between these different stakeholder groups. For each of the stakeholder, the ranking of the barriers will be calculated, after which the comparison can be made between the different stakeholders and the overall ranking of the barriers.

3.5. Investigating the most important barriers

The final step of the analysis will be to describe the top four most important barriers. This top four will first be discussed through a panel discussion with two experts in the field. During this panel discussion, the enablers that were found in the research will be discussed but also their own opinion will be asked on how to overcome these barriers.

All four barriers will be described in detail on what they entail, their potential effect on the future of the civil engineering sector and how they can potentially be overcome. These descriptions will help the civil engineering sector to consider which steps to undertake to become a sector that moves towards the vision of a circular economy.

4. DATA COLLECTION AND ANALYSIS

After explaining which methods will be used, it is time to get to work. In this chapter relevant data will be collected and the analysis will be performed. The data has been collected through three different sources and the analysis has been performed by using two different methods. All the different steps will be explained in the coming chapter.

"We cannot solve our problems with the same thinking we used when we created them"

ALBERT EINSTEIN

4.1. Introduction

As stated before, the interviews with experts in the field were leading in the information gathering. However, other data gathering techniques were also used such as attending sessions about the subject of the CE, and reading articles and other papers regarding the circular economy. In this chapter the data collection for the Grounded Theory will be stated, with a triangulation ending this part of the method. Hereafter, it will be explained how this data is used for the Fuzzy Delphi Method.

4.2. From raw data to focused coding

Hereafter, the interviews themselves were summarized and relevant pieces of text were highlighted. All the relevant data from the literature review, sessions that were attended, interviews performed, articles and papers were then copied into tables to initiate the coding.

The raw data was kept sorted by the three different type of sources: Interviews, Research articles and, governmental papers. This was done so that at a later stage information could still be identified about how the different source types were different in terms of the barriers and enables they selected as being important for implementing CE in the sector. For example, the government considers different problems or challenges within the sector than researchers that are more focused on the concept of the circular economy and not specifically on the civil engineering sector. Also, because the data from the interviews, articles, and papers contained both barriers and enablers, the coding was performed in separate tables for the barriers and enablers that have been identified. In conclusion, this led to six different tables: three (different sources) times two (barriers and enablers).

Table 2 – Part of coding table, articles barriers (Source: Supplement IX)

Raw data	Initial coding	Focused coding
One of the key principles often quoted of the circular economy is to keep materials at a high value wherever possible (EMF, 2013a; SG, 2015; ZWE, 2016). **However, there has been criticism of limited research in this area** (Lieder and Rashid, 2015) and there is an underlying question on **how to develop a clear economic case** for circularity in the built environment. There is a large amount of **uncertainty on material resource prices into the future** (Morgan, 2014), **resulting in the difficulty to predict the potential value of materials at the end of life, particularly for long-lived products**. **(Adams et al., 2017)**	Lack of knowhow on reutilization of materials Uncertainty about resource prices in the future Difficulty to predict potential value of materials	42) No good financial case for reutilization 43) Lack of knowledge on reutilization 44) Lack of awareness […]
The **lack of market mechanisms to aid recovery** was ranked as one of the top challenges (3·26) by all of the stakeholders, which corresponds with the development of financial incentives to use secondary materials as an enabler (3·21). **(Adams et al., 2017)**	Lack of market mechanisms to aid recovery of materials Lack of knowledge on reutilization of materials	
Additionally, many construction **products at their end of life at today's prices are also low in value**, making it uneconomical to reuse. **(Adams et al., 2017)**	Uneconomical financial case for second hand materials	

The initial coding breaks down the qualitative data into smaller, manageable and understandable pieces (Saldaña, 2009). This first step can be seen in the second column of Table 2. When the initial coding has finished, the next step is to condense the coding, which results in the focused coding. The initial codes have been combined where possible and other, more comprehensive codes, were converged to make them more functional. After, the codes were numbered. In Table 2, an example is given of a fragment of such a table. The example shows how the different steps of initial coding and focused coding were reached from raw data, the complete tables can be found in Supplement VII to XII.

4.3. Categorization

This coding has led to 81 focused codes, containing both barriers and enablers, in the six different tables. Coding was performed in different tables per source and different sources could mention the same barrier or enabler. Therefore, these codes can be of similar and totally different nature. To further specify these codes, categories were defined to further distribute the codes in understandable groups. The categories selected were based upon articles concerning the circular economy, and insights gained from the raw data collection and the background literature review performed in chapter 2 of this report.

The starting point for categorization was based on prior scientific work on barriers that concern the circular economy. Multiple articles on the CE mentioned recurrent themes or categories such as economic, judicial and technological barriers (e.g. Adams et al., 2017; Pomponi & Moncaster, 2017; Twynstra Gudde, 2018). Other themes that were broadly mentioned are more based upon the behavioral change that concerns the implementation of the circular economy (e.g. Kipling, Taft, Chadwick, Styles, & Moorby, 2019; Pomponi & Moncaster, 2017). These combined formed the first six categories that have been identified in this thesis: Technological, Policy and Regulation, Financial and economic, Organizational, Performance indicators and Awareness.

The final category concerns the procedural barriers within the civil engineering sector itself, the 'Operational' category. This category became more evident during the literature review of chapter 4 and the interviews. While less obvious, the procedural barriers also came forwards in literature from chapter 2. The categories are described hereafter.

<u>1. Technological</u>
The technological dimension concerns all technological innovations that may influence the implementation of the CE such as software tools to make the CE more measurable or data collection that provides insight into the current stock of materials in the sector. Scientific literature and interviewees often discussed how data and tools are necessary to "handle, store and manage the huge amount of data" associated with the implementation of the CE (Pomponi & Moncaster, 2017). The technical category also encompasses the knowledge that must be gained on new technologies and innovations regarding the reutilization of materials and the development of new materials.

<u>2. Policy and regulatory</u>
This dimension focusses on the effects of the rules, policies, and regulations in the sector that are not in line with the vision of the CE. It includes policies regarding tax, subsidies, policy and other governmental factors. It can become restrictive when policy and legislation are not circular economy-specific and do not promote, for example, the reutilization of materials (Adams et al., 2017).

<u>3. Financial and economic</u>
The financial and economic category is about the financial implication of the CE and the new economic models that are related to the CE. Also, the interpretation of the word 'value' is included in this

category, since the sector is mainly focused on creating financial value within the projects. The sector is mostly a profit driven sector. The contractors want to gain the highest profit margin while the client wants to pay the lowest price. This can also be identified in the fact that often the cheapest tenders win (Pomponi & Moncaster, 2017). However, in order to innovate, letting the cheapest tender win is not always the best way to go.

4. Organizational
This category is related to the structure of the sector. This structure is the way how the different stakeholders relate to each other and the way they interact with each other. All three source types discuss upon the relationship between the different stakeholders and urge the sector to improve earlier market involvement and collaboration (Pomponi & Moncaster, 2017; RWS1, 2018).

5. Performance indicators
To evaluate whether the CE has been successfully implemented in the civil engineering sector, it is necessary to know how the level of implementation can be measured. People in the sector are still struggling with the definition of the CE and, in addition, they do not have a clear way how to identify which option contributes to the circular economy in the best way. The barriers and enablers related to this 'how' were placed within this category.

6. Awareness
Next to the inability to measure the success of an implementation, it is still and foremost necessary to raise awareness on the concept of the circular economy. Many articles about the CE, not only for the construction sector, identify the lack of information about the benefits of the CE and the lack of incentive to adopt the CE vision as a significant barrier to implementation (e.g. Araujo Galvão et al., 2018; Dutch Ministry of Infrastructure and the Environment & Dutch Ministry of Economic Affairs, 2016)

7. Operational
The final category was selected as a result of gained insight throughout the data collection. Barriers and enablers regarding the process within the civil engineering sector did not fit well in the other categories. These were mainly identified by the interviewees which describe that the standardized processes were not in line with the circular vision of the sector (RWS2, 2019; Wuestman, 2019). These standardized processes and the habit to use them makes it difficult for the sector to change. The category will focus on these discrepancies between the current way of working in the sector and its circular perspective.

This is in line with the barriers previously identified in the literature performed in chapter 2. However, the categorization did not take place at that time, one can see that the six categories already came forward in the sub-chapter 2.4 of the literature review. Where one can clearly see that the paragraph of 'Circular strategies for materials and products' has a strong relationship with the technological category, 'Making circularity measurable' discussed the performance indicators that are missing in the sector, 'Relationships in CE' talks about the organizational factors of the sector such as (the lack of) collaboration and the paragraph concerning 'Economic mindset and CE' talks about the financial side of the circular economy. The last paragraph, 'Contracts and legislation', contains two categories. Firstly the legislation that can be put within the category of the rules and regulations, however the contracts are far more related to the operational category that was personally added by the researcher.

The categories led to the sortation of the barriers and enablers, which can be found in Table 3 and Table 4. Where the blue codes represent the codes derived from the interviews, the red codes are found in literature and the green codes are related to the governmental papers .

Table 3 - Categorized barriers

	Technological	Policy & Regulatory	Financial & Economic	Organizational	Performance indicators	Awareness	Operational
Barriers	(17) Uncertainty of technological advancements	(9) Rules and regulations restrict reutilization	(8) Not including residual value	(3) Many stakeholders involved	(4) There is no standard way to implement CE	(2) Lack of experience in reutilization and	(1) Standard specification does not include CE
	(20) Validation of new materials and reused materials	(52) Rules and regulations restrict reutilization	(10) CE sometimes more expensive	(6) Lack of trust between stakeholders	(7) No clear definition of CE	(12) Lack of awareness on CE	(5) Standardized processes in the sector
	(44) Lack of knowledge on reutilization	(74) Rules and regulations restrict reutilization	(11) Financial uncertainty	(15) Fragmented sector	(18) Uncertainty of market demands	(43) Financial mindset	(13) CE little included in granting process
	(47) Lack of tools to make the CE measurable		(42) No good financial case for reutilization	(49) Lack of holistic approach	(48) No clear definition of CE	(46) Lack of awareness	(14) Fragmented process
	(50) Lack of knowledge on new materials and		(45) Financial uncertainty	(51) Traditional sector	(54) Uncertainty of market demands	(53) Lack of an incentive to design for end-of-life	(16) Long life-span of constructions
	(69) Lack of knowledge			(68) Too little market involvement	(71) No clear definition of CE	(55) Lack of interest	(19) Ever changing environment
				(73) Little to no information sharing	(72) Not able to measure CE	(66) Value only seen as financial value	(65) Deconstruction and reutilization are not in the
						(67) Financial mindset	
						(70) Limited awareness	

Table 4 - Categorized enablers

	Technological	Policy & Regulatory	Financial & Economic	Organizational	Performance indicators	Awareness	Operational
Enablers	(29) Improving knowledge on materials, innovations and technologies	(39) Re-evaluate rules and regulations that restrict reutilization	(20) Including residual value	(25) Earlier market involvement	(23) Creating clear definition of CE	(26) Improving awareness	(22) Including demolition and maintenance in project
	(30) Improving knowledge on current stock of materials		(38) Initially start with creating extra money to implement CE	(31) Enabling holistic approach	(35) Improving circular design	(34) Pioneering (pilots)	(24) Keeping proposal as open as possible
	(77) Gaining insight and knowledge in current stock of the sector		(59) Value definition and value creation	(32) Improving trust	(60) Defining the CE and making it measurable	(41) Think bigger (system thinking)	(27) Including the CE in awarding criteria
				(33) Setting agreements beforehand about risks and responsibilities	(63) Circular design	(56) Raising CE awareness	(28) Including the CE in demands
				(36) Knowledge sharing, learning environments	(76) Circular design	(78) Using pilots	(37) Initially start with creating extra time to implement CE
				(40) Enabling long-term partnerships	(79) Making the CE measurable		(61) Creating other forms of contracts
				(57) Holistic approach			(62) Creating extra space in projects for the CE
				(58) Enabling knowledge sharing			(63) Keeping proposal as open as possible
				(80) Improving collaboration			(75) Including disassembly and/or reutilization in process
				(81) Knowledge sharing			

4.4. Triangulation of the data

A condensed version of the categorization can be found in Table 5 where the numbers correspond to the identified enablers and barriers. The full list can found in Supplement VII to XII and Appendix III. A more detailed table can be found in Table 3.

Table 5 - Categorization of codes

		Technological	Policy & Regulatory	Financial & Economic	Organizational	Performance indicators	Awareness	Operational
Barriers	interviews	17, 20	9	8, 10, 11	3, 6, 15	4, 7, 18	2, 12	1, 5, 13, 14, 16, 19
	literature	44, 47, 50	52	42, 45	49, 51	48, 54	43, 46, 53, 55	
	govern-mental	69	74		68, 73	71, 72	66, 67, 70	65
Enablers	interviews	29, 30	39	21, 38	25, 31, 32, 33, 36, 40	23, 35	26, 34, 41	22, 24, 27, 28, 37
	literature			59	57, 58	60, 63	56	61, 62, 64
	govern-mental	77			80, 81	76, 79	78	75

To provide a clear overview, an overview of the categorizations has been made by means of colored post-its, which provided an enhanced insight in how the views of the different source types relate to each other. This overview can be found in Supplement XIII. The analysis of the three different sources and the identified barriers and enablers within the different categories came with some remarkable differences and some self-evident similarities. These differences and similarities will be investigated with more detail.

Barriers

There are quite a few similarities to be found between the opinion of the three source types. All three mention the fact that a lot of people struggle with the lack of clear definition of the circular economy and what it entails. Also, which benefits are related to having a circular economy in the civil engineering sector (codes 7, 48, 71). This barrier has two effects: (1) Because people do not understand the concept, they will have less interest in the implementation of the CE (code 55) and (2) because of the unclear definition, the sector finds it difficult to evaluate or measure the level of implementation of the circular economy within their projects (codes 47, 72).

Another similarity concerns the limited awareness within the sector (codes 12, 46, 70), this could partially be explained by the unclear definition of the CE, but can also be explained by the newness of the concept. It frequently takes some time for new concepts or innovations to become the new standard (Rogers, 1983). The circular economy is a rather new concept and just started to gain popularity around five years ago (Geissdoerfer et al., 2017; Kirchherr et al., 2017), this might explain why knowledge about the concept and its implementation has not yet reached the entire sector.

Within the category 'policy and regulatory', a mutual considered barrier is the fact that rules and regulations restrict the reutilization of materials (codes 9, 52, 74).

The final similarity concerns the barriers that the sector is fragmented (14, 49, 68), that little collaboration takes place between the different stakeholders (code 73) and that there is little mutual trust between the several stakeholders (code 6). Governmental sources consider this as a barrier because they have a lack of information about the innovations that are taking place in the market. When people tend to stay in their own bubble and share little information, it is difficult for a governmental organization to enable a clear overview of the innovations and in that line, where they need to invest. Literature discusses the fragmentation in a more general way where stakeholders of different process steps do not interact with each other and the competitive nature of the sector and that the high level of competitiveness in the sector cripples collaboration (Adams et al., 2017). This competitiveness and lack of trust is also mentioned in the interviews and it is stated that this causes the contracts and rules mentioned in them to become more strict which enables less space for the market to be innovative.

In the other categories some differences can be identified between the three source types. Remarkable was the number of barriers found in the interviews that focus on the operational category (codes 1, 5, 13, 14, 16, 19). However, this was to be expected since the interviews were held with experts that are working with the circular economy in practice. It didn't come as a surprise that these experts would mention barriers that were related to practical issues in their work expertise and the different processes within the sector.

Remarkable too is the fact that the governmental papers did not mention any financial or economic barriers. Especially since several papers underline that the government takes a more active role and should financially aid the implementation of the CE (e.g. Genovese et al., 2017; Pomponi & Moncaster, 2017).

The final barriers worth mentioning were the barriers that concern some kind of uncertainty. Within the table there were three different type of uncertainties. The financial uncertainty (codes 11, 45), which mostly concerns the investors that have uncertainties related to the value change over time of the project, product or material that they have an interest in. This affects their consideration to invest in a CE related project/product or material. Hereafter there is the uncertainty of technological advancements (code 17), which concerns the fact that we do indeed need new innovative technologies to boost the implementation of the circular economy. However, we cannot know at this point in time when these technologies will come and what they will do. The final uncertainty is related to market demands (code 18) and focusses on the unreliable future of the market. With the large number of technological advancements, also in other sectors, it is uncertain how the future of infrastructure will look like and what the market will demand. While the objects/subjects of uncertainties vary, the common denominator lies in the requirement of the sector that involves the willingness to take some sort of risk.

<u>Enablers</u>

Similar to the barriers, experts mentioned a lot of enablers in the interviews regarding the organizational and operational categories. Which is not a big surprise since when a barrier is mentioned in the interview, the related enabler was often also discussed. So, when there are a lot of barriers in these categories, there is also a good chance that there are more enablers.

The three source types all mentioned that the circular design should be improved (codes 35, 63, 76). Circular design encompasses all the design decisions that should be made while keeping in mind end-of-life, reutilization and the future demand of the market. A designer should really discuss the circular options for every design.

Two other similarities can be found in the organizational categories. All sources agreed upon the fact that knowledge sharing is an important enabler when it comes to the implementation of the circular economy (codes 36, 58, 81). Knowledge sharing should be done between all groups within the sector, the material or product suppliers, governmental parties, contractors, engineering firms, etc. Also, all three sources propose improving the manner of holistic approach throughout the sector (codes 31, 57, 80). While the circular economy is occasionally referred to as the 'sharing economy', sharing information, sharing technologies, improving partnerships and collaboration is certainly an important step towards a more circular sector (Pomponi & Moncaster, 2017).

It is notable that governmental papers and literature mention significantly fewer enablers than the interviews did. Research articles are often focused on identifying barriers, but as a result, how to enable these barriers are only briefly discussed. For the lack of enablers within the governmental papers, two reasons can be described. Governmental documents are, on the one hand, mostly written with a political compromise because all parties must consent with the document. On the other hand, the government does not want to restrict innovation out of the market so prefers to keep their documents open for interpretation, leaving the solutions to the market.

4.5. The survey

All of the barriers are now analyzed and a condensed version of the barriers can be found in Table 6. These barriers will be the ones used in the survey. The survey will be send out as a word-file to be filled out by experts in the field that have dealt with the implementation of the circular economy within their field.

In the survey, it will be asked to select the importance level of the categories and the barriers within the categories. The method of Fuzzy Delphi will be explained by several steps which will be described hereafter. The steps are as follows:

Step 1 - Design the questionnaire
Step 2 - Identify the appropriate scale and numbers for the linguistic expressions
Step 3 - Calculate the sample size
Step 4 - Fuzzy aggregation of the values
Step 5 - Defuzzification
Step 6 - Ranking and analysis of the barriers and categories

1.Questionnaire Design

To obtain the importance levels of the barriers, a survey is set up. This survey is designed by using other related articles as a reference and consisted out of two sections. The first section was about the kind of company the experts worked at. The second and third section contain the barriers and categories to be graded by the experts concerning the perceived importance level of them. The final list of barriers, sorted in their respective categories can be found in Table 6. For both the categories and the barriers, a linguistic 1-5 point scale is used. The survey was first send to two experts in the field to adapt unclear barriers. Hereafter, the survey was send out to the final list of experts that worked in all three fields within he sector: contracting firms, governmental organizations and engineering firms. The experts were informed by email and the survey itself was online. The survey can be found in Supplement XIV.

Table 6 - Barriers per category

Category	Code	Barriers
Technological (C1)	TE1	Uncertainty of technological advancements
	TE2	Lack of knowledge on reutilization
	TE3	No nationally recognized tool to measure CE
	TE4	Lack of knowledge on new materials and innovations
Policy and Regulatory (C2)	PR1	Strict norms and warranty terms makes reutilization of materials difficult
	PR2	Standardized rulesets are used which do not include the CE
Financial and Economic (C3)	FE1	Not including residual value
	FE2	The implementation of CE is more expensive
	FE3	Financial uncertainty of initial investor
	FE4	Reutilization of materials is more expensive than using new materials
Organizational (C4)	OR1	Many stakeholders with all their demands makes the CE to be left behind
	OR2	Lack of trust between stakeholders
	OR3	Little to no information sharing
	OR4	Lack of holistic approach
Performance indicators (C5)	PI1	There is no standard way to implement CE
	PI2	No clear definition of CE
	PI3	Uncertainty of market demands
	PI4	Not able to measure CE
Awareness (C6)	AW1	Social value does not receive due attention
	AW2	Profit driven sector
	AW3	Limited awareness of CE
	AW4	Lack of experience in reutilization and innovations
Operational (C7)	OP1	Standard contract specifications do not include CE
	OP2	The CE is little included in awarding criteria of the procurement
	OP3	Fragmented process causes information loss
	OP4	Long life-span of constructions makes it difficult to predict what will be done with the materials at the end-of-life
	OP5	Ever changing environment due to demand of the market
	OP6	Deconstruction and reutilization are not considered

2. Linguistic expressions

To be able to score the barriers and categories, an appropriate spectrum has to be developed. In deliberation with the experts where the survey was initially send out to and the supervisors of this graduation, it was decided that a 5-point scale will be used for this analysis while 7 and even 9 point scales where considered to be broad and did not contribute to a better analysis.

Every point on the scale does not have one crisp number, but is considered as an approximate value (Habibi et al., 2015). This is called a Triangular Fuzzy Number (TFN) and is displayed by three real values:

$$F_A(L_A, M_A, U_A) \qquad (1)$$

Where *M* is the most plausible value of that expression, *L* is the lower bound and *U* is the upper bound of the linguistic expression (Kuo & Chen, 2008). This is geometrically described in Figure 11.

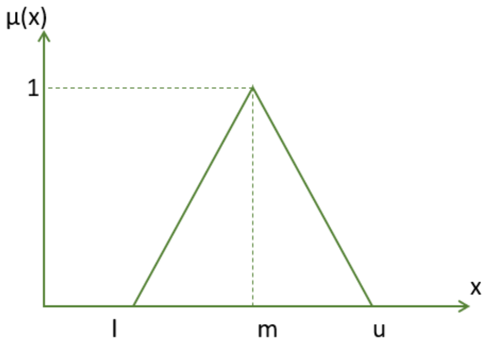


Figure 11 - Triangular fuzzy number (Own image, adapted from Habibi et al (2015)

Furthermore, the expressions have been set up with the intention of equal distances between the different variables and with the middle step ("Medium") to be directly in the middle with no preference for a side, see Figure 12. This will give the membership function of the linguistic expression used in this report which can be found in Table 7.

Table 7 - Linguistic variables for importance

Linguistic term	Triangular Fuzzy Number (TFN)
Very Low (VL)	(0, 0, 0.25)
Low (L)	(0, 0.25, 0.5)
Medium (M)	(0.25, 0.5, 0.75)
High (H)	(0.5, 0.75, 1.0)
Very High (VH)	(0.75, 1, 1)

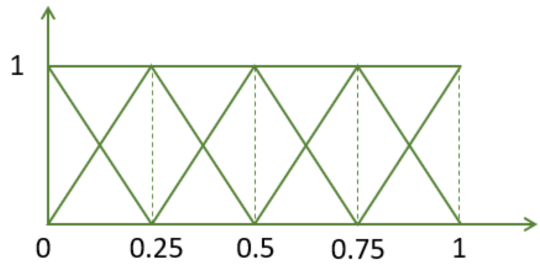


Figure 12 - TFN for five- point scale

<u>3. Sample size</u>

Out of a research performed in 2013 the total amount of people working in the civil engineering sector was at that time 65.000 people (Inspectie SZW, 2015). When the traditional calculation (2) of Cochran (1963) for the sample size will be used, considering the population (*p*), a 90% confidence level (this gives a *z*-score of 1.65) and a 10% error margin (*e*) will give us a sample size of 68 people.

$$Sample\ size = \frac{\frac{z^2 * p(1-p)}{e^2}}{1 + (\frac{z^2 * p(1-p)}{e^2 N})} \qquad (2)$$

However, because this survey is not the main analysis of the research, it is discussed that the amount of minimum 4 people per type of company is desired. This amount will give the research enough experts per type of company to draw conclusions on the differences.

Eventually, 17 surveys that returned were valid and could be analyzed. In Table 8, the amount of respondent per section can be found. The minimum amount set by the researcher was reached for every section and thus grounded conclusion can be drawn from the results.

Table 8 - Respondents per stakeholder

Stakeholders	# Respondents
Contractors	5
Engineering/ consultancy firms	6
Governmental organizations	6
Total	17

<u>4. Aggregation of the values</u>

When the opinions of the experts have been gathered, their opinions have been fuzzified using the fuzzy spectrum found in Table 7. This means that for every linguistic variable filled in by the expert, the related TFN is written down. Hereafter, all opinions have been merged into one aggregated triangular fuzzy number, called F_{agr}.

This is calculated as follows (Habibi et al., 2015):

$$F_{agr} = (\min\{L\}, \{\frac{\sum M}{n}\}, \max\{U\}) \qquad (3)$$

Where the first number represents the lowest *L* given, the second number is the average of all means and the third number is the upper bound of the TFN's gathered. The aggregation of the values is performed per section, for the triangulation, and also the overall F_{agr} is calculated.

For this research, the method of aggregated fuzzy numbers is chosen. Although Habibi et al. (2015) is critical about this method, because the article believes working with the minimum lower bound and maximum upper bound can have as a result that an optimistic of pessimistic person strongly affects the outcome, the researcher of this report does not see this as a threat because of the small scale that is used.

5. Defuzzification

To interpret the results, the triangulation fuzzy numbers will be defuzzified into one crisp number which is easier and more understandable to interpret (Habibi et al., 2015). The simple calculation of the average triangular fuzzy number is chosen to defuzzify the triangular numbers (Glumac et al., 2011; Hsu, Lee, & Kreng, 2010).

$$if\ \tilde{F} = (L, M, U)\ then\ F = \frac{L + M + U}{3} \qquad (4)$$

The aggregated results and the defuzzification of the survey can be found in Appendix V.

6. Ranking and analysis of the barriers and categories

The beforementioned calculations resulted in the overall weight and rank of the different categories, shown in Table 9 and Figure 13. In this table and figure, the highest weight represents the highest importance described by the experts. It can be noticed that the weights of ranks 2 to 7 are really close to each other since the weights are between 0,603 and 0,635. However the first rank stands out with a weight of 0,776. The experts identify Policy and Regulatory as the category that contains the most significant and important barriers to be overcome for the implementation of the CE in the sector.

Table 9 - Overall weight of categories

Category	Weight	Rank
Technological (C1)	0,622	**4**
Policy and Regulatory (C2)	0,776	**1**
Financial and Economic (C3)	0,635	**2**
Organizational (C4)	0,635	**2**
Performance indicators (C5)	0,609	**6**
Awareness (C6)	0,603	**7**
Operational (C7)	0,622	**4**

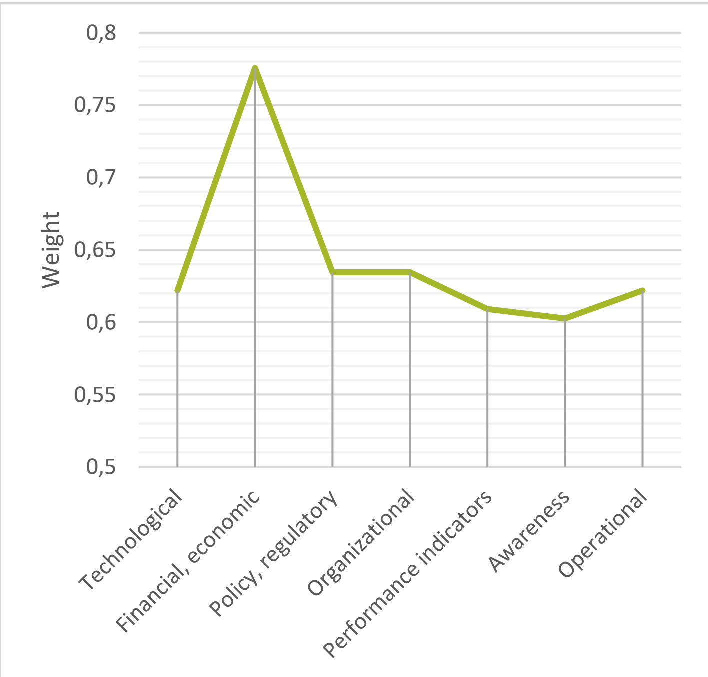


Figure 13 - Categorical ranking

The second section of the questionnaire required the experts to rank the importance of the individual barriers, which led to their relative weights. After, the global weight has been calculated, which takes into account the weights of the respective categories as well (see Table 9). Both the relative and global weights can be found in Table 10 and Figure 14. The third and fourth columns present the relative weights and ranks of the individual barriers. The fifth and sixth columns, represents the weight of the barriers for which the weights of their respective categories have been taken into account.

When investigating the relative ranking, by far the most important barrier considers the uncertainties of materials and products at the end-of-life due to the long life-span within the sector. Other important barriers are the lack of holistic approach and that social value does not receive due attention in projects. In the global weight, which takes into account the weight of the categories, the ranking of the barriers and their weights shift. Since the category of Policy and Regulatory is considered as a very important category, both barriers that cover this come out of the global analysis as being the most important barriers. Hereafter, the long life-span of the constructions and lack of holistic approach are still important barriers.

When looking at the least important barriers there is more variation between the relative and global weights and ranks. The least important barriers considered in the relative analysis are the believe that the implementation of the CE is more expensive than the current way and that the reutilization of materials is more expensive than using new resources. Both barriers have a financial factor in them. When looking at the global weight and rank of the barriers, some minor shifts of importance can be identified. The least important barriers now are respectively that every project is unique and that there is no standard way to implement the CE and the uncertainties of market demands. Other barriers that were considered less important in the relative ranking are less affected when considering the category weighting.

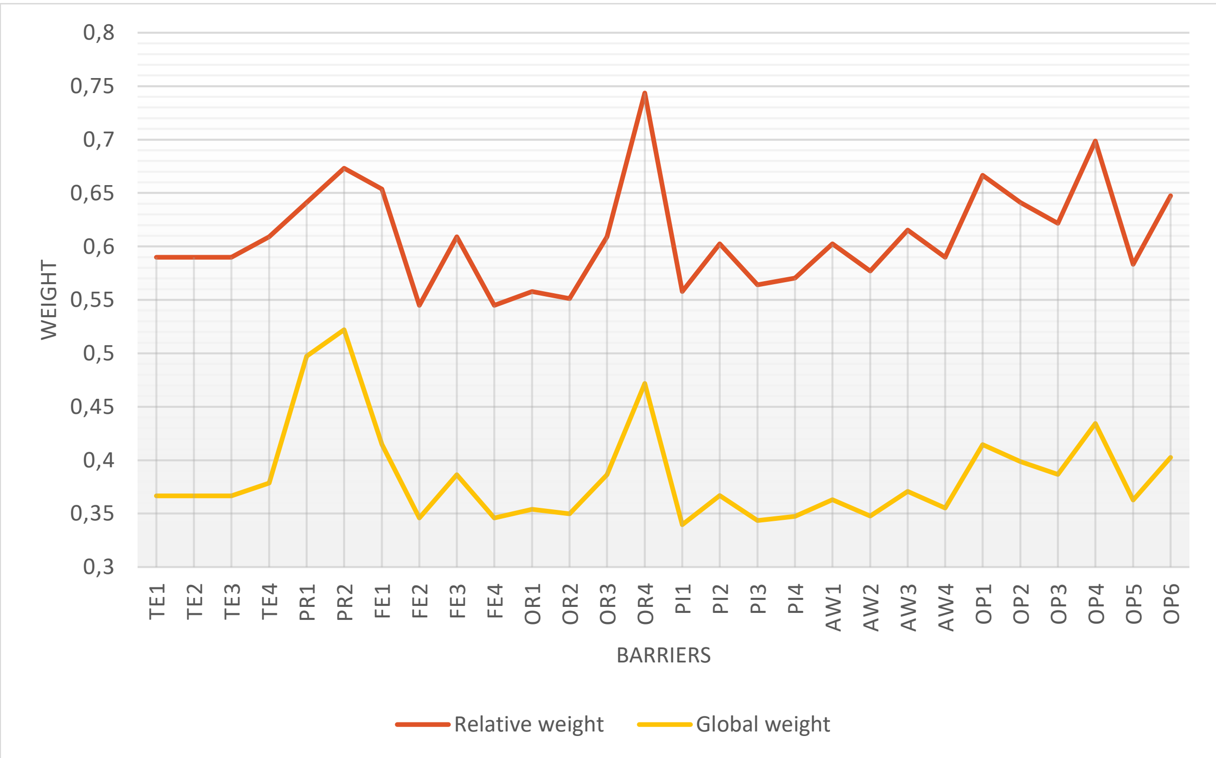


Figure 14 - Overall ranking

Table 10 - Overall weight of barriers

Cat.	Code	Barrier	Relative weight	Relative Rank	Global weight	Global Rank
C1	TE1	Uncertainty of technological advancements	0,590	**16**	0,367	**15**
	TE2	Lack of knowledge on reutilization	0,590	**16**	0,367	**15**
	TE3	No nationally recognized tool to measure CE	0,590	**16**	0,367	**15**
	TE4	Lack of knowledge on new materials and innovations	0,609	**11**	0,379	**12**
C2	PR1	Strict norms and warranty terms makes reutilization of materials difficult	0,641	**7**	0,497	**2**
	PR2	Standardized rulesets are used which do not include the CE	0,673	**3**	0,522	**1**
C3	FE1	Not including residual value	0,654	**5**	0,415	**5**
	FE2	The implementation of CE is more expensive	0,545	**27**	0,346	**25**
	FE3	Financial uncertainty of value of materials after end-of-life	0,609	**11**	0,386	**10**
	FE4	Reutilization of materials is more expensive than new materials	0,545	**27**	0,346	**25**
C4	OR1	Many stakeholders with all their demands makes the CE to be left behind	0,558	**24**	0,354	**21**
	OR2	Lack of trust between stakeholders	0,551	**26**	0,350	**22**
	OR3	Little to no information sharing	0,609	**11**	0,386	**10**
	OR4	Lack of holistic approach (lack of system thinking)	0,744	**1**	0,472	**3**
C5	PI1	There is no standard way to implement the CE	0,558	**24**	0,340	**28**
	PI2	No clear definition of the CE	0,603	**14**	0,367	**14**
	PI3	Uncertainty of market demands	0,564	**23**	0,344	**27**
	PI4	Not able to measure the CE	0,571	**22**	0,347	**24**
C6	AW1	Social value does not receive due attention	0,603	**14**	0,363	**18**
	AW2	Profit driven sector	0,577	**21**	0,348	**23**
	AW3	Lack of experience in reutilization and innovations	0,615	**10**	0,371	**13**
	AW4	Limited awareness of the CE	0,590	**16**	0,355	**20**
C7	OP1	Standard contract specifications do not include the CE	0,667	**4**	0,415	**6**
	OP2	The CE is little included in awarding criteria of the procurement	0,641	**7**	0,399	**8**
	OP3	Fragmented process causes information loss	0,622	**9**	0,387	**9**
	OP4	Long life-span of constructions makes it difficult to predict what will be done with the materials at the end-of-life	0,699	**2**	0,434	**4**
	OP5	Ever changing urban environment due to demand of the market	0,583	**20**	0,363	**19**
	OP6	Deconstruction and reutilization are not in the scope of the contractor	0,647	**6**	0,403	**7**

4.6. Triangulation of the survey

In this section the differences and similarities in opinion between the contractors, engineering and governmental stakeholders of the sector are compared. To identify whether the different stakeholders of the sector vary in their opinions, the weight and ranks of the barriers and categories have been calculated per stakeholder as well. The weighting and ranking of the categories can be found in Figure 15 and Table 11.

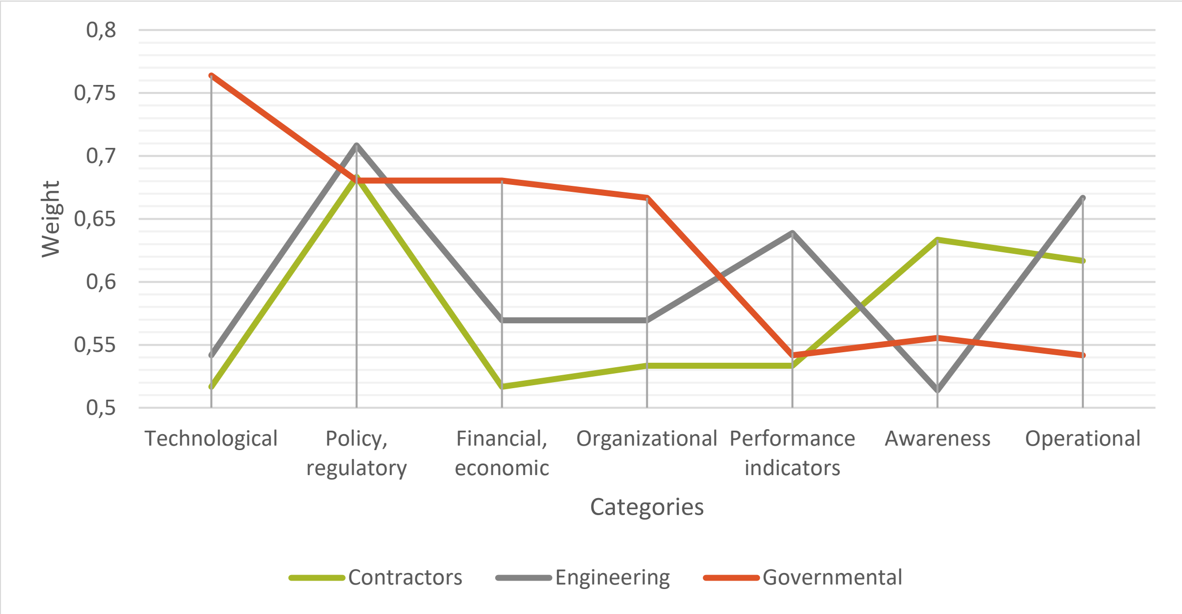


Figure 15 - Categorical ranking per stakeholder

Table 11 - Category weight from different stakeholders

	Contractor		Engineering		Governmental	
Category	**Weight**	**Rank**	**Weight**	**Rank**	**Weight**	**Rank**
Technological (C1)	0,517	**6**	0,542	**6**	0,764	**1**
Policy and Regulatory (C2)	0,683	**1**	0,708	**1**	0,681	**2**
Financial and Economic (C3)	0,517	**6**	0,569	**4**	0,681	**2**
Organizational (C4)	0,533	**4**	0,569	**4**	0,667	**4**
Performance indicators (C5)	0,533	**4**	0,639	**3**	0,542	**6**
Awareness (C6)	0,633	**2**	0,514	**7**	0,556	**5**
Operational (C7)	0,617	**3**	0,667	**2**	0,542	**6**

For each stakeholder in the sector an important category is the policy and regulatory category. This category was ranked first by both the contractors and engineering firms, and second by the governmental experts. The categories that are considered as least important, are different for every stakeholder. Contractors believe the least important categories are both the Technological and the Financial and Economic categories, for engineering companies the least important category is Awareness, and for governmental organisations it's a tie between the category of Performance indicators and Operational. Interesting to note, are the categories Technological and Operational. These categories were ranked oppositely by the governmental stakeholder when compared to the Contractors and Engineering firms of the sector.

Table 12 - Barrier weight from different stakeholders

		Contractor				Engineering				Government			
Category	Barrier	Relative weight	Relative rank	Global weight	Global rank	Relative weight	Relative rank	Global weight	Global rank	Relative weight	Relative rank	Global weight	Global rank
C1	TE1	0,533	**14**	0,276	**19**	0,500	**23**	0,271	**24**	0,556	**11**	0,424	**5**
	TE2	0,533	**14**	0,276	**19**	0,500	**23**	0,271	**24**	0,639	**4**	0,488	**1**
	TE3	0,533	**14**	0,276	**19**	0,528	**16**	0,286	**20**	0,528	**20**	0,403	**8**
	TE4	0,550	**12**	0,284	**18**	0,528	**16**	0,286	**20**	0,556	**11**	0,424	**5**
C2	PR1	0,667	**6**	0,456	**3**	0,653	**8**	0,462	**4**	0,556	**11**	0,378	**9**
	PR2	0,683	**5**	0,467	**2**	0,792	**1**	0,561	**1**	0,556	**11**	0,378	**9**
C3	FE1	0,667	**6**	0,344	**11**	0,556	**13**	0,316	**17**	0,681	**2**	0,463	**2**
	FE2	0,417	**26**	0,215	**26**	0,500	**23**	0,285	**22**	0,556	**11**	0,378	**9**
	FE3	0,750	**3**	0,388	**5**	0,639	**9**	0,364	**10**	0,500	**25**	0,340	**16**
	FE4	0,483	**23**	0,250	**24**	0,375	**28**	0,214	**28**	0,625	**5**	0,425	**4**
C4	OR1	0,350	**28**	0,187	**28**	0,681	**5**	0,388	**8**	0,472	**28**	0,315	**19**
	OR2	0,500	**19**	0,267	**22**	0,472	**27**	0,269	**26**	0,528	**20**	0,352	**13**
	OR3	0,650	**8**	0,347	**10**	0,528	**16**	0,301	**19**	0,542	**19**	0,361	**12**
	OR4	0,767	**2**	0,409	**4**	0,639	**9**	0,364	**10**	0,681	**2**	0,454	**3**
C5	PI1	0,467	**25**	0,249	**25**	0,528	**16**	0,337	**14**	0,514	**24**	0,278	**26**
	PI2	0,383	**27**	0,204	**27**	0,694	**4**	0,444	**6**	0,528	**20**	0,286	**24**
	PI3	0,717	**4**	0,382	**6**	0,486	**26**	0,311	**18**	0,500	**25**	0,271	**27**
	PI4	0,500	**19**	0,267	**22**	0,514	**21**	0,328	**15**	0,528	**20**	0,286	**24**
C6	AW1	0,483	**23**	0,306	**17**	0,667	**6**	0,343	**13**	0,625	**5**	0,347	**14**
	AW2	0,500	**19**	0,317	**15**	0,514	**21**	0,264	**27**	0,625	**5**	0,347	**14**
	AW3	0,533	**14**	0,338	**13**	0,639	**9**	0,328	**15**	0,556	**11**	0,309	**20**
	AW4	0,500	**19**	0,317	**15**	0,528	**16**	0,271	**23**	0,556	**11**	0,309	**20**
C7	OP1	0,783	**1**	0,483	**1**	0,764	**2**	0,509	**2**	0,556	**11**	0,301	**23**
	OP2	0,550	**12**	0,339	**12**	0,667	**6**	0,444	**5**	0,569	**10**	0,308	**22**
	OP3	0,617	**9**	0,380	**7**	0,625	**12**	0,417	**7**	0,583	**9**	0,316	**18**
	OP4	0,600	**10**	0,370	**8**	0,708	**3**	0,472	**3**	0,778	**1**	0,421	**7**
	OP5	0,533	**14**	0,329	**14**	0,542	**15**	0,361	**12**	0,500	**25**	0,271	**27**
	OP6	0,567	**11**	0,349	**9**	0,556	**13**	0,370	**9**	0,597	**8**	0,323	**17**

Table 12 and Figure 17 show the weight and rank of the different barriers. Similarly to Table 10, the left two columns per stakeholder are the relative weights and ranks, and the right two columns per stakeholder are the global weight and global rank, which include the category weighting. There are two ways to compare the barriers: through their relative weight and ranking and through their global weight and ranking. Firstly, the barriers are compared between the different stakeholders that seem to be quite similar. To assess the similarity, two criteria have been set up:

1. The considered weight difference is smaller or equal to 0.05;
2. The rank difference should be no more than 10.

Considering these two criteria, five similar barriers can be found in the relative ranking and weight and three barriers are similar in the global ranking and weight. The similar relative barriers are TE3, TE4, PI4, OP3 and OP6. The similar global barriers are AW3, AW4 and OP6. Since there are only a few barriers that are weighted equally by the stakeholders, it can be concluded that there is a large variety in which barriers are considered to be important by the different stakeholders.

Relative weighting

A general difference considers the top ranked barriers, the relative rank 1 to 4 of all stakeholders. The relative weight of the barriers per stakeholder can be found in Figure 16 and Table 12. The engineering and contractor stakeholders weigh these barriers all relatively high (0.694-0.792), while the government has rated its top ranks much lower, where only the first ranked really stands out (0.778). The relative weights of the second ranked barrier of the governmental stakeholder only starts after the fourth barrier of the other stakeholders with a weight of 0.681. The opposite is true with the weighting of the categories, where the governmental stakeholder weightings are all relatively higher compared to the other two, see Figure 15.

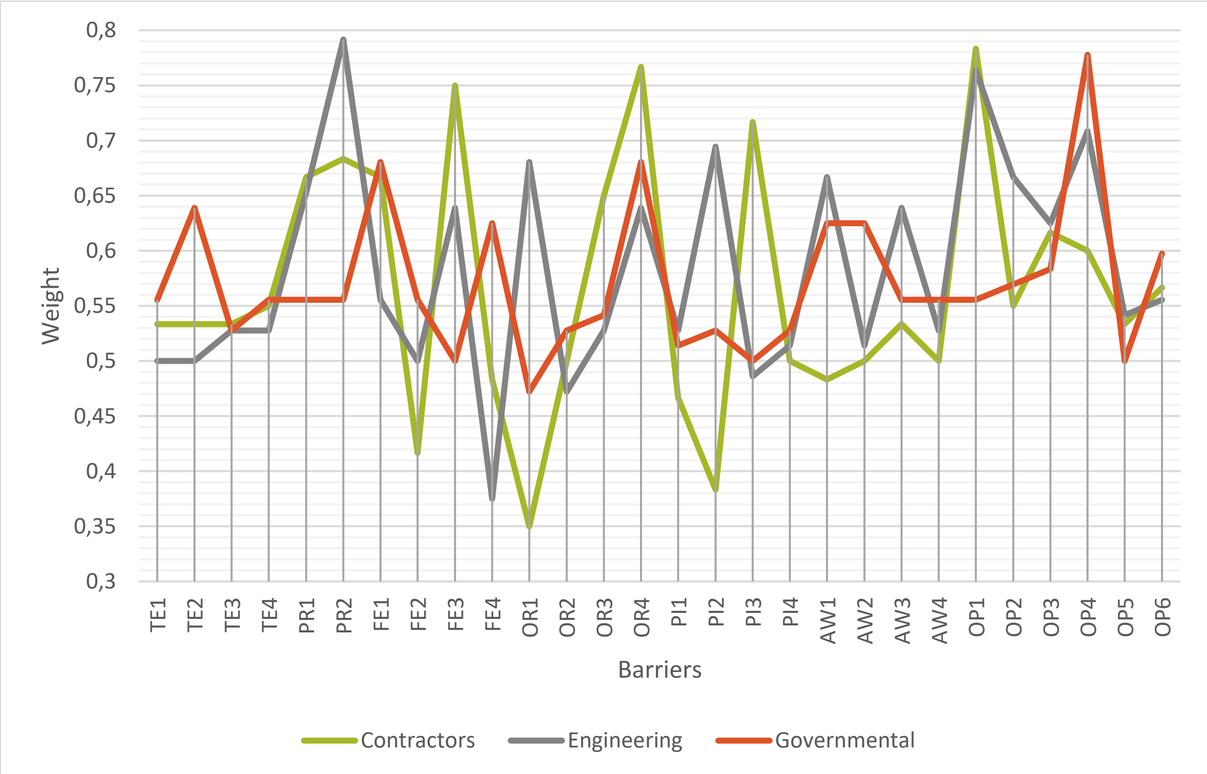


Figure 16 - Relative weight per stakeholder

Second, there are some barriers that are uniquely found important by the individual stakeholders. For the government the barriers, Lack of knowledge on reutilization (TE2), the reutilization of materials is more expensive than new materials (FE4), and that the sector is profit driven (AW2), are considered to be important, while this is not true for the others. The engineering sector considers the barriers, many stakeholders with all their demands makes the CE to be left behind (OR1) , and that there is no clear definition for CE (PI2), both as important, but the other stakeholders do not. The contractors, in contrary to the other stakeholders, find the uncertainty of market demands (PI3) a very important barrier.

Finally, there are barriers in which two stakeholders find a barrier very important, while the third stakeholder does not. The engineering firms agree with the contractors on the importance of the standardized rulesets used (PR2), and the standard contract specifications (OP1). The engineering firms also agree with the governmental stakeholders on the importance of the barriers concerning that social value does not receive due attention (AW1) and that the long life span of constructions makes it difficult to predict what will be done with the materials at the end-of-life (OP4). The contractors and governmental stakeholder agree on the importance of the barrier that concerns not including residual value (FE1).

Global weighting

When investigating the global weight values, seen in Figure 17 and Table 12, which include the category weighting, it can be observed that a slight shift happens in the top 4 ranked barriers of the different stakeholders. The top ranked of the governmental stakeholder is rated much lower in this case (from rank 1 to 7). Furthermore, for both the contractors and engineering firms the category weighting affect both the barriers in the Policy and Regulatory category, with the result that these two barriers are now in the top 4 for both stakeholders.

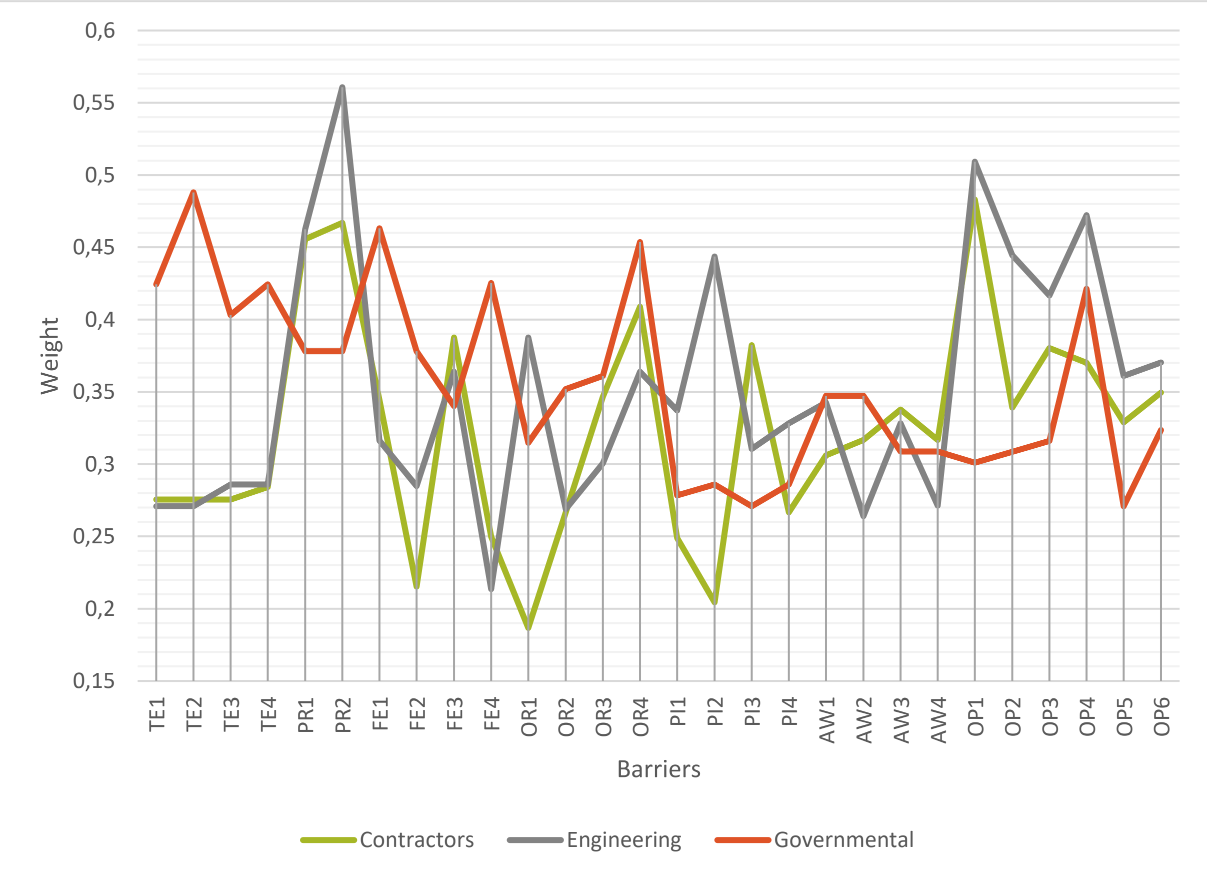


Figure 17 - Global weight per stakeholder

In the Technological category large shifts happen for the governmental stakeholders, in which the barriers are now ranked much higher, this because of the highly weighted technological category by the governmental stakeholder, see Figure 15. Also, while the relative weights of the barriers in the Awareness category were ranked relatively high at first, these are now considered as moderately to not important by the governmental stakeholder. Within this category the same happens for the engineering firms. The contractor firms experience a minor shift in the Financial and Economic category.

5. RESULTS

The data collection and analysis has led to a vast amount of relevant information. The results obtained in the previous chapter will be discussed hereafter. This chapter will end with an informative description of the most relevant barriers and their related enablers.

" I'm going to move forward, because going backwards isn't an option and standing still is not enough."

STACEY ABRAMS

5.1. Results of the analyses

In the previous chapter all the results were identified. These results will be discussed in more detail in this chapter. After, the most important barriers that were identified will be discussed.

While the circular economy is still quite a new concept, several parties are already putting in a lot of effort in trying to implement the CE in the sector. It is good to see that the sector is unambiguous on the existence of several barriers when it comes to the implementation of the circular economy. It is a positive sign that on several aspects regarding the circular economy, all stakeholders are on the same line and acknowledge the barriers that arise when wanting to implement the circular economy in the civil engineering sector. Related to the newness of the concept it is interesting to see that barriers related to a certain investment were ranked as least important by the experts. This can mean that the sector is already aware of the possible initial investments related to the implementation and that the sector is willing to take the first steps.

In order to implement the circular economy, several procedural barriers are recognized. Still most projects in the sector do not implement the CE and are executed with standardized procedures. While the sector does acknowledge the fact that there is no standard way to implement the CE, and every project should be considered as unique, see barrier PI1 which is considered as not important, the standardized rulesets and standard contract specifications are not yet in line with this mindset, see barriers PR2 and OP1 which are graded very high and thus still considered as important barriers.

Furthermore, an interesting observation can be made within the Policy and Regulatory category. All three stakeholders consider this an important category that stands in the way of the implementation of the CE. However, it is noteworthy that the governmental experts do not grade the individual barriers within this category as important. This discrepancy between the importance of the barriers and the overall importance of the category could have two reasons. The first reason is that this specific category is seen as the first category to overcome to reach a circular civil engineering sector. This also is in line with what several interviewee said about rules and regulations that currently do not enable reutilization and that reutilization is one of the first things that need to be enabled as one of the first things (RWS1, 2018). The second reason for this contrast could be that the barriers mentioned by the researcher are found to be too general by the respondents or that existing barriers within this category are not found throughout the data collection. For example, a missing barrier could relate to the governmental parties that could experience regulatory and policy barriers themselves by a higher governmental layer. For example on a parliamentary level, where not enough budget could be made available for the necessary actions that the governmental stakeholders want to undertake.

In general the results of the survey show that the contractors and engineers agree on a lot of important barriers. However, the government disagrees more and considers different, unique, barriers of higher importance. An important aspect of implementing the CE is collaboration in the sector, which means that the different stakeholders that work together in the sector do need to agree on some level on the manner in which the CE will be implemented. Looking at the different opinions on certain barriers, this is not yet the case which can stand in the way of collaboration. The cause of these different points of view can be related to the hierarchical structure of the sector. Where contractors and engineering feel that the governmental stakeholder needs to take the responsibility and take initiative to start a shift towards a circular economy. This contrast could also induce positive change and accelerate the implementation of the CE, where contractors and engineering firms focus their expertise on solutions in other areas, in which the believe they have the knowledge for. However, this does not resolve the barrier that concerns collaboration between the stakeholders.

Within the individual barriers, several of them can be assigned as the responsibility of, or being more important to, one individual stakeholder. For the engineering firms this can be clearly seen in the barriers PI2 and OR1. PI2 concerns the unclear definition of the circular economy and since the engineering firms have a pivotal role translating the demand of the government to clear contract specifications in the contract, it can be understandable that the engineering firms are seeking a more explanatory definition of the CE that helps them with this translation. Furthermore, as stated in chapter 2, the engineering firms are responsible for attaining the demands from all the different stakeholder of a project. It is thus no surprise either that they find the barrier concerning these demands (OR1) important.

A barrier that was considered important by the contractors is the uncertainty of market demands. This is not surprising, because contractors fully depend on market demands. It is key for them to stay in line with what the market asks from them. When they do not respond to innovations in the sector, they risk falling by the wayside.

Regarding the analysis, there are three barriers which specifically concern the government and are also seen as important barriers for them. These barriers are FE4, TE2 and AW2. The first two barriers both regard the reutilization of materials. The government finds the high costs related to, and the lack of knowledge on reutilization important barriers. Because the governmental stakeholders considered the technological category as very important, they can steer the sector towards innovations and information gathering regarding reutilization. As launching customer and biggest client of projects within the sector, the governmental stakeholders have the power to set clear directions for the sector to develop towards.

The last barrier which is believed important by the government and also has an effect on their situation is the barrier AW2, which concerns the profit driven sector. While the governmental stakeholders are not focused on gaining a profit, other organizations within the sector do find it important to stay financially healthy. When taking on projects that concern the CE, these profit driven companies take more risks compared to traditional projects due to the uncertainty of several aspects related to materials, process and future market demands. While, this is a risk not every company is willing to take at this stage, the governmental organizations are sometimes having difficulties finding the right contractors for the job.

5.2. Investigating the most important barriers

This sub-chapter focusses on the barriers which the experts in the field described as the most important barriers that are in the way of becoming a circular civil engineering sector. To select the most important barriers several approaches can be used. To start off, the most important barriers are selected using the overall weights of all respondents in all stakeholder groups. Since the distribution between the several stakeholder groups is even (5 or 6 respondents per group), this will give a clear general view of the importance of the barriers. Usually the threshold value of the important barriers is equal to the average weighting of the barriers, in this case 0.385. However, since there will only be looked at the most important barriers a threshold value of $\alpha = 0{,}425$ is selected. The reasoning for selecting this threshold is drawn from the experts opinion depicted in Figure 18. The selected barriers have a significant higher weight than the other barriers which means that they can be considered as the most important barriers.

In the Fuzzy Delphi Method, the 80/20 rule can be used to select which factors (in this case barriers), have to be selected for the specific analysis. This rule explains that often 20% of the factors, explain 80% of the weighting off all the factors (Kuo & Chen, 2008). The total weighting of the found barriers in the data set was 10.787. Taking 20% of this would mean that the selected barriers would need a total weighting of at least 2.157. Combining the four barriers above the threshold value would add up to a weighting just below the 20% level (1.926). Therefore, to meet the 20% requirements, the barrier OP1 was added resulting in a total weighting of 2.340. While the barrier OP1 (0.415) was just below the threshold, it was chosen because if its strong relationship with the barrier PR2. Looking at these two barriers one can notice that they have quite a strong relationship:

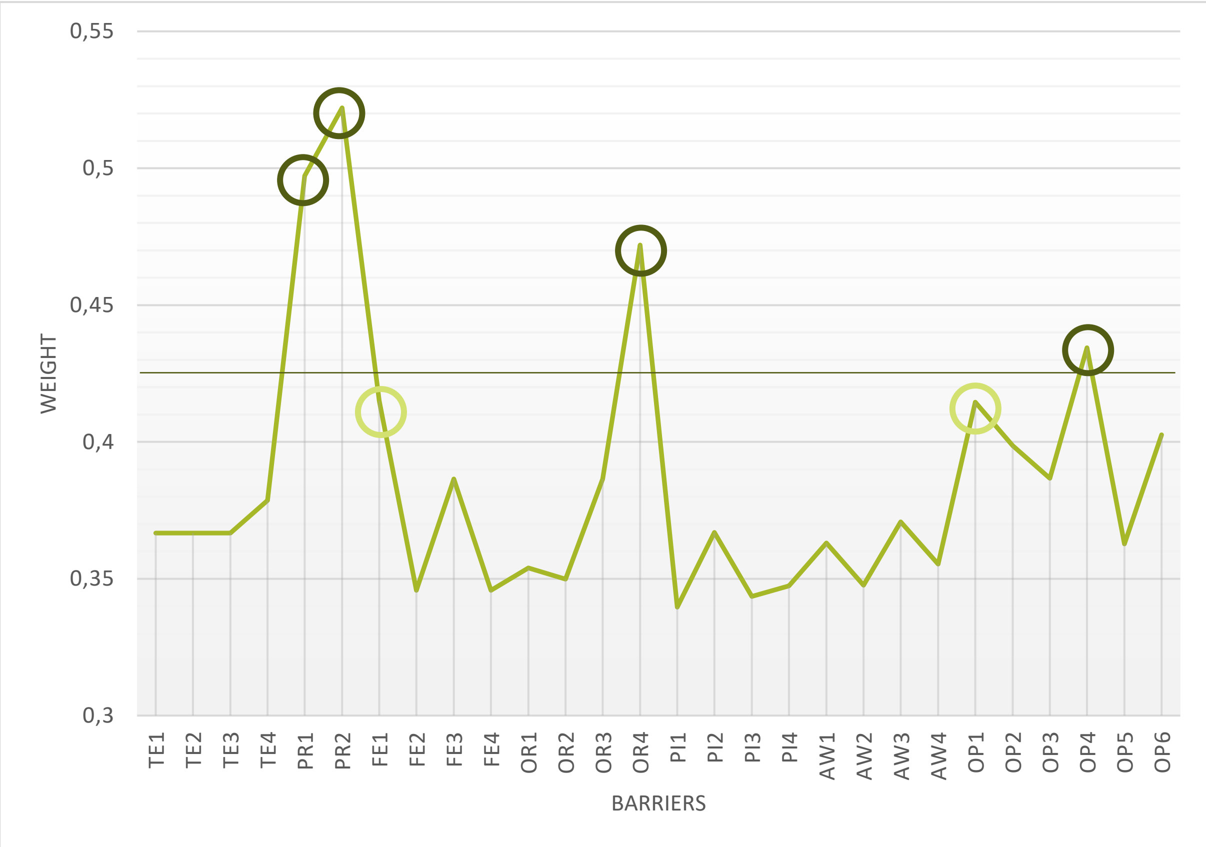


Figure 18 - Global barriers ranking

PR2 - Standardized rulesets are used which do not include the CE
OP1 - Standard contract specifications do not include the CE

Both these barriers state the standardization of the sector and these barriers will thus be discussed as the general barrier 'The standard procedures of the sector do not include the CE'.

Barrier FE1 (0.415) is also just below the threshold. Since no other barriers above the threshold have a link with this barrier concerning the residual value, it will not be discussed. However, the sector is working on enabling this barrier. As stated in chapter 2, Dura Vermeer is calculating the residual value of roads in their new pilot where they are investigating the possibilities of the 'as-a-service' format for roads (Dura Vermeer, n.d.).

Each following paragraph will first explain the barrier in a more comprehensive way, hereafter several enablers will be discussed with their related effects. These enablers were set up by analyzing the enablers that were found during the Grounded Theory Approach (see Supplement VIII, X, XII and Appendix IV) and a discussion with an expert in the field. The discussion was set up as follows:

1. Does the expert understand the barrier? Define a clear definition of the barrier
2. Which enablers are found in the Grounded Theory approach? Do they relate to this barrier? In which way do they relate?

3. Are there more enablers possible that were not identified by the analysis? Which are they and how should they be defined?
4. What are the effects of these different enablers to the people working in the sector, the process or the market in general?
5. Step 1 to 4 are repeated for every barrier.

5.2.1. Standardized procedures

The standard procedures of the sector do not include the CE

Barriers PR2 and OR1

This section discusses two important barriers, PR2 and OR1, and concerns 'The standardized procedures of the sector do not include the CE'. This barrier encompasses all problems that are related to the standardized method that the sector is currently using to design their projects. Most projects currently include predefined rulesets. These rulesets prescribe, for example, which materials should be used for the project. This standardization has become integrated in the process of the governmental organizations because of several positive effects. First, organizing the processes and developing the contracts are often related to costs. Using these standardized rulesets means that this takes less time, which reduces the related costs and other procedural difficulties. Furthermore, standardization leads to easier operations and maintenance of the construction. This because all maintenance will be of the same material and thus less different types of equipment is needed to provide for this maintenance.

However, there are several disadvantages to this standardized way of working. Standardization causes a vicious circle, which locks in the manner in which is operated in the sector. Contracts do not change and no new equipment will be purchased if no other materials is used, and in turn, the operations and management stakeholders will keep requesting materials for which they already have the equipment. This results in limited change in contract forms, available equipment and the used materials in projects. The circular economy asks for flexibility and a different approach to each project, this is currently not the case. Furthermore, these standard rulesets are so tightly integrated into the process that now, if anybody wants to change something in a contract of Rijkswaterstaat, they need to be held to account and describe why they want to deviate from the standard. The other way around, always considering the best option for each project, is more in line with the circular vision.

Because high costs are involved for the purchase of new equipment, the maintenance and operational sector take the largest risk when a non-standard project is conducted with new materials. A solution should be found that allows more flexibility in material maintenance and takes away some of the risks involved for this stakeholder. More flexibility that a more diverse variety of equipment brings, allows contractors more freedom in their design and material choice for which the engineering firms could draw up contracts that focus on earlier contractor involvement that allows for more flexibility in the project design. To break this vicious circle, several enablers can be found. The first and most 'simple' enabler is to give more money to the companies that currently perform the operation and maintenance of the civil engineering sector so that they can invest in new equipment, which was an enabler mentioned by the expert during the discussion. This will give more space within the civil projects to use other materials. However, this enabler only solve a small part of the standardized process and is not the overall solution.

Another way to overcome this barrier, mentioned by the expert during the discussion is to arrange the operations and maintenance sections in a different way. An option could be to outsource these responsibilities. Currently, most operations and maintenance is performed by the government itself.

When outsourcing this to the contractors, for example by using DBFMO contracts, the contractor is responsible for the maintenance and operations of the project for a certain amount of time. This will enable the contractor to think about the materials that he is planning to use and consider their ease of maintenance, life-span, and flexibility of dismantling amongst other things. A possible disadvantage of this enabler is the fact that the sector will undergo more privatization. Although the market forces can cause more quality in the sector, the downside of the privatization may be that safety and reliability, which the government feels strongly about, can come in second place since profit is the most important goal for the contractors. Furthermore, other questions also arise when more DBFMO contracts will be used such as: ‘What will happen with the road when the contract ends or when the contractor will go bankrupt?’.

Another way to rearrange the sector is to keep the responsibility for operation and maintenance at the government level, but to reorganize this part of the sector. Currently the arrangement of the maintenance is spatially organized and, on top of that, there is a separation of responsibility between municipality, provinces and Rijkswaterstaat. An organization of responsibility per material or, for example, type of bridge, would make more sense in terms of equipment availability and equipment use. This asks for better collaboration between the different governmental parties but can eventually lead to more maintenance companies that are specialized in one material or one type of bridge which will give a higher quality of maintenance and operations. Collaboration should exceed the organizations of the municipalities and the provinces and should be more focused on sharing information and finding different cross connections between the parties. These enablers are in line with the enablers found during the Grounded Theory Approach, respectively enablers 22, 36, 58, 75, and 81 (see Table 4).

5.2.2. Strict norms and warranty terms

Strict norms and warranty terms makes reutilization of materials difficult

Barrier PR1

The second barrier regards the strict norms and warranty terms that have an effect on the reutilization of materials. This means that when a building or bridge is deconstructed and reusable materials become available, they cannot get the certificates that are required when wanting to construct with these materials. These warranty terms and norms are in place for a reason. They guarantee the safety that can be expected from constructions and also guarantees the reliability and disposability in the life-spans of all constructions in the sector. These norms and warranty terms, set up by different companies, institutions or organizations, are based on a lot of research in practice and give trust to the parties using the products (NEN, n.d.)

While they are necessary for safeguarding the strength, life-span and safety of the constructions, these certificates are formulated in a strict manner and therefore limit the implementation of the circular economy. The demand for certificates is a hindrance when it comes to using new materials and products for constructions, because new materials and products first need to be validated before they can be used in big projects. Also, due to the lack of validation and certificates for reusable products, clients are more reluctant to ask for these products in projects since the contractor cannot guarantee that that specific material will last for the life-span that the client asks for.

An enabler to this barrier could be to re-evaluate the requirements and norms that are given to reused materials (see enabler 39 in Table 4). To enable more reutilization, the life-span of the materials and flexibility of the construction need to be considered with more deliberation. While the requirements and norms for materials that are used in the civil engineering sector often require the products to have a long life-span, reused products might not always comply to these high standards. Therefore an option would be to investigate whether the norms for reused materials can be adjusted and investigate whether they could be used in other ways or in other projects with a shorter life-span. Also, by investigating reuse capabilities in other sectors, more materials can be extracted and reutilized at deconstruction. While the tests for the reusable materials should still be strict in nature, for shorter life-spans, the norms could be set lower and therefore more reusable materials can be used in new constructions.

To enable reutilization of and innovation in materials, the validation of reusable and new products should be looked into in more detail to investigate whether these processes can become faster and easier. This was an enabler mentioned by the expert. An example to validate reused materials is by giving them a reutilization label. However, this form of validation is very cost intensive since the products need to be individually validated and analyzed on which forces they can still withstand to determine the kind of certificate or label that can be given to it. For the field of innovation and introduction of new materials similar issues can be identified. Where testing, the requirements of the materials and norms still have to be formulated which slows down the possibility to implement such materials. This is demotivating for contractors and material manufacturers to innovate and experiment with new materials.

To be able to validate innovative new materials, Rijkswaterstaat has currently set up a collaboration with several municipalities and other governmental organizations so that materials can be validated on a smaller scale (enabler 34 and 78). Solutions in this area could also prove to be successful for validating used materials. If the tests turn out to be good, Rijkswaterstaat will be able to implement them on a larger scale. The fact that Rijkswaterstaat is already seeking collaboration with other parties is very positive. Also, since the triangulation showed that the governmental stakeholders find the technological category to be very important, it is good to see that they suit the action by the word. Hopefully, more of these collaborations will take place in the future and more knowledge sharing will be enabled.

5.2.3. Long life-span of constructions

Long life-span of constructions makes it difficult to predict what will be done with the materials at the end-of-life

Barrier OP4

The third barrier is a barrier that is quite specific for the civil engineering sector. The overall view of the sector is one of constructions that can last a 100 years, which makes it difficult to predict when and in what state materials become available again at the end of life. Especially in the design phase, this poses difficulties when planning for the deconstruction of the product and requires planning far ahead of time. Also from a contractor point of view, investing in constructions that can be reutilized is unattractive, due to the uncertainties that such a long life-span causes for the materials. Collaborative constructions in which materials remain the property of the contractor could motivate contractors to invest more in the ability to reuse the construction materials in a later stage, however the uncertainties related to when these materials become available again makes this unattractive.

However, such a long-term design is not always the correct vision for a civil construction. While the sector constructs in a way that it is possible for constructions to last a 100 years, the reality is that most of the constructions do not last that long. Due to the growing amount of car-usage, a lot of bridges, roads and tunnels cannot cope with the amount of cars passing every day and are in desperate need to be widened, renovated or even replaced. Additionally, many technological advancements currently take place for which we cannot predict the outcome. Who says that we will still need our roads, tunnels and bridges in a 100 years? Maybe by that time, automated transport will be the main mode of transport, or maybe we will do all the traveling through the air and we will not need any roads at all. This means that maybe the current vision of the life-spans in the sector is not at all a logical or realistic one.

With these remarks in mind, a good point to take into consideration is the way that the circular economy is described. It is important that the CE is not only seen as reaching the longest life-span of a material, because it is impossible to know what its function will be after that many years. The focus should lie at designing more in a flexible and adaptive way to be prepared for every future of the civil engineering sector. This raises the question if it is truly necessary to describe these long life-spans for the constructions in the sector. The civil engineering sector should stop seeing the long life-span of a construction as the holy grail and should consider more for which time period the construction is required by society.

To enable this barrier an additional step should be added to the process of the project: the deconstruction and reuse phase (see enabler 22 and 75) . When adding this phase to the process, it can be considered at the earliest stages of the project. When a client is formulating its requirements for the project, several demands that concern different stages in the project are formulated already. This forces stakeholders to think about the deconstruction phase at a very early stage of the project, which forces them to think about the end-of-life of the construction as well. A consideration towards the lifespan of the product could be added to take account for the demands of society towards the potential construction. This has an effect on the flexibility for the entire process and therefore could stimulate the implementation of the CE in the project.

In the following stages, the project design is developed. While making design choices several aspects that relate to later stages are already considered such as the construction and maintenance phases (see enabler 35, 63 and 76 in Table 4). The deconstruction phase is added to this list and the manner in which the construction will be deconstructed in the future is prepared for. This is now too often still forgotten and materials end up demolished and mixed together at the end-of-life of the construction. The responsibility for the requirements related to deconstruction that were set in the design phase can be endorsed in the contract. This obliges the responsible parties, in the deconstruction or demolition phase to adhere the demands regarding the dismantling of the product. If the responsible party is not involved yet at this stage of the project, it is important that the information is well documented and transferred at a later stage.

When the construction is deconstructed and materials are separated, the next step is to find a new purpose for them. For this step it is important to keep in mind the R-levels, to keep the material in the same state as much as possible and to not only consider reutilization within the sector but to also look for opportunities outside the sector (enablers 29, 30 and 77). A good example of such an implementation outside the sector is a lock keepers house that is currently being transformed into a Bed & Breakfast which was mentioned by the expert. When no direct purpose is found for that specific material or product, it is still an important consideration to keep the product or materials in the Netherlands and to not send it back too easily to other countries to repurpose or recycle because it is believed that the scarcity of resources will eventually lead to a rise in prices of materials. This consideration should always be made, that if we have already have these materials in the country, it might be uneconomical and unsustainable to send it away.

5.2.4. Lack of holistic approach

Lack of holistic approach (lack of system thinking)

Barrier OR4

The last important barrier mentioned by the experts is a barrier that also arose in several articles concerning the circular economy. The circular economy asks for the sector to think more in advance and not consider reutilization of products only after they are already dismantled. Furthermore, the people working on the construction or renovation of projects do not currently have the full insight in the products available for reutilization. Finally, the lack of holistic approach also encompasses the collaboration and knowledge sharing amongst the different stakeholders within the sector.

This first consideration asks for a better calibration between demand and supply. The first thing that needs to come to mind when a new project will be initiated should be: 'Do we really need a new bridge or a new road or can we solve this problem in another way?'. If this is not the case and there is a clear need for a new construction, this construction should preferably be designed based on the materials that are available or will be available in the near future. This requires to think about reutilization at an earlier stage of the project, which can be solved in a similar fashion as the previous barrier discussed in section 5.2.3, by adding an additional phase to the project: The deconstruction and reuse phase. By considering the end-of-life at an earlier stage, the reutilization of products can be considered as well and incorporated in the design.

This has a direct relation to the amount of information that is available on the amount of products that can be reutilized and will become available in the future. To plan for using reutilized products in the project, it is fundamental to have some sort of security in terms of when and where materials become available for reuse. Currently, the people in the sector have no notion on the availability of materials.

Therefore, to enable planning for reusing materials requires some sort of database that has information on which materials are available and will become available in the future. Several projects have been set up to create a kind of website where people can find the materials that are available. However, it is key that such a project is rolled out nationally to enable the availability for all. Rijkswaterstaat, being the company that operates nation-wide, is a company that could help with the facilitation of such a tool. When such a tool is effectuated, the governmental organizations can put in their contract specifications that the contractor should use such a database for the retrieval of materials and also to contribute by the input of reusable products when a construction will be dismantled (enabler 28).

Furthermore, because not all materials will be used at the same time that they will become available, some sort of facility to store the materials and products is mentioned by the expert during the discussion. For this enabler two problems arise: (1) The consideration on how long and what type of material we are willing to store, and (2) who are the owners of the materials and what will their prices be. While outsourcing this process to a private party can cause prices to rise, it might be better to let the governmental organizations facilitate this. The government can make sure that the prices will be in conformity with the market since they are less interested in gaining a profit on these materials. If necessary, this means that contracts should include more run time for the projects to promote the reutilization of materials.

Finally, the lack of holistic approach can also be found in the way that the sector works together. Many experts in the field of the circular economy, in- and outside the civil engineering sector, underline that it is very important to collaborate, to share information and to get out of the personal bubble (enablers

25, 31, 32, 57 and 80 in Table 4). The sector is currently too focused on their own tasks within the projects and often forget to consider the system which the project is part of and sometimes look at it with a helicopter view (enabler 41). To improve this, no clear enabler can be given, but it is believed that all enablers beforementioned regarding information sharing or information gain can have a positive effect on this barrier (enablers 36, 58 and 81). These could be a good step forward to create more awareness for solutions regarding the CE while it forces people to think about the end-of-life in the different stages of a project. Information sharing and creating learning environments will hopefully bring the different stakeholders together which will improve collaboration. Further issues related to the lack of holistic approach can be found in, for example, the current standards and contracts that force the different contractors in a more linear format. Different types of contracts can have an effect on collaboration during the project and should be considered to enable more (early contractor) involvement.

5.3. Interrelation of the four barriers and their enablers

The different barriers have been discussed in the previous sub-chapter, this coming sub-chapter will focus more on the overall relationships between the different barriers and will dig deeper into the enablers and their characteristics. To create a clear overview, all the identified enablers for the top ranked barriers can be found in Table 13 below.

Table 13 - Overview of enablers

Barrier	Enabler
The standard procedures of the sector do not include the CE	1. Give extra money to maintenance companies to that they can invest in new equipment. 2. Reorganize operations and maintenance a) First option is to draw up more DBFMOR contracts so that contractors are responsible for the maintenance instead of a different party. b) Second option is within RWS itself, reorganize they maintenance divisions per material or type of construction to center knowledge and enable more innovation.
Strict norms and warranty terms makes reutilization of materials difficult	1. Re-evaluate rules and regulations 1. Firstly to enable individual validation of reused materials so that reutilization is easier. 2. Secondly, make the process itself faster so that new innovations could also be implemented easier. 2. Consider shorter life-span of constructions to enable lower norms. 3. Use pilots on smaller scale to validate materials and eventually being able to use them on a larger scale.
Long life-span of constructions makes it difficult to predict what will be done with the materials at the end-of-life	1. Consider shorter life-span of constructions 2. Circular vision needs to change: instead of the longest life-cycle to flexibility and adaptability of constructions 3. Add deconstruction and reuse in process to also enable it to be integrated in other stages of the process 4. Looking outside sector for new purpose of materials
Lack of holistic approach (lack of system thinking)	1. Add deconstruction and reuse in process 2. Database of available materials 3. Storage of available materials 4. Looking outside sector for new purpose 5. Collaboration, knowledge sharing and learning environments

First of all, it is clear from the results of the analysis that the contractors and engineering firms are seeking guidance from the governmental stakeholders in the direction to move forward with the implementation of the circular economy. For this reason, the fact that Rijkswaterstaat is an organization that works nationwide, and they have quite a lot of power in the sector, a lot of the enablers may concern this organization as a launching customer or the responsible party. Enablers such as the database and storage for reusable materials, and the introduction of a reutilization label are most effective when they are rolled out nationwide. For these enablers, Rijkswaterstaat could play a major role in the initiation. Also in the restructuring of the operations and maintenance phase it is important that governmental stakeholders investigate the options to reorganize the way that responsibilities are set. At least on these four enablers, the governmental stakeholder should take a leading role.

Secondly, many enablers have a common ground, which is the need for more collaboration and knowledge sharing. The need for an information database and the collaboration requirements that spur from the introduction of the deconstruction and reutilization phase to the projects' process, are two enablers that both clearly have these concepts as a common denominator. The suggestion to look at other sectors for reutilizing materials even requires collaboration and knowledge sharing with parties outside the civil engineering sector. The overall notion to enhance collaboration and knowledge sharing is an immense objective for the sector and should not be thought of lightly. However, a good first step starts with the realization that more collaboration and knowledge sharing is needed. The suggested enablers could prove to be small steps in the right direction and are also expected to provide a first basis for improving the collaboration issues related to the barrier 'lack of holistic approach'. This common factor is in line with the notion of the circular economy that collaboration, flexibility and knowledge sharing are of key importance (Adams et al., 2017).

Furthermore, multiple enablers are focused on enabling the reutilization of materials at the end-of-life. These enablers affect different phases within the process of a project and have a strong causal relationship with each other. The addition of the deconstruction and reutilization phase needs to be considered already in the exploration phase, where the lifespan of the construction needs to be critically estimated. In the concept and development phase the type of contract and level of collaboration with the contractor should be considered. The way the construction should be deconstructed, available reusable materials and type of material that is used should be taken into account all the way to the execution phase. In the operations and maintenance phase it is key that the construction is maintained the way it was meant to be to not corrupt the circular intentions of the design. Finally, in the deconstruction and reutilization phase, the product is deconstructed in the way that was planned for, it will provide the information on which materials become available and the kind of construction label can be given to the different materials. In order to make reutilization possible in the sector, the process of the project should be considered more circular, where the deconstruction and reutilization phase of one project provides important input to the exploration phase of the next project. Also, these different enablers are reinforcing each other and have the largest effect when they are implemented together.

The barrier that is the most difficult to enable concerns the rules and regulations. During the research, little to no information has been gathered about the judicial process of the norms and warranty terms. Also, because the implementation of these norms and warranty terms are not the responsibility of the investigated stakeholder groups or the expert with whom the discussion was held, it is difficult to say how easy the enablers mentioned could be implemented.

6. CONCLUSION

This final chapter concludes all the steps that were taken in this report. The research questions will be answered in the first sub-chapter, hereafter the limitations and topics that arose during this thesis will be discussed. The third sub-chapter will concern the scientific and societal relevance, and the report will end with a brief discussion of future recommendations and research directions.

"And we are all connected to each other. In a circle, in a loop that never ends"

COLORS OF THE WIND - POCAHONTAS

6.1. Conclusion

This report is conducted as an exploration for a successful transition to a circular civil engineering sector. The data collection, consisting of, among other things, an elaborate literature review and interviews was analyzed by using the Grounded Theory Approach and the Fuzzy Delphi Method. The eventual results of the analysis will answer all research questions. Leaded by the sub-questions, this sub-chapter will answer the main question of this research.

> What are the benefits of a circular civil engineering sector and where does the concept of the CE currently stand in the sector?

Sub-question 1

The current way of using our planets resources will not be sufficient to provide to the demands of the world for much longer since resources are running out. As one of the biggest users of natural resources and a big creator of waste, the construction sector is a big contributor to this problem. The concept of the circular economy has gained much interest when it comes to solving this problem. Not only in small circles, but nationally and internationally the CE is an topic on several governmental agendas. The Dutch government has stated that the construction sector is one of the five sectors that needs to be fully circular in 2050.

The approach of the circular economy is to use as little new resources as possible and preserving and reusing the products and materials already available. The civil engineering sector, a sub-sector of the construction sector, still has a long way to go to become a circular sector. Little information is written about the concept of the CE in this sector and thus this is an interesting sector to investigate which barriers and enablers are related to the implementation of the CE.

The benefits of creating a circular civil engineering sector are not only the reduction of natural resources that are used, but it is also a way to make the sector more future proof. Since life-spans in the civil engineering sector are mostly very long (50 to 100 years) it is key to start with the implementation of solutions as soon as possible. Currently in the sector, several pilots have been set up with their own interpretation of the circular economy. All have good intentions, but it is now key to gather all relevant information, share knowledge and create some clear questions everybody needs to consider when commencing a project with a circular vision. This will help create one direction in which the sector can develop itself further.

As the biggest client in the sector, Rijkswaterstaat can become leading in which direction the sector can move towards regarding the CE. This task, as being the launching customer, is already clearly noticeable while many projects are already put in motion with the initiative of Rijkswaterstaat.

> What is a civil project, out of which phases does a civil project consist and what is the relationship between the CE and these phases?

Sub-question 2

Within the civil engineering sector, different projects can be considered. They can be broadly categorized in three themes: water, rails and roads. Since there is quite a big different between the projects and clients within these three themes, this thesis focused on the construction and/or renovation of (high)ways, roads, bridges and tunnels.

The process of a civil project can be described in many ways. For this research a six step process has been used with the addition of a final step to incorporate the circular economy in the process. This final step does already exist, however, it is little integrated in the current contracts and way of working. These seven steps are:

1. Exploration;
2. Concept phase;
3. Development and contracting;
4. Sub-development;
5. Execution;
6. Utilization and maintenance;
7. And deconstruction and reuse.

For each specific step in the process, the relationship with the circular economy was analyzed and discussed. To generate more circular civil projects, it is important to generate more loops throughout the process. The 'thinking loops', which are the upper grey arrows in Figure 19, represent an important moment to stand still at the possibilities of the circular economy. In the exploration phase it is important to consider whether it is necessary to start a new project, and whether the option is available to reuse materials that will become available in the deconstruction phase of different projects. For the execution it is key to think about the way the construction will be built and what other possibilities arise, apart from the construction itself, to make the project even more circular. Think about the addition of social value to the project or the logistics of the materials to the site.

The lower green arrows in Figure 19 represent 'material loops', these are the loops that are related to material and product design. In both development phases it is key that the right design choices are made to improve circular design. Materials and products should be of a flexible and adaptive nature and furthermore, the longest life-span is not always the best circular choice. During maintenance and utilization it is important that it is clear, for the organizations in charge of this phase, what the intention of every material and product was so that the flexibility of the design can be preserved. Information transfer between the different steps within the process it thus very important.

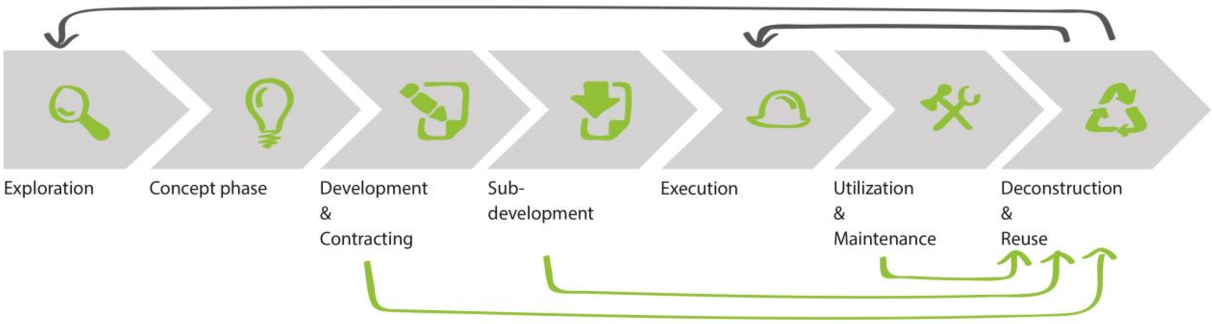


Figure 19 - Deconstruction and Reuse and its relationships (own image)

> What barriers arise when wanting to implement a circular vision in civil projects?

Sub-question 3

Regarding the implementation of the CE, this sector is faced with several barriers. Some of these barriers consider general challenges, found to be a concern for the implementation of the CE in many sectors, and some barriers are related to specific factors regarding the civil engineering sector. This report has analyzed, by means of the Grounded Theory Approach, which barriers arise when wanting to implement a circular vision in the civil engineering sector. These barriers where found in literature, by performing interviews with experts in the field and by attending sessions about the subject. These can be found, sorted by category, in Table 14.

Table 14 - Barriers per category

Category	Code	Barriers
Technological (C1)	TE1	Uncertainty of technological advancements
	TE2	Lack of knowledge on reutilization
	TE3	No nationally recognized tool to measure CE
	TE4	Lack of knowledge on new materials and innovations
Policy and Regulatory (C2)	PR1	Strict norms and warranty terms makes reutilization of materials difficult
	PR2	Standardized rulesets are used which do not include the CE
Financial and Economic (C3)	FE1	Not including residual value
	FE2	The implementation of CE is more expensive
	FE3	Financial uncertainty of initial investor
	FE4	Reutilization of materials is more expensive than using new materials
Organizational (C4)	OR1	Many stakeholders with all their demands makes the CE to be left behind
	OR2	Lack of trust between stakeholders
	OR3	Little to no information sharing
	OR4	Lack of holistic approach
Performance indicators (C5)	PI1	There is no standard way to implement CE
	PI2	No clear definition of CE
	PI3	Uncertainty of market demands
	PI4	Not able to measure CE
Awareness (C6)	AW1	Social value does not receive due attention
	AW2	Profit driven sector
	AW3	Limited awareness of CE
	AW4	Lack of experience in reutilization and innovations
Operational (C7)	OP1	Standard contract specifications do not include CE
	OP2	The CE is little included in awarding criteria of the procurement
	OP3	Fragmented process causes information loss
	OP4	Long life-span of constructions makes it difficult to predict what will be done with the materials at the end-of-life
	OP5	Ever changing environment due to demand of the market
	OP6	Deconstruction and reutilization are not considered

What are possible enablers to the most important barriers?

Sub-question 4

For this report, the four most important barriers where chosen to be investigated further. The importance of the barriers was established by carrying out a survey amongst experts in the field. The barriers that were graded most important were:

- The standard procedures of the sector do not include the CE (PR2 and OP1);
- Strict norms and warranty terms makes reutilization of materials difficult (PR1);

- Long life-span of constructions makes it difficult to predict what will be done with the materials at the end-of-life (OP4);
- Lack of holistic approach (OR4).

These four barriers have been discussed with experts to obtain a clear view on the possible enablers but also the effects of these enablers on the sector. The results of these discussions and the characteristics of these barriers have been discussed in detail in chapter 5 of this thesis and were especially important for answering the main research question.

What are the first steps needed for a successful implementation of the CE in the civil engineering sector?

Main question

The civil engineering sector is trying hard to implement the circular economy within their projects. However, since the concept is still unclear and the benefits are not always apparent, the sector does not know exactly how to approach this challenge yet. By the means of pilots and other initiatives, small steps have been taken to investigate several directions for the sector, but no big steps have been taken yet. The analysis has shown that the sector is already shifting from the original profit driven mindset towards a more purpose driven sector, which is a good first step to create an anchor for CE related innovations.

In the barrier specific analysis, several enabler have been identified that the sector can undertake to overcome significant challenges related to the implementation of the circular economy in the sector. Several of these enablers should be targeted at a national level to have a significant impact and to facilitate knowledge sharing at the sector level. Since Rijkswaterstaat is an entity that works at this level, have a relatively high amount of power in the sector by being one of the biggest clients, and with the self-made task to act as launching customer, it is believed that Rijkswaterstaat can carry their position a little bit forward and take the lead in this process. Not all tasks prescribed hereafter should be executed by Rijkswaterstaat but they could consider to be the initiator for many of them and take the first steps.

The first actions that the civil engineering sector should undertake for the implementation of the circular economy are:

1. Setting up demands and guidelines to better implement the deconstruction and reuse phase into the current process of the civil engineering sector. Adding this phase to the process requires considerations towards deconstruction and material reutilization in the other steps throughout the projects' process. Since this phase is not automatically included yet in current project procedures, considering this phase earlier in the process is fundamental to enable reutilization and making the sector more circular;
2. A database should be set up to give insight into the available products and materials and the materials that will be available in the near future. This goes hand in hand with the fact that the design choices in the early project phases can be based more on materials that are available. Also, the possibility to use extra time if it is known that materials are going to be available on the short term is recommended. In this way more knowledge is available that enables the consideration of reutilization throughout the entire process of the project;
3. To enable more reutilization of materials, a solution has to be found for all the materials where no immediate use is possible. To enable this, a storage bank for materials that come available for deconstruction should be made available. This provides more flexibility when it comes to

reusing materials in new constructions. While such a storage location would involve new costs, it could enable more reuse of higher grade products which could result in savings in the long-term;

4. The operations and maintenance sector needs to be restructured. It is advised to keep these tasks under governmental supervision but to reorganize it according to type of material or type of construction. This will mean that better collaboration is required between all governmental layers: municipalities, provinces and Rijkswaterstaat. If the government wants the market to innovate, the market should gain more freedom in the materials they want to choose from, rather than being restricted by the lack of equipment for maintenance;
5. Norms and warranty terms should be researched to better line up with materials that can be reused. While the sector is willing to reuse materials, the sector is not ready for this yet, especially concerning the norms and warranty terms for the second hand use of products. More research should be conducted on how these norms and warranty terms should change to better support this. This will help accelerate a better reutilization and reduces the barrier for different stakeholders to construct with reutilized materials;

Finally, there are two general circular views that all stakeholders in the civil engineering sector should consider. First, it should be kept in mind that a circular construction is not always the construction with the longest life-span. An adaptive and flexible construction with materials that can be reused in many different ways (also outside the sector) is more able to cope with the uncertainty that is the future. A project should be considered as unique and solutions should be fitted to the requirements of the task at hand. Second, a big barrier acknowledged by the sector is the lack of holistic approach. The five actions that have been presented are first steps towards a more thoughtful and collaborative sector. However, the entire sector should be mindful that the only way forward is by working together.

To conclude: when the sector wants to innovate, the people need to innovate too. This means that they need to step out of their comfort zone and the bubbles in which they operate. The bubble of standardized rulesets and instead seeing every project as a new and unique challenge to implement the CE. The bubble of their current way of working and looking to explore different approaches. The bubble of their own companies and region, by seeking more collaboration with the focus on type of construction or type of material. And the bubble of the project, by looking further, outside the sector, outside the scope of the project, to identify what that specific project can contribute to its surroundings in the broadest way.

6.2. Discussion

It is always relevant to reflect on the analysis and the results of the research performed. The following paragraphs will describe the limitations and discussion of the methods used and scope of the project.

Regarding the methods used several remarks can be made. Firstly, Grounded Theory is a very personal method and is based on the personal opinion of the researcher. This could cause the outcome to unintentionally shift towards a certain outcome. This was by all means not the objective of the research but certainly something to consider when using such a method. For the Grounded Theory Approach a division of three different sources had been made to investigate views of the different sources. Unfortunately, for the Fuzzy Delphi Method, the method used hereafter, a different division has eventually been made. Although this difference between the triangulation has been deliberated upon, more results could have been drawn if the same division was made.

For the Fuzzy Delphi Method, many different approaches are described in different articles and a wide variety of calculations is known to use for this analysis. Through reading a lot of articles regarding the Fuzzy Delphi Method, especially the ones that had a relationship with the topic of this research, the calculations and linguistic variables are chosen. But it is important to note that there are different approaches that could have been used. What is also noteworthy is the way that the researcher has collected and discussed the data. During the research, many discussions have been held regarding the data with the supervisors whom are researchers and engineers. This means that there was less interaction with the governmental and contractor side of the sector.

The circular economy is a new and emergent concept that is gaining more and more interest every month. This means that this research could provide a good starting point for the civil engineering sector to implement the circular economy, but this also leads to several discussions. Because of the newness of the concept, new articles or other papers still appear every month, while the research has taken six months, it might be very well possible that in the meantime interesting information has come forward that could have been valuable for this analysis. Also, if more interviews were conducted with more experts, more information could have been gathered. Unfortunately, the line had to be drawn somewhere. Furthermore, the overall lack of experience with the concept of the circular economy made it sometimes difficult to identify the difference between this lack of experience of the people in the sector and the real barriers.

After the analysis was finished for this thesis, an article was published in the 'Cobouw', the newspaper that discusses everything that is going on in the construction sector. This article mentioned that the sector is still struggling to find enough contractors since the profit margins for them are low, while the projects are rather risky in nature (Cobouw, 2019). This could mean that the contractors are even more reluctant when it comes to circular projects because they might not want to take even more risks. However, it can also be seen in a different perspective: the circular economy can also help to make the sector become healthy again. When the contractors are looking for bigger profit margins, it might be interesting to further investigate how to calculate the residual value so that this can be implemented in civil projects. This could provide additional profit and, in turn, more motivation for contractors to take on civil projects.

6.3. Societal relevance

The circular economy is a relatively new but promising concept to help with the depletion of resources on our planet. The implementation of the circular economy has large effects, especially when implementing this concept within the civil engineering sector, because this sector is a big user of natural resources and generates a vast amount of waste. Knowledge on how to preserve our resources is currently of vital importance if we want to generate a sustainable society. As this diminishment of resources is a current societal problem that is asked to be solved, this report can contribute to this and help understand the position of the civil engineering sector within these environmental dilemma's.

6.4. Scientific relevance

A lot of documents have already been written on the CE, however, little documents have been found specifically for the civil engineering sector. This thesis provided an elaborate description of the sector and its relationship with the CE. This already provided insight in the challenges regarding the CE implementation that the sector faces in general, which has created a foundation on which future research regarding the CE in the civil engineering sector can base upon.

This thesis also aimed at identifying the barriers that the CE implementation is currently facing and to provide solutions to the first major bumps on the roads towards a circular civil engineering sector. Since this concept asks for new ways of collaboration and other business models than are currently used in this sector, the implementation does not consist of an easily written manual, but it requires a constant evaluation of the difficulties that the sector is facing and how these can be overcome. This thesis has provided a good example how different challenges can be identified regarding CE implementation in the sector and unravels some of the complicated connections between different process stages and stakeholders that go hand in hand with the CE implementation.

Furthermore, this thesis has gathered information regarding the opinions of the different stakeholders in the field. This provides a good impressing on what the different stakeholders consider important topics and on which themes they generally agree upon.

To conclude, while some recommendation have been done for the sector, this thesis was only the first step towards a circular sector. Looking at this challenge from multiple perspectives and reviewing the general challenges for implementation, this enables future researchers to conduct more specific research to sections of the sector. Therefore this research can act as a good basis for further research on the CE in this sector.

6.5. Future recommendations and research

When using a method such as the Grounded Theory Approach a lot of data is gathered. Although a big part of that data has been used, some interesting focus point have not been investigated with more detail but are worth mentioning for further research.

The enabler that concerns adding the deconstruction and reutilization phase to the project was also discussed at the beginning of this report. As an important first action that has been identified by this thesis and previous work, it is important to investigate what the impact of such an addition has on the way the sector operates. Therefore, further research should be conducted into the effects of such an addition and it should be investigated more in detail what should be done to implement this step in the different stages of the current process in the civil engineering sector.

There are still a lot of technical barriers that can be investigated. There is a big demand on creating a national database that keeps track of the materials that are available now and in the future. Investigating how such a database could be organized and shaped can certainly aid the sector in setting up such a database that provides more knowledge on the availability of reusable materials and products. Similarly, research should be conducted to the enabler concerning the introduction of a national storage bank. Especially because of the high costs related to such a storage bank (e.g. costs concerning space, time, transport and more), it is important to investigate who could become the responsible party and also how to make it financially attractive to maintain the storage bank.

An interesting theory came up to enable the barrier of the strict norms and warranty terms. This enabler is unfortunately not further investigated due to the time limit but might still be interesting to further investigate. This potential enabler is captured in the method of the Industry Technical Agreement (ITA) (In Dutch: 'Nederlandse Technische Afspraak, NTA'). ITA can be helpful to implement new and innovative products into a project where currently no norms have been written down for yet. With an ITA, the contractor is allowed to deviate from the set norms in a justified way. This ITA will still be written in cooperation with the institute that is responsible for all norms but an ITA is only valid for three years where after it will need to be examined again. This would allow some flexibility to stimulate circular friendly norms.

Another interesting factor that this research did not investigate in detail is hindrance. A lot of maintenance or other works to the roads is currently planned in order to minimize the hindrance to the road users. This means that products or materials are sometimes replaced even if they have not yet reached their full life-span. This factor is very interesting to look into with more detail and to investigate the optimal time to replace certain parts of the construction.

Finally, related to this topic, is the optimal lifespan of materials and constructions. While constructions in the sector are constructed to last for 50-100 years, they are sometimes not needed for this amount of time. An analysis of the past projects lifetime of different projects could provide insights in how to optimally design for the (corrected) life-span of the product. This could increase efficiency of material use, allow reutilization of materials that would otherwise be thrown away, and allow flexibility for uncertain future market demands.

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Appendices

Appendix I - Interview questions (Dutch)

Wat is uw functie binnen projecten als werknemer van ….
Op welke manier ben u op dit moment in uw projecten bezig om circulariteit van de grond te krijgen?
Wat maakt het specifiek binnen de GWW moeilijk om CE te implementeren?
Hoe wordt circulaire economie op dit moment vertaald naar contracteisen?
Wat betreft de contracten die op dit moment gebruikt worden, welke vorm contracten gebruikt u op dit moment en bent u van mening dat dit goede contractvormen zijn om CE van de grond te krijgen of ziet u hier graag verandering in? En op welke manier dan?
Hoe zorg je bij projecten ervoor dat: - CE onderdeel wordt van de scope en hoe vertaal je dat naar eisen? - CE uiteindelijk niet wordt wegbezuinigd?
Wat betreft het huidige proces wat doorlopen wordt (initiatief, aanbesteden/ontwerpen, realiseren, slopen, maar ook informatieoverdracht, tussen de stappen) hoe kan dit optimaal ingericht worden om CE op een zo positief mogelijke manier te promoten?
Hoe kan je ervoor zorgen dat een contract zo lang mogelijk zo flexibel mogelijk is.
Wordt er veel over sloop nagedacht in contracten? Hoe zou je dat kunnen verwerken?
In een ideaal circulair inkoopvraagstuk is er juist een lange termijn relatie tussen de inkopende organisatie en de leverancier, hoe kan je dit in een contract verwerken?
Wat zijn de moeilijkheden van functioneel specificeren?
Bent u van mening dat de sector de drang ziet om te veranderen? Zo ja, waar baseert u dit op? Zo nee, hoe komt dat?
Denkt u dat de mensen binnen de GWW weten wat CE precies inhoudt? Waar lopen ze tegenaan?
Denkt u dat de mensen binnen de GWW dezelfde definitie voor ogen hebben t.a.v. CE? Zo ja, waar baseert u dit op? Zo nee, waarom bent u van mening dat hier geen sprake van is.
Bent u van mening dat om een CE te introduceren in de GWW het nodig is om de circulaire gedachte zwart op wit als eisen in contracten te verwerken?
Wat zou de opdrachtgever moeten doen om circulaire economie toe te passen in projecten en uiteindelijk in contracten?
Welke factoren spelen een rol om zorg te dragen dat de sector de (financiële) waarde van circulaire projecten inziet?
Wat doet de overheid op dit moment om CE te implementeren in relatie tot het inkoopproces?
CE gaat over lange termijn investeren, politiek handelt daarentegen in korte termijnen van 4 jaren. Zijn er belemmeringen ten aanzien van de implementatie van CE in relatie tot de 'kortetermijnpolitiek'?
Is CE wel interessant voor de GWW aangezien het gaat over veelal permanente constructies die meer dan 100 jaar blijven staan? Is hergebruik van materiaal voor en brug die vervolgens 100 moet staat wel nodig?
Uit literatuur kwam naar boven dat de sector een eenduidige meetmethode (denk aan MPG) wil zien om circulariteit te kunnen meten. Gebruikt Rijkswaterstaat al een methode?
Hoe ziet u de GWW in 2030 en 2050?
Denkt u dat de GWW ooit volledig circulair zou kunnen zijn?

Appendix II – Memo-writing

Date	What
November 7th 2018	Circular Fair @ Den Haag

On November 7th I have visited the Circular Fair. This fair was not specifically focused on the civil engineering sector, but more on the CE in general. It was very nice to get in touch with other people that have the same mindset.
At the fair I participated in a debate that was about the CE in the civil engineering sector. Participants were, amongst others, from Rijkswaterstaat, municipalities and contractors.
Comments that I have written down during that event were:

- We have good pilots right now, but scaling these up to more projects is still a bottle-neck within the sector
- We are now searching for innovation at the end of the projects**, when everything is already decided upon**, that doesn't work.
- We need to establish a 'best for project' mindset
- **CE needs to become the new standard**, but the sector is very traditional and is not very good in changing
- We do not need contractors but entrepreneurs with vision

Date	What
December 12th 2018	Interview RWS1

The interview with miss RWS1 was I found useful on multiple levels. First it was nice to gain insight in her vision on RWS. It was interesting to hear how different this vision can be between difference companies in the sector. Miss RWS1 said that there is enough space for companies to innovate and that RWS tries its best to be Launching customer. However, other stakeholders in the sector claim that the RWS is not doing enough in this area. I belief this will always remain this way.
Second, miss RWS1 is of opinion that you are too late if you start implementing the CE in the contract phase, this should already be happening in the initiative phase and all parties should be included as early as possible in the process. Also, she is of opinion that if companies are willing to take the necessary risks for innovation, a solution should be to support them, for example in covering a part of the risks. These two things should be come about in collaboration and discussion.
Finally, a very interesting remark of her. Miss RWS1 said that at this moment in a linear system we aim to implement circular concepts. However, this is not a complete solution because in this way the system would never become fully circular. She called this the Lock-in principle, where only symptoms of the problem are treated which does not solve the real issue at hand. How can we make the sector fully circular and should that be the goal? Those were the questions that arose after.

Date	What
December 13th 2018	Interview Ahsmann

Mr. Ahsmann was an optimistic man that see the circular economy as the future for the civil engineering sector. He is of opinion that it is of major importance to start making the sector more circular. The conservative sector of the civil engineering sector should become more trusting towards each other, should stop appointing the blame to individuals and start working together. In addition, the different facets of the sector should understand why the transition should happen, which is not always completely clear for all. The entire sector must participate to make the transition possible.
He let me know that the civil engineering sector will always be a difficult sector due to the long life-time of projects, the number of stakeholders in each project and the fact that they are of a public nature which means that they have to be of a high standard. A lot of projects in the civil engineering sector are unique for which the requirements should not be too specific but instead should remain of open nature, and the method of construction should not be seen as the most important aspect of the project. Mr. Ahsmann is of opinion that it is better that public tenders are not selected based on price, but rather on quality and the plan of action of the contractor. The client and contractor should become more of a team, with a similar vision and best intentions for the project in which trust and transparency should be central.

Date	What
December 17th 2018	Interview Kooij

I had a very pleasant conversation with Mr. Kooij. While he had less knowledge on the concept of CE, he did know a lot about contract and has tried to explain this to me as clear as possible. In the interview I felt very comfortable to say if I did not understand everything completely the first time. The interview was mainly to gain a clear understanding of the concept of contracts. He explained the pro and cons of different variances of contracts and how one can promote innovation with them. He did stretch that a certain amount of flexibility is very difficult within the civil engineering sector due to the client, people responsible for maintenance and the manner of safety that is expected by the tax-payer. Mr. Kooij also underlined that he is of opinion that the entire sector is aware that change is necessary and that they willing to make that change. However, at this moment it is still uncertain how this change should come about. He stated that if someone would tell him that a specific type of contract should be used from this point forwards because that was the best way to implement the circular approach, the entire sector would start using it.
Mr. Kooij sees a good solution in raising the standard requirements in the contract (and in this way also challenge the contractors), and to allow for some space by adding options in the contracts. He saw the ladder as follows: Minimal requirements, a plan of action/EMVI, options. Also beneficial would be to have a fixed price for the project and allow contractors to diversify themselves with their plan of action. In this way there is no competition over the price.
All things considered it was a very interesting conversation that provided me with a lot of insight.

Date	What
January 7th 2019	Interview Schäffner
I had a nice conversation with Mr. Schäffner. Mr. Schäffner is a man that is extremely dedicated in making this planet more sustainable and is someone that does its work with passion. That was also where the start of the conversation was all about: If everybody is on the same page on the subject, beautiful things can be realized. It is a lot harder to act sustainable or circular if it is imposed in a top-down fashion. In this way concepts such as 'bouwteam' can be realized in the right way and not just with profits at one side. Unfortunately, this is still far away, the sector is still very conservative of nature and innovation is going at slow pace because it is going very well economically with the Netherlands. Due to this, clients do not see the necessity to change their current approach. Thankfully there are still people that do understand this, such as Mr. Schäffner, and in this manner, step by step, project by project, we can pass it on to the entire sector. Next to this Mr. Schaffner mentioned something else that could help the implementation of CE. By not only thinking within the scope of the project but looking more at the project being part of a system, we could be much more efficient. To include for example energy transfer of the district next to the road or to consider nature reserves around the corner. A lot of improvements can be done on the current way of collaboration, public tender and contracting.	

Date	What
January 8th 2018	Interview Wuestman
Mr. Wuestman is even more optimistic than Mr. Schäffner, he highly motivates you to get into a positive vibe and you stop seeing barriers for the sector when in a conversation with him. However, he is so extremely positive that I'm unsure whether the transition will go as he envisioned, but it was interesting to brainstorm together on how the ideal world would look like. In contrast with Mr. Kooij, he does see appliances of the 'As a service' approach in the civil engineering sector. Next to that we discussed that the sector has be on the same page before innovative projects for the CE can be expected, however Mr. Wuestman does state that he is slowly seeing people dodge back to the idea of the CE in the civil engineering sector. We should not expect that change would happen overnight, but he is already very pleased with the mere number of policy documents with the word 'circular' in it. The interview provided some less useful information because the RCC was broadly discussed, I should have changed topic quicker.	

Date	What
January 11th 2019	Interview RWS2
This morning I had a comfortable conversation with RWS2. As senior advisor circular economy she is busy to implement the CE in RWS in projects and to create supportive measure to enable this. Especially in the area of maintenance, management and purchase. Funny was that RWS2 came with entirely different issues and solutions than all the other interviews. This provided an entirely different vision on which aspects were also important to implement the CE, which was very nice! She talked for example about how important people find to have the least amount of annoyance or hindrance of maintenance. But because of that often the choice is made to replace everything at once, instead of coming back on multiple occasions for different issues. This is not in line with the circular mindset which I didn't consider yet. Next to that she made me realize that standardization of parts could entail parts of the road but can also be applied for example in the automation of a process. It was a good and eye-opening conversation.	

Date	What
January 16th 2019	Session 'CE in de GWW'@ InfraTech Fair

I went to another session about the CE in the civil engineering sector. It is nice to see that there is clearly a demand for these kinds of knowledge sharing opportunities, however, people still need to go to this session to gather more information about the CE. It is apparent that people are still struggling with the concept of the CE and what is entails. Of course, there a lot of people that are involved in the CE projects but also a lot of people asking questions (and even some reluctant people that did not believe in the CE that much?)
Remarks I have written down during the session were:

Part of municipality Amersfoort:

- Implementing the CE through 4 different tracks: 1; knowledge & culture, 2; good foundation, 3; pilots and 4; other forms of procurement
- People should not decide upon materials directly, they need to develop a broader view on the project: **system thinking**
- Create more distance between municipality and projects: give more space to innovation and knowledge of contractors.
- **Each project should have an individual deliberation on best of project**
- The municipality has created his own storehouse to store materials/products (in and outflow!)
- We should facilitate more **knowledge sharing** between municipalities

Part of Province of Overijssel (they have a pilot of a highway which is procured as-a-service)

- **We should not forget that a transition is always hard**.
- In this project, **trust** is a must
- **Sharing lessons learned and other knowledge** needs to become standard
- The way the governments are acting should change
- The sector handles its stock and the value of is quite badly. They do not do anything with the current value of all the roads in NL.

Part of Rijkswaterstaat:

- First, we need a workable definition before we can make it measurable
- ABN AMRO has developed 5 different sorts of capital for the CE:
    - Social/relationship
    - Digital/technological
    - Natural
    - Human/intellectual
    - Financial
- Materials we could still use need to be kept in NL, we should not send them to China for example

Date	What
February 6th 2019	Categories

To find a way to find a general way to categorize all tables, I have looked at different articles that have already sorted circular topics or sustainability topics in categories. One of those articles stood out in a way that I saw many similarities between their categories and my coded barriers and enablers. It was the following article:

Araujo Galvão, G. D., de Nadae, J., Clemente, D. H., Chinen, G., & de Carvalho, M. M. (2018). Circular Economy: Overview of Barriers. *Procedia CIRP*, *73*, 79–85.

In this article they have categorized their barriers in seven different groups, namely:

1. Technological
2. Policy and regulatory
3. Financial and economic
4. Managerial
5. Performance indicators
6. Customer
7. Social

I think this can be a good base to find my own categories. Looking at my own barriers and enablers there are some changes I want to implement so that I can use them too.

1. Technological

This is a good category where I can sort many barriers and enablers under. Such as the enabler to develop a tool to measure CE, or the ability to have more insight into the current stock of materials within the sector.

2. Policy and regulatory

I have seen many barriers regarding policies and regulations that are not up to date or that do not promote the CE within the sector, this is thus definitely a category to keep

3. Financial and economic

This category relates to the financial side of the circular economy. While we are talking about an economy it is still sometimes hard to see the value of investments. Especially in this sector where life spans are long, and the construction is no longer in the hands of the initial investor, it is sometimes hard to create a business model where the money ends at the right person. Also, sometimes, new innovations initially cost money, this is also something to keep in mind.

4.Managerial

Because the article does not explain what the different categories entail, it is a little bit up to me how I interpret the categories. I think managerial is an interesting category when looking at enterprises. But because I am looking at a whole sector I think I need to rewrite this category and focus more on the different stakeholders, how they interact and how they should interact according to the circular economy. I think the word organizational is more is place for this category

5. Performance indicators

I believe there is indeed a big gap between the fact that we are really excited to begin with the implementation of the circular economy within the sector, but we still do not have any idea what this exactly entails, what is the most circular option and how we can measure this.

6. Customer

This is the only category that is shortly described in the article. They describe this category as "interest in the environment issues or lack of information on environmental impacts" (Araujo Galvão et al., 2018). In the barriers within my research I also see that there is a lack in interest within the sector. Also, the enablers state several methods such as pilots to improve awareness. But I think the category awareness is better and covers more what I have found in my report.

7. Social

Glancing at my barriers and enablers, I don't think that I have many barriers and enablers that go in this category, they are more linked to category 4 and 6. This category will be removed in my research.

Looking through my coding tables, there a still some barriers and enablers that do cannot be placed under the previously mentioned categories. These barriers and enablers focus mainly on the way of working in the sector that is not in line with the circular economy, barriers such as standardized processes and organizational barriers. This is thus a category that I need to add. The name of this category

The following categories will thus be used for this research:

1. Technological
2. Policy and regulatory
3. Financial and economic
4. Organizational
5. Performance indicators
6. Awareness
7. Operational

Appendix III - Condensed barriers

		Technological	Policy & Regulatory	Financial & Economic	Organizational	Performance indicators	Awareness	Operational
Barriers	interviews	17) Uncertainty of technological advancements 20) Validation of new materials and reused materials takes time	9) Rules and regulations restrict reutilization	8) Not including residual value 10) CE sometimes more expensive 11) Financial uncertainty	3) Many stakeholders involved 6) Lack of trust between stakeholders 15) Fragmented sector	4) There is no standard way to implement CE 7) No clear definition of CE 18) Uncertainty of market demands	2) Lack of experience in reutilization and innovations 12) Lack of awareness on CE	1) Standard specifications do not include CE 5) Standardized processes in the sector 13) CE little included in granting process 14) Fragmented process 16) Long life-span of constructions 19) Ever changing environment
	literature	44) Lack of knowledge on reutilization 47) Lack of tools to make the CE measurable 50) Lack of knowledge on new materials and innovations	52) Rules and regulations restrict reutilization	42) No good financial case for reutilization 45) Financial uncertainty	49) Lack of holistic approach 51) Traditional sector	48) No clear definition of CE 54) Uncertainty of market demands	43) Financial mindset 46) Lack of awareness 53) Lack of an incentive to design for end-of-life 55) Lack of interest	
	govern-mental	69) Lack of knowledge	74) Rules and regulations restrict reutilization		68) Too little market involvement 73) Little to no information sharing	71) No clear definition of CE 72) Not able to measure CE	66) Social value does not receive due attention 67) Financial mindset 70) Limited awareness	65) Deconstruction and reutilization are not in the process
	condensed	• **Uncertainty of technological advancements** • **Validation of new materials and reused materials takes time** • **Lack of knowledge on reutilization** • **Lack of tools to make the CE measurable** • **Lack of knowledge on new materials and innovations**	• **Rules and regulations restrict reutilization**	• **Not including residual value** • **The implementation of CE is more expensive** • **Financial uncertainty of initial investor** • **Reutilization of materials is more expensive than new materials**	• **Many stakeholders involved** • **Lack of trust between stakeholders** • **Lack of holistic approach** • **Little to no information sharing**	• **There is no standard way to implement CE** • **No clear definition of CE** • **Uncertainty of market demands** • **Not able to measure CE**	• **Social value does not receive due attention** • **Profit driven sector** • **Limited awareness of CE** • **Lack of experience in reutilization and innovations**	• **Standard contracts specifications do not include CE** • **Standardized processes in the sector** • **CE little included in granting process** • **Fragmented process** • **Long life-span of constructions** • **Ever changing environment** • **Deconstruction and reutilization are not considered**

Appendix IV - Condensed enablers

		Technological	Policy & Regulatory	Financial & Economic	Organizational	Performance indicators	Awareness	Operational
Barriers	interviews	29) Improving knowledge on materials, innovations and technologies 30) Improving knowledge on current stock of materials	39) Re-evaluate rules and regulations that restrict reutilization	38) Initially start with creating extra money to implement CE	25) Earlier market involvement 31) Enabling holistic approach 32) Improving trust 33) Setting agreements beforehand about risks and responsibilities 36) Knowledge sharing, learning environments 40) Enabling long-term partnerships	23) Creating clear definition of CE 35) Improving circular design	26) Improving awareness 34) Pioneering (pilots) 41) Think bigger (system thinking)	21) Including residual value 22) Including demolition and maintenance in project 24) Keeping proposal as open as possible 27) Including the CE in awarding criteria 28) Including the CE in demands 37) Initially start with creating extra time to implement CE
	literature			59) Value definition and value creation	57) Holistic approach 58) Enabling knowledge sharing	60) Defining the CE and making it measurable 63) Circular design	56) Raising CE awareness	61) Creating other forms of contracts 62) Creating extra space in projects for the CE 64) Keeping proposal as open as possible
	govern-mental	77) Gaining insight and knowledge in current stock of the sector			80) Improving collaboration 81) Knowledge sharing	76) Circular design 79) Making the CE measurable	78) Using pilots	75) Including disassembly and/or reutilization in process
	condensed	• Improving knowledge on materials, innovations and technologies • Improving knowledge on current stock of materials	• Re-evaluate rules and regulations that restrict reutilization	• Initially start with creating extra money to implement CE • Value definition and value creation	• Holistic approach • Knowledge sharing • Enabling long-term partnerships • Setting agreements beforehand about risks and responsibilities • Improving trust • Earlier market involvement	• Defining the CE and making it measurable • Circular design	• Improving awareness • Pioneering (pilots) • Think bigger (system thinking) • Raising CE awareness	• Including residual value • Including demolition and maintenance in project • Keeping proposal as open as possible • Including the CE in awarding criteria • Including the CE in demands • Initially start with creating extra time to implement CE • Creating other forms of contracts

Appendix V - Aggregated results

						AGGR				
What kind of company are you working for within the sector?	Contractor	Contractor	Contractor	Contractor	Contractor	min	tot	mean	max	**Crisp**
Uncertainty of technological advancements	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	0,00	3,00	0,60	1,00	**0,533**
Lack of knowledge on reutilization	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,00	3,00	0,60	1,00	**0,533**
No nationally recognized tool to measure CE	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	0,00	3,00	0,60	1,00	**0,533**
Lack of knowledge on new materials and innovations	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,00	3,25	0,65	1,00	**0,550**
Strict norms and warranty terms makes reutilization of materials difficult	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,25	3,75	0,75	1,00	**0,667**
Standardized rulesets are used which do not include the CE	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	0,25	4,00	0,80	1,00	**0,683**
Not including residual value	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.75, 1, 1)	0,25	3,75	0,75	1,00	**0,667**
The implementation of CE is more expensive	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0, 0.25)	(0, 0, 0.25)	0,00	1,25	0,25	1,00	**0,417**
Financial uncertainty of value of materials after end-of-life	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,50	3,75	0,75	1,00	**0,750**
Reutilization of materials is more expensive than new materials	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0, 0.25)	0,00	2,25	0,45	1,00	**0,483**
Many stakeholders with all their demands makes the CE to be left behind	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0, 0, 0.25)	0,00	1,50	0,30	0,75	**0,350**
Lack of trust between stakeholders	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	0,00	2,50	0,50	1,00	**0,500**
Little to no information sharing	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	0,25	3,50	0,70	1,00	**0,650**
Lack of holistic approach (lack of system thinking)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,50	4,00	0,80	1,00	**0,767**
There is no standard way to implement the CE	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.75, 1, 1)	(0, 0.25, 0.5)	(0.75, 1, 1)	0,00	2,00	0,40	1,00	**0,467**
No clear definition of the CE	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	0,00	2,00	0,40	0,75	**0,383**
Uncertainty of market demands	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	0,50	3,25	0,65	1,00	**0,717**
Not able to measure the CE	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	0,00	2,50	0,50	1,00	**0,500**
Social value does not receive due attention	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	0,00	2,25	0,45	1,00	**0,483**
Profit driven sector	(0.75, 1, 1)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	0,00	2,50	0,50	1,00	**0,500**
Lack of experience in reutilization and innovations	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	0,00	3,00	0,60	1,00	**0,533**
Limited awareness of the CE	(0.75, 1, 1)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	0,00	2,50	0,50	1,00	**0,500**
Standard contract specifications do not include the CE	(0.75, 1, 1)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,50	4,25	0,85	1,00	**0,783**
The CE is little included in awarding criteria of the procurement	(0.75, 1, 1)	(0.75, 1, 1)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	0,00	3,25	0,65	1,00	**0,550**
Fragmented process causes information loss	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,25	3,00	0,60	1,00	**0,617**
Long life-span of constructions makes it difficult to predict what will be done with the materials at the end-of-life	(0.75, 1, 1)	(0.75, 1, 1)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.75, 1, 1)	0,00	4,00	0,80	1,00	**0,600**
Ever changing urban environment due to demand of the market	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	0,00	3,00	0,60	1,00	**0,533**
Deconstruction and reutilization are not in the scope of the contractor	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,00	3,50	0,70	1,00	**0,567**

							AGGR				
What kind of company are you working for within the sector?	Eng	Eng	Eng	Eng	Eng	Eng	min	tot	mean	max	**Crisp**
Uncertainty of technological advancements	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0, 0.25)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,00	3,00	0,50	1,00	**0,500**
Lack of knowledge on reutilization	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0, 0, 0.25)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,00	3,00	0,50	1,00	**0,500**
No nationally recognized tool to measure CE	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	0,00	3,50	0,58	1,00	**0,528**
Lack of knowledge on new materials and innovations	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,00	3,50	0,58	1,00	**0,528**
Strict norms and warranty terms makes reutilization of materials difficult	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	0,25	4,25	0,71	1,00	**0,653**
Standardized rulesets are used which do not include the CE	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.75, 1, 1)	0,50	5,25	0,88	1,00	**0,792**
Not including residual value	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.25, 0.5, 0.75)	0,00	4,00	0,67	1,00	**0,556**
The implementation of CE is more expensive	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	0,00	3,00	0,50	1,00	**0,500**
Financial uncertainty of value of materials after end-of-life	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	0,25	4,00	0,67	1,00	**0,639**
Reutilization of materials is more expensive than new materials	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	0,00	2,25	0,38	0,75	**0,375**
Many stakeholders with all their demands makes the CE to be left behind	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	0,25	4,75	0,79	1,00	**0,681**
Lack of trust between stakeholders	(0, 0, 0.25)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	0,00	2,50	0,42	1,00	**0,472**
Little to no information sharing	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	0,00	3,50	0,58	1,00	**0,528**
Lack of holistic approach (lack of system thinking)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	0,25	4,00	0,67	1,00	**0,639**
There is no standard way to implement the CE	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0, 0, 0.25)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	0,00	3,50	0,58	1,00	**0,528**
No clear definition of the CE	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.75, 1, 1)	0,25	5,00	0,83	1,00	**0,694**
Uncertainty of market demands	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	0,00	2,75	0,46	1,00	**0,486**
Not able to measure the CE	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	0,00	3,25	0,54	1,00	**0,514**
Social value does not receive due attention	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	0,25	4,50	0,75	1,00	**0,667**
Profit driven sector	(0.75, 1, 1)	(0, 0.25, 0.5)	(0.75, 1, 1)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	0,00	3,25	0,54	1,00	**0,514**
Lack of experience in reutilization and innovations	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	0,25	4,00	0,67	1,00	**0,639**
Limited awareness of the CE	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0, 0, 0.25)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,00	3,50	0,58	1,00	**0,528**
Standard contract specifications do not include the CE	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,50	4,75	0,79	1,00	**0,764**
The CE is little included in awarding criteria of the procurement	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	0,25	4,50	0,75	1,00	**0,667**
Fragmented process causes information loss	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	0,25	3,75	0,63	1,00	**0,625**
Long life-span of constructions makes it difficult to predict what will be done with the materials at the end-of-life	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.75, 1, 1)	0,25	5,25	0,88	1,00	**0,708**
Ever changing urban environment due to demand of the market	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,00	3,75	0,63	1,00	**0,542**

Deconstruction and reutilization are not in the scope of the contractor	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	0,00	4,00	0,67	1,00	**0,556**
							AGGR				
What kind of company are you working for within the sector?	Gov	Gov	Gov	Gov	Gov	Gov	min	tot	mean	max	**Crisp**
Uncertainty of technological advancements	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	0,00	4,00	0,67	1,00	**0,556**
Lack of knowledge on reutilization	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	0,25	4,00	0,67	1,00	**0,639**
No nationally recognized tool to measure CE	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	0,00	3,50	0,58	1,00	**0,528**
Lack of knowledge on new materials and innovations	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,00	4,00	0,67	1,00	**0,556**
Strict norms and warranty terms makes reutilization of materials diffcult	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	0,00	4,00	0,67	1,00	**0,556**
Standardized rulesets are used which do not include the CE	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	0,00	4,00	0,67	1,00	**0,556**
Not including residual value	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.75, 1, 1)	0,25	4,75	0,79	1,00	**0,681**
The implementation of CE is more expensive	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,00	4,00	0,67	1,00	**0,556**
Financial uncertainty of value of materials after end-of-life	(0.5, 0.75, 1.0)	(0, 0, 0.25)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	0,00	3,00	0,50	1,00	**0,500**
Reutilization of materials is more expensive than new materials	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	0,25	3,75	0,63	1,00	**0,625**
Many stakeholders with all their demands makes the CE to be left behind	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	0,00	2,50	0,42	1,00	**0,472**
Lack of trust between stakeholders	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	0,00	3,50	0,58	1,00	**0,528**
Little to no information sharing	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	0,00	3,75	0,63	1,00	**0,542**
Lack of holistic approach (lack of system thinking)	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	0,25	4,75	0,79	1,00	**0,681**
There is no standard way to implement the CE	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	0,00	3,25	0,54	1,00	**0,514**
No clear definition of the CE	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	0,00	3,50	0,58	1,00	**0,528**
Uncertainty of market demands	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	0,00	3,00	0,50	1,00	**0,500**
Not able to measure the CE	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	0,00	3,50	0,58	1,00	**0,528**
Social value does not receive due attention	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	0,25	3,75	0,63	1,00	**0,625**
Profit driven sector	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	0,25	3,75	0,63	1,00	**0,625**
Lack of experience in reutilization and innovations	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	0,00	4,00	0,67	1,00	**0,556**
Limited awareness of the CE	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	0,00	4,00	0,67	1,00	**0,556**
Standard contract specifications do not include the CE	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	0,00	4,00	0,67	1,00	**0,556**
The CE is little included in awarding criteria of the procurement	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	0,00	4,25	0,71	1,00	**0,569**
Fragmented process causes information loss	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0, 0, 0.25)	(0.75, 1, 1)	0,00	4,50	0,75	1,00	**0,583**
Long life-span of constructions makes it difficult to predict what will be done with the materials at the end-of-life	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.75, 1, 1)	0,50	5,00	0,83	1,00	**0,778**
Ever changing urban environment due to demand of the market	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	0,00	3,00	0,50	1,00	**0,500**
Deconstruction and reutilization are not in the scope of the contractor	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0, 0.25, 0.5)	(0.75, 1, 1)	0,00	4,75	0,79	1,00	**0,597**

Overall					
	AGGR				
	min	tot	mean	max	**Crisp**
Uncertainty of technological advancements	0,00	10,00	0,769	1,00	**0,590**
Lack of knowledge on reutilization	0,00	10,00	0,769	1,00	**0,590**
No nationally recognized tool to measure CE	0,00	10,00	0,769	1,00	**0,590**
Lack of knowledge on new materials and innovations	0,00	10,75	0,827	1,00	**0,609**
Strict norms and warranty terms makes reutilization of materials difficult	0,00	12,00	0,923	1,00	**0,641**
Standardized rulesets are used which do not include the CE	0,00	13,25	1,019	1,00	**0,673**
Not including residual value	0,00	12,50	0,962	1,00	**0,654**
The implementation of CE is more expensive	0,00	8,25	0,635	1,00	**0,545**
Financial uncertainty of value of materials after end-of-life	0,00	10,75	0,827	1,00	**0,609**
Reutilization of materials is more expensive than new materials	0,00	8,25	0,635	1,00	**0,545**
Many stakeholders with all their demands makes the CE to be left behind	0,00	8,75	0,673	1,00	**0,558**
Lack of trust between stakeholders	0,00	8,50	0,654	1,00	**0,551**
Little to no information sharing	0,00	10,75	0,827	1,00	**0,609**
Lack of holistic approach (lack of system thinking)	0,25	12,75	0,981	1,00	**0,744**
There is no standard way to implement the CE	0,00	8,75	0,673	1,00	**0,558**
No clear definition of the CE	0,00	10,50	0,808	1,00	**0,603**
Uncertainty of market demands	0,00	9,00	0,692	1,00	**0,564**
Not able to measure the CE	0,00	9,25	0,712	1,00	**0,571**
Social value does not receive due attention	0,00	10,50	0,808	1,00	**0,603**
Profit driven sector	0,00	9,50	0,731	1,00	**0,577**
Lack of experience in reutilization and innovations	0,00	11,00	0,846	1,00	**0,615**
Limited awareness of the CE	0,00	10,00	0,769	1,00	**0,590**
Standard contract specifications do not include the CE	0,00	13,00	1,000	1,00	**0,667**
The CE is little included in awarding criteria of the procurement	0,00	12,00	0,923	1,00	**0,641**
Fragmented process causes information loss	0,00	11,25	0,865	1,00	**0,622**
Long life-span of constructions makes it difficult to predict what will be done with the materials at the end-of-life	0,00	14,25	1,096	1,00	**0,699**
Ever changing urban environment due to demand of the market	0,00	9,75	0,750	1,00	**0,583**
Deconstruction and reutilization are not in the scope of the contractor	0,00	12,25	0,942	1,00	**0,647**

Contractors										
Importance level C1	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	0,00	2,75	0,55	1,00	**0,517**
Importance level C2	(0.75, 1, 1)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	0,25	4,00	0,80	1,00	**0,683**
Importance level C3	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0, 0.25, 0.5)	0,00	2,75	0,55	1,00	**0,517**
Importance level C4	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,00	3,00	0,60	1,00	**0,533**
Importance level C5	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	0,00	3,00	0,60	1,00	**0,533**
Importance level C6	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	0,25	3,25	0,65	1,00	**0,633**
Importance level C7	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,25	3,00	0,60	1,00	**0,617**

Engineering											
Importance level C1	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	0,00	3,75	0,63	1,00	**0,542**
Importance level C2	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(0.75, 1, 1)	0,25	5,25	0,88	1,00	**0,708**
Importance level C3	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.75, 1, 1)	(0, 0.25, 0.5)	(0.75, 1, 1)	(0.25, 0.5, 0.75)	0,00	4,25	0,71	1,00	**0,569**
Importance level C4	(0.75, 1, 1)	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	0,00	4,25	0,71	1,00	**0,569**
Importance level C5	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	0,25	4,00	0,67	1,00	**0,639**
Importance level C6	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	0,00	3,25	0,54	1,00	**0,514**
Importance level C7	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	0,25	4,50	0,75	1,00	**0,667**

Governmental											
Importance level C1	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.75, 1, 1)	0,50	4,75	0,79	1,00	**0,764**
Importance level C2	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	0,25	4,75	0,79	1,00	**0,681**
Importance level C3	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	0,25	4,75	0,79	1,00	**0,681**
Importance level C4	(0.5, 0.75, 1.0)	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	0,25	4,50	0,75	1,00	**0,667**
Importance level C5	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	0,00	3,75	0,63	1,00	**0,542**
Importance level C6	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.75, 1, 1)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	0,00	4,00	0,67	1,00	**0,556**
Importance level C7	(0.5, 0.75, 1.0)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1.0)	(0.5, 0.75, 1.0)	(0, 0.25, 0.5)	(0.5, 0.75, 1.0)	0,00	3,75	0,63	1,00	**0,542**

Overall					
Importance level C1	0,00	11,25	0,865	1,00	**0,622**
Importance level C2	0,25	14,00	1,077	1,00	**0,776**
Importance level C3	0,00	11,75	0,904	1,00	**0,635**
Importance level C4	0,00	11,75	0,904	1,00	**0,635**
Importance level C5	0,00	10,75	0,827	1,00	**0,609**
Importance level C6	0,00	10,50	0,808	1,00	**0,603**
Importance level C7	0,00	11,25	0,865	1,00	**0,622**

	Contractors	RANK	Engineering	RANK	Governmental	RANK	Overall	Ranking
Importance level C1 - technological	0,517	6	0,542	6	0,764	1	0,622	4
Importance level C2 - financial, economic	0,683	1	0,708	1	0,681	2	0,776	1
Importance level C3 - policy, regulatory	0,517	6	0,569	4	0,681	2	0,635	2
Importance level C4 - organizational	0,533	4	0,569	4	0,667	4	0,635	2
Importance level C5 - perf. Ind.	0,533	4	0,639	3	0,542	6	0,609	6
Importance level C6 - awareness	0,633	2	0,514	7	0,556	5	0,603	7
Importance level C7 - operational	0,617	3	0,667	2	0,542	6	0,622	4

		Contractors					Engineering					Governmental					Overall				
		crisp	**rank**	cat cr	mult	**rank**	crisp	**rank**	cat cr	mult	**rank**	crisp	**rank**	cat cr	mult	**rank**	crisp	**rank**	cat cr	mult	**rank**
C1	TE1	0,533	**14**	0,517	0,276	**19**	0,500	**23**	0,542	0,271	**24**	0,556	**11**	0,764	0,424	**5**	0,590	**16**	0,622	0,367	**15**
	TE2	0,533	**14**	0,517	0,276	**19**	0,500	**23**	0,542	0,271	**24**	0,639	**4**	0,764	0,488	**1**	0,590	**16**	0,622	0,367	**15**
	TE3	0,533	**14**	0,517	0,276	**19**	0,528	**16**	0,542	0,286	**20**	0,528	**20**	0,764	0,403	**8**	0,590	**16**	0,622	0,367	**15**
	TE4	0,550	**12**	0,517	0,284	**18**	0,528	**16**	0,542	0,286	**20**	0,556	**11**	0,764	0,424	**5**	0,609	**11**	0,622	0,379	**12**
C2	PR1	0,667	**6**	0,683	0,456	**3**	0,653	**8**	0,708	0,462	**4**	0,556	**11**	0,681	0,378	**9**	0,641	**7**	0,776	0,497	**2**
	PR2	0,683	**5**	0,683	0,467	**2**	0,792	**1**	0,708	0,561	**1**	0,556	**11**	0,681	0,378	**9**	0,673	**3**	0,776	0,522	**1**
C3	FE1	0,667	**6**	0,517	0,344	**11**	0,556	**13**	0,569	0,316	**17**	0,681	**2**	0,681	0,463	**2**	0,654	**5**	0,635	0,415	**5**
	FE2	0,417	**26**	0,517	0,215	**26**	0,500	**23**	0,569	0,285	**22**	0,556	**11**	0,681	0,378	**9**	0,545	**27**	0,635	0,346	**25**
	FE3	0,750	**3**	0,517	0,388	**5**	0,639	**9**	0,569	0,364	**10**	0,500	**25**	0,681	0,340	**16**	0,609	**11**	0,635	0,386	**10**
	FE4	0,483	**23**	0,517	0,250	**24**	0,375	**28**	0,569	0,214	**28**	0,625	**5**	0,681	0,425	**4**	0,545	**27**	0,635	0,346	**25**
C4	OR1	0,350	**28**	0,533	0,187	**28**	0,681	**5**	0,569	0,388	**8**	0,472	**28**	0,667	0,315	**19**	0,558	**24**	0,635	0,354	**21**
	OR2	0,500	**19**	0,533	0,267	**22**	0,472	**27**	0,569	0,269	**26**	0,528	**20**	0,667	0,352	**13**	0,551	**26**	0,635	0,350	**22**
	OR3	0,650	**8**	0,533	0,347	**10**	0,528	**16**	0,569	0,301	**19**	0,542	**19**	0,667	0,361	**12**	0,609	**11**	0,635	0,386	**10**
	OR4	0,767	**2**	0,533	0,409	**4**	0,639	**9**	0,569	0,364	**10**	0,681	**2**	0,667	0,454	**3**	0,744	**1**	0,635	0,472	**3**
C5	PI1	0,467	**25**	0,533	0,249	**25**	0,528	**16**	0,639	0,337	**14**	0,514	**24**	0,542	0,278	**26**	0,558	**24**	0,609	0,340	**28**
	PI2	0,383	**27**	0,533	0,204	**27**	0,694	**4**	0,639	0,444	**6**	0,528	**20**	0,542	0,286	**24**	0,603	**14**	0,609	0,367	**14**
	PI3	0,717	**4**	0,533	0,382	**6**	0,486	**26**	0,639	0,311	**18**	0,500	**25**	0,542	0,271	**27**	0,564	**23**	0,609	0,344	**27**
	PI4	0,500	**19**	0,533	0,267	**22**	0,514	**21**	0,639	0,328	**15**	0,528	**20**	0,542	0,286	**24**	0,571	**22**	0,609	0,347	**24**
C6	AW1	0,483	**23**	0,633	0,306	**17**	0,667	**6**	0,514	0,343	**13**	0,625	**5**	0,556	0,347	**14**	0,603	**14**	0,603	0,363	**18**
	AW2	0,500	**19**	0,633	0,317	**15**	0,514	**21**	0,514	0,264	**27**	0,625	**5**	0,556	0,347	**14**	0,577	**21**	0,603	0,348	**23**
	AW3	0,533	**14**	0,633	0,338	**13**	0,639	**9**	0,514	0,328	**15**	0,556	**11**	0,556	0,309	**20**	0,615	**10**	0,603	0,371	**13**
	AW4	0,500	**19**	0,633	0,317	**15**	0,528	**16**	0,514	0,271	**23**	0,556	**11**	0,556	0,309	**20**	0,590	**16**	0,603	0,355	**20**
C7	OP1	0,783	**1**	0,617	0,483	**1**	0,764	**2**	0,667	0,509	**2**	0,556	**11**	0,542	0,301	**23**	0,667	**4**	0,622	0,415	**6**
	OP2	0,550	**12**	0,617	0,339	**12**	0,667	**6**	0,667	0,444	**5**	0,569	**10**	0,542	0,308	**22**	0,641	**7**	0,622	0,399	**8**
	OP3	0,617	**9**	0,617	0,380	**7**	0,625	**12**	0,667	0,417	**7**	0,583	**9**	0,542	0,316	**18**	0,622	**9**	0,622	0,387	**9**
	OP4	0,600	**10**	0,617	0,370	**8**	0,708	**3**	0,667	0,472	**3**	0,778	**1**	0,542	0,421	**7**	0,699	**2**	0,622	0,434	**4**
	OP5	0,533	**14**	0,617	0,329	**14**	0,542	**15**	0,667	0,361	**12**	0,500	**25**	0,542	0,271	**27**	0,583	**20**	0,622	0,363	**19**
	OP6	0,567	**11**	0,617	0,349	**9**	0,556	**13**	0,667	0,370	**9**	0,597	**8**	0,542	0,323	**17**	0,647	**6**	0,622	0,403	**7**