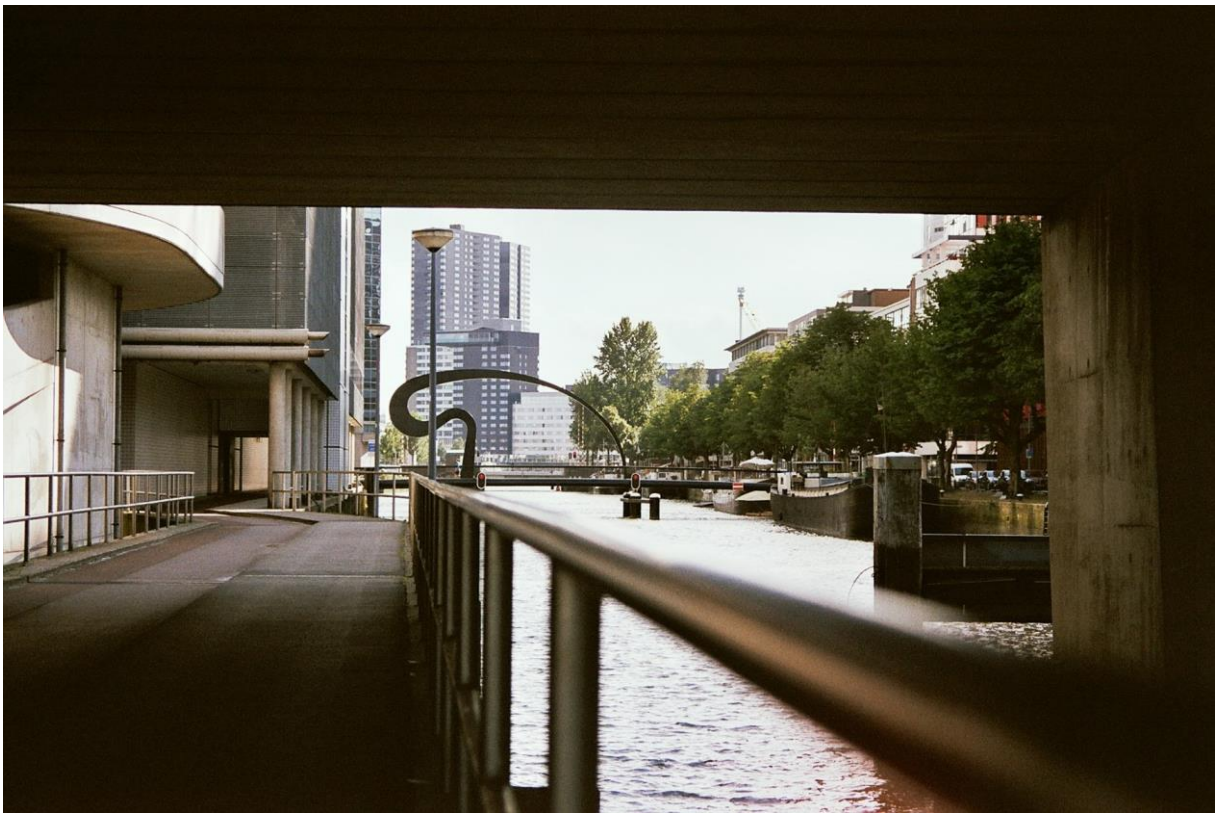
In search of the barriers and drivers for the implementation of a Circular Economy in Dutch infrastructure projects



Master thesis – Lennart van der Sande

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Cover image: some buildings and infrastructure assets in Rotterdam, the Netherlands. What will happen with these materials once these structures reach their end-of-life? Source: own work

In search of the barriers and drivers for the implementation of a Circular Economy in Dutch infrastructure projects

By

Lennart van der Sande

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Preface

This thesis concludes the Master of Science program 'Construction Management & Engineering' (CME) at the Delft University of Technology. The research was conducted during ten enjoyable months at Antea Group, one of the leading engineering and consultancy firms in the Netherlands.

During my studies, I acquired the knowledge and skills that were required to realise this final project. Looking back, it is no surprise that I conducted my thesis on the particular topic of Circular Economy (CE) in Dutch infrastructure projects. From an early age, I have always been fascinated by both by the built environment and by nature, playing with Lego for countless hours and making wooden structures. I also loved being in nature. While my studies enabled me to get more knowledgeable on constructing (civil engineering) works, it also made me more aware of the impact that the construction sector has on the environment. By conducting a study on the implementation Circular Economy in infrastructure projects (the aim of which is to construct while minimizing the environmental impact), this thesis gave me the opportunity to merge these two fields of interest.

The complexity of the task at hand became more clear to me over the course of my research. During the interviews I spoke with a lot of people who are working hard on the implementation of a Circular Economy in Dutch infrastructure projects, all looking for a better understanding of how this can be achieved. While there is no single answer to how this task may be solved, I hope that my findings are a helpful contribution.

The realisation of this thesis has been made possible by a great number of people. First of all, I would like to thank my graduation committee for their guidance throughout the past months. Professor Hertogh, thank you for your inspirational ideas and insights during the meetings. Daan, you have been a great supervisor and went to great lengths to help me finish this thesis in time, for which I cannot thank you enough. Mark, thank you for your enthusiasm and the time you invested in me. Your comprehensive feedback on my work, guidance in writing of the report and other aspects of writing a thesis have been of great help. Jasper, thanks for your time and the 'sparring sessions' we had, both via phone and at office. Moreover, I would like to thank the people of Antea Group, especially the Contracts department in Capelle aan den IJssel for providing a workspace and an excellent learning environment. Many thanks to my fellow graduates at the 'CME graduation office' at the CEG faculty in Delft. The countless coffees and chats have been of great help and a welcome distraction. Moreover, I would like to thank all the people I interviewed for sharing their time and knowledge with me.

Lastly, I would like to thank the people who supported me during the last years of my studies. To my friends I grew up with and the ones I got to know in Delft: thanks for all your support and all the great times. To my mountain biking mates I made countless trips with to Belgium, France, Germany and in the Netherlands: thanks guys. These trips were all amazing experiences and enabled me to start the weeks again with new energy to work on this thesis. And last but not least, I want to thank my parents, Rob and Margreth, and my sister, Mado for their love and support.

Lennart van der Sande
Rotterdam, August 2019

Summary

Introduction

In order to limit global warming, the Paris Agreement has been established. The central aim of this agreement is to strengthen the global response in limiting the *"increase in the global average temperature [by 2100] to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels"* (United Nations, 2015, p. 3). This will be done by, amongst other measures, lowering of CO_2 emissions. The Netherlands also signed the agreement. Studies have shown that adoption of a Circular Economy (CE) may contribute to about half of the required CO_2 reductions to meet the Paris Agreement goals (Circle Economy & Ecofys, 2016, pp. 4-5). However, focus should also be on other measures to reduce the remaining half of the CO_2 'emission surplus', but these are outside the scope of this research.

The Dutch government wants to lower the CO_2 emissions by adopting a CE before 2050 and has established 'Transition Agendas' for the five main economic sectors: Biomass and food, Plastics, Manufacturing industry, Construction and lastly, Consumer goods. The Dutch construction sector is responsible for 36% of the national CO_2 emissions, 50% of the national material usage and 40% of the total energy consumption (Schoolderman et al., 2014). Implementation of a CE in this sector may significantly lower these CO_2 emissions and material usage (Circle Economy & Ecofys, 2016). Until now, only limited progress has been made on the implementation of CE in the Dutch construction sector (Rijksvastgoedbedrijf, 2018). The progress made thus far focussed mainly on the building sector. In the other part of the Dutch Construction sector, the infrastructure sector, CE is still in its infancy (Crielaard & Dijcker, 2018).

Despite the establishment of several agreements that have the aim to accelerate the transition towards a CE in Dutch infrastructure projects, progress is slow. Several barriers are assumed to hamper this transition. Opposed to barriers, drivers (or enabling/stimulating factors) may accelerate the transition towards a CE. Which barriers and drivers apply to the implementation of CE in Dutch infrastructure projects, is unknown. The practical problem to be solved in this research is searching these barriers and drivers, as this is considered the first step in respectively overcoming and enhancing them. The following research question has been formulated:

"What are the barriers and drivers that respectively need to be overcome and enhanced in order to accelerate the implementation of a Circular Economy in Dutch infrastructure projects?"

Research approach

For the research question to be answered, the research is divided into four phase. Phase I consists of a literature review, during which the most frequently appearing categories of barriers and drivers for the implementation of CE have been studied. A total of 26 articles were considered, which formed the basis for the development of a literature-based framework of CE barrier- and driver-categories. This framework provides insight in the generally applicable categories of barriers and drivers for the implementation of CE. In phase II, the research methodology has been determined. Semi-structured interviews were found to be the appropriate research type. Subsequently, respondents were selected and an interview guide was developed. The literature-based framework provided the basis in formulating the interview questions. In phase III of the research, the barriers and drivers as experienced by the respondents are presented. A discussion on both the practical and scientific implications of this research is presented in phase IV. Further insights and the limitations to this research are also discussed in this part. This research has been conducted in collaboration with Antea Group, an engineering and consultancy firm specialised in, among other types of projects, infrastructure projects in the Netherlands.

Results

For the research question to be answered, a literature-based framework of CE barrier- and driver-categories has been developed. The framework provided the basis for the development of the questions for the interviews, during which respondents from a variety of stakeholders involved in Dutch infrastructure projects were asked what they think are the barriers or drivers for the implementation of CE in Dutch infrastructure projects. A total of 15 interviews have been conducted, from which a total of 135 barriers to, and 72 drivers of the implementation of CE in Dutch infrastructure projects were derived.

The most frequently mentioned barriers relate to the procurement of infrastructure projects, the aversion of risks and the higher costs of secondary or circular materials as compared to 'virgin' materials. Moreover, the lack of a clear and unambiguous definition for CE, the lack of consensus on the level of circularity of the different R-strategies and how

circularity should be measured were found to be barriers. Several respondents indicated intra-organisational barriers which related to resources for the implementation of CE being unavailable, or that the certain department of the organisation are unwilling to change or cooperate. Lastly, respondents indicated that the current standards and guidelines are unfit and sometimes even obstruct the use of secondary or circular materials.

The drivers that were mentioned most frequently, often require the government to take steps. The driver that was mentioned most frequently was that the government should develop more binding legislation and regulations on the use and application of circular materials in infrastructure projects. As the commissioner of the majority of infrastructure projects in the Netherlands, the government providing more room for circular innovations or pilot projects was mentioned as a driver. Doing so may act as a catalyst for CE; the successful application of circular materials or projects takes away a perceived risk or 'fear for the unknown' and has already proven to increase the demand for such materials or projects. Another frequently mentioned driver is financial support by the government for the development of circular innovations. Additionally, sharing of knowledge and information on the implementation of CE by both public and private organisations has been indicated to be a driver. Drivers that do not comprise solely of actions for the government are related to standardisation of infrastructural assets.

The literature based framework of CE barrier- and driver-categories was found to be applicable to Dutch infrastructure projects. In addition, the research findings have been put into larger context. Moreover, the applicability of the identified barriers and drivers for the implementation of CE in infrastructure projects in other European countries has been studied. It has been concluded that the majority of barriers and drivers that apply to infrastructure projects in the Netherlands can also be applied to other European countries.

Conclusion

Based on the findings of this research, several conclusions are drawn in order to answer the main research question:

"What are the barriers and drivers that respectively need to be overcome and enhanced in order to accelerate the implementation of a Circular Economy in Dutch infrastructure projects?"

In section 5.2 has been determined what the selection criteria for the barriers and drivers that respectively need to be overcome and enhanced in order to accelerate the implementation of a Circular Economy in Dutch infrastructure projects are. These are the top-3 most frequently mentioned barriers and the top-3 most frequently mentioned drivers.

The barriers that were mentioned most frequently mentioned by the respondents relate to the procurement of infrastructure projects, the aversion of risks, the high costs of circular or secondary materials as compared to primary or 'virgin' materials and the lack of a clear, unambiguous definition for CE (a total count of four, as two barriers share the third place).

The barrier related to procurement prevents the implementation of CE in an early stage. Circularity or the implementation of CE is a requirement in only a limited number of infrastructure tenders. In the tenders that are labelled as 'circular', awarding of the tender is still often largely based on lowest price and minimisation of traffic hindrance, not on circularity. This poses a barrier for the implementation of CE in infrastructure projects. Risk aversion is paramount in Dutch infrastructure projects as structural (or premature) failure of infrastructure assets can result in fatalities and enormous economic costs. Clients are therefore hesitant in adopting circular innovations or solutions in their projects and prefer to stick to the conventional, 'known' way of working. Whereas the Dutch infrastructure sector is often labelled as being conservative, this can more likely be ascribed to the aversion of risks.

The costs of circular or secondary materials as compared to primary or 'virgin' materials was often mentioned as a barrier. These costs result from the additional expenses for transportation and possible processing of secondary materials, along with the lack of economies of scale for secondary materials. Given the higher costs for secondary or circular materials, using primary or virgin materials in infrastructure projects is the preferred option from a financial point of view. Moreover, the lack of a clear, unambiguous definition for CE has also been considered an important barrier as it prevents a clear dialogue and a common goal which is worked towards.

The majority of drivers that were mentioned most frequently by the respondents require the Dutch government to take the lead. These drivers relate to the Dutch government developing more binding legislation and regulation on the use and application of circular materials in infrastructure projects, providing more room for circular innovations

or pilot projects, providing more financial support for circular innovations and the government taking the lead in establishing non-binding agreements (i.e. 'Asfalt-Impuls' and 'Betonakkoord'). Moreover, the government should award its tenders more heavily on circularity. The final driver on the third place (the third place is shared by a total of five drivers) relates to standardisation of infrastructural assets, in which the government does not necessarily have to take the lead.

Limitations and recommendations for future research

This research faced several limitations, which may be improved in future studies. The first limitation relates to the external validity of the interview results. While effort has been put in minimising the room for subjectivity, some interpretation by the researcher will have coloured the research outcomes. Additionally, while a one-hour interview seems like a sufficient amount of time for all the interview questions, in practice time proved to run out very soon, which may have resulted in not identifying certain barriers or drivers.

Recommendations for future research relate to a more extensive study into the different barriers and drivers for the implementation of CE in Dutch infrastructure projects, as experienced by the different types of stakeholders. At the time of writing this report, only one circular infrastructure project was realised in the Netherlands. A study of several cases of circular infrastructure projects can likely be conducted soon and provides an opportunity to study if the identified barriers and drivers were in fact experienced. And if so, how these were overcome or enhanced. The final practical recommendation for this research is the organisation of a session in which the barriers and drivers identified in this research can be discussed with practitioners from the sector.

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1. INTRODUCTION

1.1. Circular Economy explained

Circular Economy – The cause & concept

Global warming is increasingly gaining attention. Weather extremes such as heat waves, droughts, hurricanes and heavy downpours are a result of the rising temperature and they are becoming ever more frequent (IPCC, 2018). The current world population of 7.6 Billion is expected to rise to 9.8 billion in 2050 (United Nations, 2017). As the world population grows and incomes rise, so does the consumption of resources to provide energy, food, housing and infrastructure (McKinsey Global Institute, 2011).

In order to limit global warming, the Paris Agreement has been established. This agreement is part of the United Nations Framework Convention on Climate Change (UNFCCC) and was signed by 195 countries (United Nations, 2015). The main goal of the Paris Agreement is to keep the global temperature rise "well below" two degrees, with the aim to limit it to 1.5°C by 2100 (compared to pre-industrial levels). This is done by reducing the amount CO_2-equivalents[1] (hereafter: CO_2e) that are emitted.

In order to meet these goals, our predominantly 'linear' consumption patterns need to change, as they are unsustainable[2]. In a linear economy, raw materials or finite resources are extracted from the earth and converted into products. These products fulfil a certain purpose during their life-cycle, but are disposed of as low-quality waste once they reach their end-of-life. The Ellen MacArthur Foundation (2013) defines this as the *"take, make and dispose principle"* (p. 6). Over the last years, a transition is being proposed to move from the current linear economy towards a Circular Economy (CE). In a CE, products are no longer disposed at their end-of-life, but kept in use (Ellen MacArthur Foundation, 2013). Mentink (2014), has defined CE as *"an economic system with closed material loops"* (p.14). In a study by Kirchherr, Reike, & Hekkert (2017), 114 definitions of the CE were analysed. The main aim of the implementation of CE is to realise economic prosperity, followed by environmental quality. The impact on social equity and future generations is barely mentioned. Based on the 114 definitions, the authors have developed their own, all-encompassing definition for CE: *"A circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and be-yond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations."* (Kirchherr, Reike, & Hekkert, 2017, p. 224).

The contribution that a CE could make to achieving the Paris Agreement and Sustainable Development Goals have been explored by the Circle Economy and Ecofys (2016). They state that in order to limit temperature rise to 1.5°C, the annual global emission of CO_2e in 2030 needs to be cut from 65 to 39 billion tonnes (the annual global emissions amounted 48 billion tonnes CO_2e in 2010, and is rising each year). Current commitments of countries will only result in a partial cut of these emissions; an 'emission surplus' remains present. The CE may reduce this CO_2 emission surplus by about half (Circle Economy & Ecofys, 2016, pp. 4-5). The CE is therefore an important instrument for lowering of global CO_2 emissions. Nevertheless, focus should also be on other measures to reduce the remaining emission surplus (Circle Economy & Ecofys, 2016, pp. 4-5).

Circular Economy in the global construction sector

Of all sectors, the construction sector is considered to be the largest global consumer of resources and raw materials (Wit et al., 2018). The construction sector thus has a large effect on economies, societies and the environment, and many other industries adopt value with or by means of buildings or other constructed assets. Global construction accounts for 6% of the global GDP, but also emits 25-40% of the world's total CO_2 emissions (World Economic Forum & The Boston Consulting Group, 2016). Within the global construction sector, the CE has not been widely adopted yet (Adams et al., 2017).

Implementation of CE in the construction sector may significantly lower CO_2 emissions. The CO_2 emissions from a building or structure can be divided into operational and embodied impacts. Operational impacts are a result of the

[1] CO_2-equivalent: a measure to compare the emissions of various greenhouse gasses, based upon their global warming potential.

[2] Sustainability has been defined by the Brundtland Commission as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland et al., 1987, p. 41).

required energy for operating of a structure during the use phase (i.e. lighting, operation). Embodied impacts on the other hand, are the result from processes in the life cycle of building materials (e.g. production, refurbishment, and end-of-life) (Rasmussen et al., 2018; Shadram & Mukkavaara, 2018). As embodied impacts make up a significant proportion of the total life cycle impacts (for buildings this impact often exceeds 50%) (Cabeza et al., 2014), addressing these impacts is vital to lower the CO_2 emissions of the construction sector. A solution to reduce the embodied CO_2 emissions is the use of secondary materials[3] for the production of construction materials (Ingrao et al., 2014; Malmqvist et al., 2018).

According to Wit et al. (2018), the global economy is currently only 9.1% circular. Given the significant amount of materials used and CO_2 emitted by the construction sector, the effect on the world economy's level of circularity due to large-scale implementation[4] of CE in the construction sector may be significant.

Circular Economy in the Netherlands

The Netherlands is one of the 195 countries that signed the Paris Agreement, and developed national (interim-)goals to reduce the amount of CO_2e emissions in 2020 by 20% compared to 1990 levels (Rijksoverheid, 2016). In September 2016, the Dutch Government launched the programme 'A Circular Economy in The Netherlands by 2050' (Dijksma & Kamp, 2016). The goal of this programme is to establish a CE in The Netherlands before 2050. According to Bastein, Roelofs, Rietveld, & Hoogendoorn (2013), the CE could create 54.000 jobs in the Netherlands and boost the economy by €7.3 billion. Along with its social partners, the Dutch Government is aiming to achieve an interim goal in 2030 to use 50% less primary resources (Dijksma & Kamp, 2016a, pp. 13). By 2050, all resources should be used and reused efficiently, with a reduction of the net CO_2-e emissions to zero (Dijksma & Kamp, 2016a, pp. 13). If using primary resources is unavoidable, these should be mined sustainably, preventing any negative impact on both the social and physical environment. The importance of designing products and materials so that they can easily be reused, with minimal loss of value and a minimal amount of CO_2 emissions is underlined in the programme "A Circular Economy in the Netherlands by 2050".

As part of the programme, the Dutch Government has taken the initiative to reach an agreement with its social partners (companies, local governments, knowledge institutes and social organisations) on CE; the Natural Resources Agreement (in Dutch '*Grondstoffenakkoord*'). The document comprises of agreements to solely use reusable materials in the Dutch economy and was signed by both the Dutch Government and private companies (Ministerie van Infrastructuur en Waterstaat, 2017). The participating parties in the Natural Resources Agreement have established five Transition Agendas, the goal of which is to accelerate the transition towards a CE in The Netherlands. This is done by measures such as changing laws and regulations, developing market mechanisms that enhance circularity or to promote circularity amongst producers and consumers (Dijksma & Kamp, 2016). Five Transition Agendas are distinguished, these are:

1. Biomass and food
2. Plastics
3. Manufacturing industry
4. Construction sector
5. Consumer goods

For all five Transition Agendas, strategic development goals have been formulated. These strategic goals provide more specific development goals for the different sectors. An example of a strategic development goal for the construction sector as formulated in the Transition Agenda Circular Construction-Economy (in Dutch: 'Transitie-Agenda Circulaire Bouweconomie') is the reduction of CO_2 emissions to half of the current levels by 2030 (Nelissen et al., 2018). Moreover, agendas for investments, social effects, knowledge-development & -sharing, and innovation projects are included. The focus of this study will be on the Dutch construction sector.

Circular Economy in the Dutch construction sector

The Dutch construction sector is responsible for 36% of the national CO_2 emissions, contributes to 50% of the national material usage and accounts for 40% of the total energy consumption (Schoolderman et al., 2014). Considering the

[3] Secondary materials: by-products and waste material

[4] Implementation of CE: the process of making the Circular Economy active or effective. In the literature, the "transition towards a Circular Economy" or similar definitions are often used.

large amounts of CO_2 emitted by the Dutch construction sector and the vast amount of (raw) materials that are used, adopting the CE may significantly lower the Netherlands' climatological impact.

The main goals of the implementation of CE in the Dutch construction sector have been described in the Transition Agenda Circular Construction-Economy (Nelissen et al., 2018). In short, the goals are to re-use[5] all materials and resources, to reduce the net CO_2 emissions to zero and no longer use fossil fuels (Nelissen et al., 2018, pp. 7-8). In the Dutch construction sector, CE has not been fully embedded yet (Schut et al., 2015). The Dutch construction sector can be split into two parts (Nelissen et al., 2018), as can be seen in Figure 1.

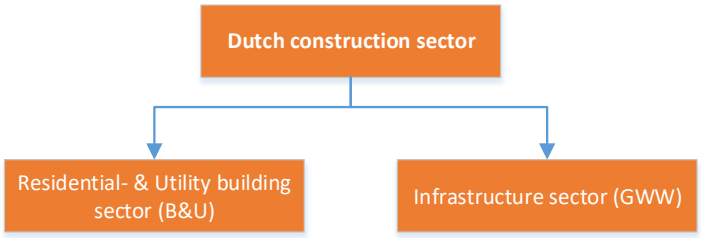

Figure 1 – Dutch construction sector breakdown. Source: Nelissen et al. (2018)

Limited progress has been made on the implementation of CE in the Dutch construction sector (Rijksvastgoedbedrijf, 2018). The progress that has been made focussed mainly on the buildings sector. In the Dutch infrastructure sector, CE is still in its infancy (Crielaard & Dijcker, 2018). Whereas in some sectors material scarcity is one of the main reasons to implement CE, this is not the case for the construction sector as construction materials and the raw materials to produce them are abundantly available (Rijkswaterstaat, 2018). Reason for implementation of CE in the construction sector is to lower the embodied CO_2 emissions, which *may* be done by the use of secondary materials for the production of construction materials (Ingrao et al., 2014; Malmqvist et al., 2018). Emphasis is put on the word 'may', as in some cases the environmental impact of using a secondary material or R-strategy (Table 2) can be higher as a result of the processes required to transport the materials to a suitable state or location for reuse than the impacts resulting from production of the primary material alternative or a 'lower-level' R-strategy (Gala et al., 2015; Geyer et al., 2016; Vadenbo et al., 2017). Assessment of the life cycle impacts are therefore required to determine whether the use of secondary materials or adoption of a R-strategy actually helps to mitigate climate change.

Definition of terms

Several terms from the title of this research need explaining prior to describing the problem definition and research question. The title of this research is: "In search of the **barriers** & **drivers** for the **implementation** of **Circular Economy** in **Dutch infrastructure projects**". Definitions for the words in bold of the title are presented in Table 1.

Table 1 – Definitions of relevant terms

Term	Definition
Barriers	Factors that impede or hinder change. Other commonly used terms for 'barriers' are: challenges, obstacle, hindrances (Kirchherr et al., 2018).
Drivers	*"Factors which cause a particular phenomenon to happen or develop"* (Oxford Dictionary, 2019a). Another commonly used term in the literature is 'enablers'.
Implementation	*"The process of putting a decision or plan into effect; execution"* (Oxford Dictionary, 2019b). In this research this means: the process of putting the Circular Economy into effect. In the literature, the "transition towards a Circular Economy" or synonyms are often used.
Circular Economy	According to Yuan et al. (2006), *"there is no commonly accepted definition of Circular Economy"* (p. 15). More recent studies by Lieder & Rashid (2016) also conclude that there are many different ways to define CE. In this report, the definition for CE as developed by Kirchherr, Reike, & Hekkert (2017) will be used: *"The circular economy […] replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, […] with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations"* (p. 229).
Dutch infrastructure	The term 'infrastructure' is difficult to define and several types of infrastructure exist: energy, transportation, water, telecommunications and social infrastructure (Grimsey & Lewis, 2002). With the term 'Dutch infrastructure' are meant the transportation infrastructure assets in the Netherlands that comprise of realising road networks, bridges, viaducts, tunnels, waterways and dykes.

[5] Re-use: application of a material or product that *"hardly needs any adaptions and works as new, with the same purpose, without refurbishment and without rework or without repair."* (Reike et al., 2018, p. 255). For the entire overview of the different R-imperatives (re-use, repair, recycle, etc.) and definitions, see Table 2 – 10-R Model, value retention options & definitions – Source: Reike et al. (2018)

Project	The Project Management Institute defines a projects as *"a temporary endeavour undertaken to create a unique products, service or result"* (Project Management Institute, n.d.). A project is 'temporary' as it has a defined beginning and end in time, and therefore defined scope and resources. A project is 'unique' in that it is not a routine operation, but a specific set of operations designed to accomplish a singular goal.

Despite having provided definitions for the terms, ambiguity remains present for the term 'Circular Economy'. This ambiguity can best be explained using an example from the Dutch construction sector. In the Dutch construction sector, 95% of Construction- & Demolition Waste (C&D Waste) is being recycled (Spijker & van der Grinten, 2014). It could therefore be argued that the Dutch construction sector is already a Circular Economy, as material loops are largely closed; little to no materials are disposed of as waste. However, recycling of the C&D Waste mainly involves the application of initially high-grade materials into low-grade purposes, such as granulated concrete in road foundations. Large volumes of primary (or virgin) material are still required to develop the materials that are used in Dutch building- and infrastructure projects (Crielaard & Dijcker, 2018).

Recycling is just one of several different 'R-strategies' (also referred to as R-imperatives or 'resource value retention options'). An interdisciplinary literature study by Reike et al. (2018) found that many different definitions and models of these R-strategies exist, many of which are unambiguous or lack clear hierarchies. Based on the study a single systematic typology of ten hierarchically listed R-strategies was developed; the 10-R model. The model includes two preventive options and eight value retention options, presented in Table 2.

Table 2 – 10-R Model, value retention options & definitions – Source: Reike et al. (2018)

Circularity level	R-strategy	Definition
High	R0 – Refuse (preventive)	Prevent the use of resources or materials
	R1 – Reduce (preventive)	Use less resources or materials
	R2 – Re-use/Re-sell	Re-use/re-sell (parts of) material or products without the loss of value
	R3 – Repair	Repair/maintain a material/product so it can fulfil the same functionality
	R4 – Refurbish	Renovate material or product
	R5 – Remanufacture	Make new products from old materials
	R6 – Re-purpose	Reuse products or materials in a different purpose
	R7 – Recycle	Process and reuse materials
Low	R8 – Recover	Generate energy by burning the products or materials
	R9 – Re-mine	Landfill products or materials

The overview of R-strategies as listed Table 2 puts the recycling level of 95% for Dutch C&D Waste in a different perspective. In terms of circularity, recycling is a relatively poor strategy, being only more circular than recovering or re-mining of materials. As a general rule of thumb for the 10-R Model holds, the higher the R-strategy, the lower the embodied CO_2 emissions as fewer resources and materials are required to turn materials back into construction materials. However, again, the life cycle impacts should be assessed in order to determine whether the use of secondary materials or adoption of a R-strategy actually has a positive environmental impact.

1.2. Problem definition

Problem background

The studied articles in the explorative literature review indicate that the Dutch government and construction industry consider the Circular Economy (CE) as an important instrument to limit global climate change and reach a sustainable world. Global implementation of CE is still in the early stages; focus lies mainly on recycling rather than high-quality re-using of materials (Ghisellini et al., 2016). While the Netherlands is considered by some as a pioneer in circularity (van Buren, Demmers, van der Heijden, & Witlox, 2016), it too is still far away from reaching a CE (Dijksma & Kamp, 2016).

As indicated in Chapter 1.1, the construction sector accounts for a significant share of material use, energy consumption and CO_2 emissions, both on the global and national level. Implementation of the CE in the construction sector may significantly lower the global use of materials, energy consumption and CO_2 emissions, hereby contributing in meeting the Paris Agreement climate goals. Despite that the CE is gaining increasing attention amongst both scholars and practitioners in the Western World (Murray, Skene & Haynes, 2017; Reike, Vermeulen & Witjes, 2018), only limited research has been conducted on the implementation of CE in the construction sector. Within the Dutch construction sector, CE has not been thoroughly embedded yet (Economisch Instituut voor de Bouw, 2015; Schut et al., 2015). The Dutch construction sector can be split into the building- and infrastructure sector. Regarding circularity,

differences exist between these sectors. Compared to the building sector, the infrastructure sector is lagging behind in implementing CE. As of today, several circular building projects have been completed, such as The Edge (Deloitte, 2015), Park 20|20 (Park 20|20, n.d.) and CIRCLE (ABN AMRO, 2017). The only circular infrastructure project that has been realised is the circular viaduct in Kampen, the Netherlands (Rijkswaterstaat, 2019). Yet this involved a relatively small-scale project. Large-scale circular infrastructure projects have not yet been realised in the Netherlands. This raises the question which barriers hinder the implementation of CE in Dutch infrastructure projects.

Practical problem

The importance and potential of implementing a Circular Economy in the Dutch construction sector has been acknowledged by a large number of public and private parties (Dijksma & Kamp, 2016; Nelissen et al., 2018). The construction sector significantly contributes to the total Dutch CO_2 emissions (36%), material use (50%) and energy consumption (40%) (Schoolderman et al., 2014). Implementation of CE in the Dutch construction sector can greatly contribute in lowering the embodied CO_2 emissions and material use (Circle Economy & Ecofys, 2016). However, as of today, implementation of the CE in specifically the Dutch infrastructure sector is still in its infancy (Crielaard & Dijcker, 2018). For the required national CO_2 reduction goals to be achieved, the Dutch infrastructure sector should rapidly transition towards a CE.

In order to accelerate this transition, agreements such as the 'Green Deal Sustainable Infra 2.0' (in Dutch: 'Green Deal Duurzaam GWW 2.0') and CB'23 (Building Circular, in Dutch: 'Circulair Bouwen') have been established. The goal of these agreements is to develop sustainable solutions for infrastructure projects (by providing a platform in which members can share their knowledge and experience). Both agreements have been signed by both public and private parties. Dutch engineering & consultancy firm Antea Group also signed the Green Deal Sustainable Infra 2.0. as they want to improve their knowledge and services in the field of CE. Despite the establishment of several agreements that have the aim to accelerate the transition towards a CE in Dutch infrastructure projects, progress is slow. Several barriers are assumed to hamper this transition. Opposed to barriers, drivers (or enabling/stimulating factors) may accelerate the transition towards a CE. Which barriers and drivers apply to the implementation of CE in Dutch infrastructure projects, is unknown. The practical problem to be solved in this research is searching these barriers and drivers, as this is considered the first step in respectively overcoming and enhancing them.

Scope of research

Whereas several large-scale circular building projects have been realised in the Netherlands, large-scale circular infrastructure projects are yet to be completed. Adams et al. (2017) state that *"there is a significant body of literature on the drivers and benefits of circular economy [in general]; however, little research or wide- scale application has been undertaken within a construction context"* (p. 22). Moreover, the literature on CE in the construction & demolition sector that is available primarily focusses on the building sector. Studies on the barriers and drivers for the implementation of CE in infrastructure projects are yet to be conducted.

Adoption of identified CE barriers and drivers from other sectors towards infrastructure projects has been considered, but several authors mentioned that their findings may be very sector- or region-specific (Ghisellini, Ripa, & Ulgiati, 2018; Kirchherr et al., 2018). Moreover, the environmental and economic sustainability of a CE framework is very site-specific and depends on several factors such as material type, building elements, transport distances, economic and political context (Ghisellini et al., 2018). Therefore, several scoping decisions have been made. CE will be studied within the geographical boundaries of the Netherlands. The implementation of CE in the Dutch construction sector may contribute largely in lowering the national CO_2 emissions and material use is. While some progress on the implementation of CE in the buildings sector has been made, both in practice and academia, the implementation of CE in Dutch infrastructure projects is yet a relatively unexplored territory. My graduation internship at Antea Group enables me to shed light on the barriers and drivers that may hamper or stimulate the implementation of CE in infrastructure projects in the Netherlands.

The scope of this research is therefore limited to identifying the barriers to, and the drivers of the implementation of Circular Economy in infrastructure projects in the Netherlands.

1.3. Relevance of the study

Scientific relevance

Over the last decade, the amount of available scientific literature on Circular Economy has been rapidly increasing (Reike et al., 2018). However, despite the available literature, a gap seems to remain present between the theoretical

concept of the CE and its implementation into practice. Only a limited amount of literature on the barriers and drivers for implementation of CE in the construction sector is available (Adams et al., 2017). Moreover, the available articles provide contradicting finding on both the categories of CE barriers and drivers and, in some cases, the importance of these categories. Studies that focus on the implementation of CE in specifically the infrastructure sector are still non-existent. Several authors acknowledge that their findings are highly sector- or region-specific and may therefore not be adopted to infrastructure projects. This study aims to shed light on the relatively unexposed yet important topic of implementing CE in Dutch infrastructure projects, hereby making a modest yet important scientific contribution in this particular field.

Practical relevance

The implementation of CE in the construction sector has gained increasing attention over the last year (Nelissen et al., 2018). Vision documents such as the Transition Agenda Circular Construction (in Dutch: 'de Bouwagenda') and agreements such as the Green Deal Sustainable Infra 2.0' (in Dutch: 'Green Deal Duurzaam GWW 2.0') have been established. Whereas several large-scale circular building projects have been realised in the Netherlands, large-scale circular infrastructure projects seem to be lagging behind. In January 2019, the first circular viaduct in Kampen, the Netherlands was completed (Rijkswaterstaat, 2019). However, this involved a small project. In order to reach the Dutch CE goals, large-scale change is needed (Nelissen et al., 2018). Many companies in the Netherlands are working hard on the transition of the infrastructure sector towards the CE. Antea Group also aims to contribute to this transition, and has formulated the following requirements for this thesis:

1. The research should contribute to (a) the familiarity with, (b) knowledge of, and (c) support for Circular Economy within Antea Group.
2. The research should contribute to the transition of the Dutch infrastructure sector towards a Circular Economy.

By means of a Webinar, the findings from this research will be spread within Antea Group, hereby meeting the first requirement. The Webinar will be publicly accessible. By sharing of the attained knowledge regarding the drivers of, and barriers to the implementation of CE in Dutch infrastructure projects from a practice-based perspective, this research makes an important, yet modest contribution to the transition of the Dutch infrastructure sector towards a Circular Economy.

Societal relevance

For decades, sustainability measures with the aim to prevent global warming have been implemented. Yet so far, few measures have had a significant effect. Humanity has reached a point on which measures that limit global warming need to be taken, before it is too late. Circular Economy is seen as an instrument to limit global climate change and reach a sustainable world. Transitioning the sectors of the global economy towards CE may significantly reduce the energy consumption, material use and CO_2 emissions that are required to meet our climate goals. This study aims to solve a small part of this enormous puzzle, by focussing on the barriers to, and the drivers of the implementation of CE in Dutch infrastructure projects. Due to the size of the Dutch infrastructure sector and the large volume of material that are being used, the impact of CE implementation in the sector may be significant. Taking into consideration that the main goals of CE implementation are to limit material use and limit global warming, -which affects all of us-, the societal relevance of a study on this topic is deemed high.

1.4. Research questions

Research question

In order to provide an answer to the problem described in chapter 1.2, the following research question is formulated:

What are the barriers and drivers that respectively need to be overcome and enhanced in order to accelerate the implementation of a Circular Economy in Dutch infrastructure projects?

1. What are the general categories of barriers and drivers for the implementation of CE?
2. How can the barriers and drivers for the implementation of CE in Dutch infrastructure projects be identified?
3. What barriers and drivers for the implementation of CE in Dutch infrastructure projects are experienced by the practitioners of the sector?
4. To what extend are the identified barriers and drivers applicable to the implementation of CE in infrastructure projects in other European countries?

1.5. Research design

In order to reach the objective and find an answer to the research questions, the research has been divided in four main phases, namely: literature review, research methodology, results & analysis and a discussion. An overview of the report structure in relation to the research phases and the research questions is provided in Figure 2**.**

Phase I: literature review

In the first phase of the research, a literature review is conducted with the aim to gain insight in the current state of knowledge regarding the barriers and drivers for implementation of CE. The goal of this phase is to develop a literature-based framework that consists of the most frequently appearing CE barrier- and driver-categories in general. Hereby meaning that the framework applies to varying sectors. After the literature-based framework is developed, sub-question 1 can be answered.

Phase II: research methodology

In the second phase, the basis for selection of the research methodology is described. Semi-structured interviews have been found to be best applicable for this research. Along with describing the basis for selection of semi-structured interviews as the research methodology, respondents are selected. The literature-based framework of CE barrier- and driver-categories from phase I provides the basis for the interview questions. A total of 15 interviews are conducted, in which the goal is to ask respondents what they think are the barriers and drivers for the implementation of CE in specifically Dutch infrastructure projects. At the end of phase II, an answer to sub-question 2 can be given.

Phase III: results and analysis

In the third phase, the gathered data is presented and analysed. The findings from the literature and the interviews are presented and potential contrasts will be highlighted. Moreover, differences in experienced barriers or drivers by the different types of stakeholders are searched for. At the end of this phase, research question 3 can be answered.

Phase IV: Discussion

In the fourth and final phase of this research a discussion on the practical and scientific implications is presented. Additionally, further insights regarding the research and the limitations are discussed. At the end of this phase, sub-question 4 is answered.

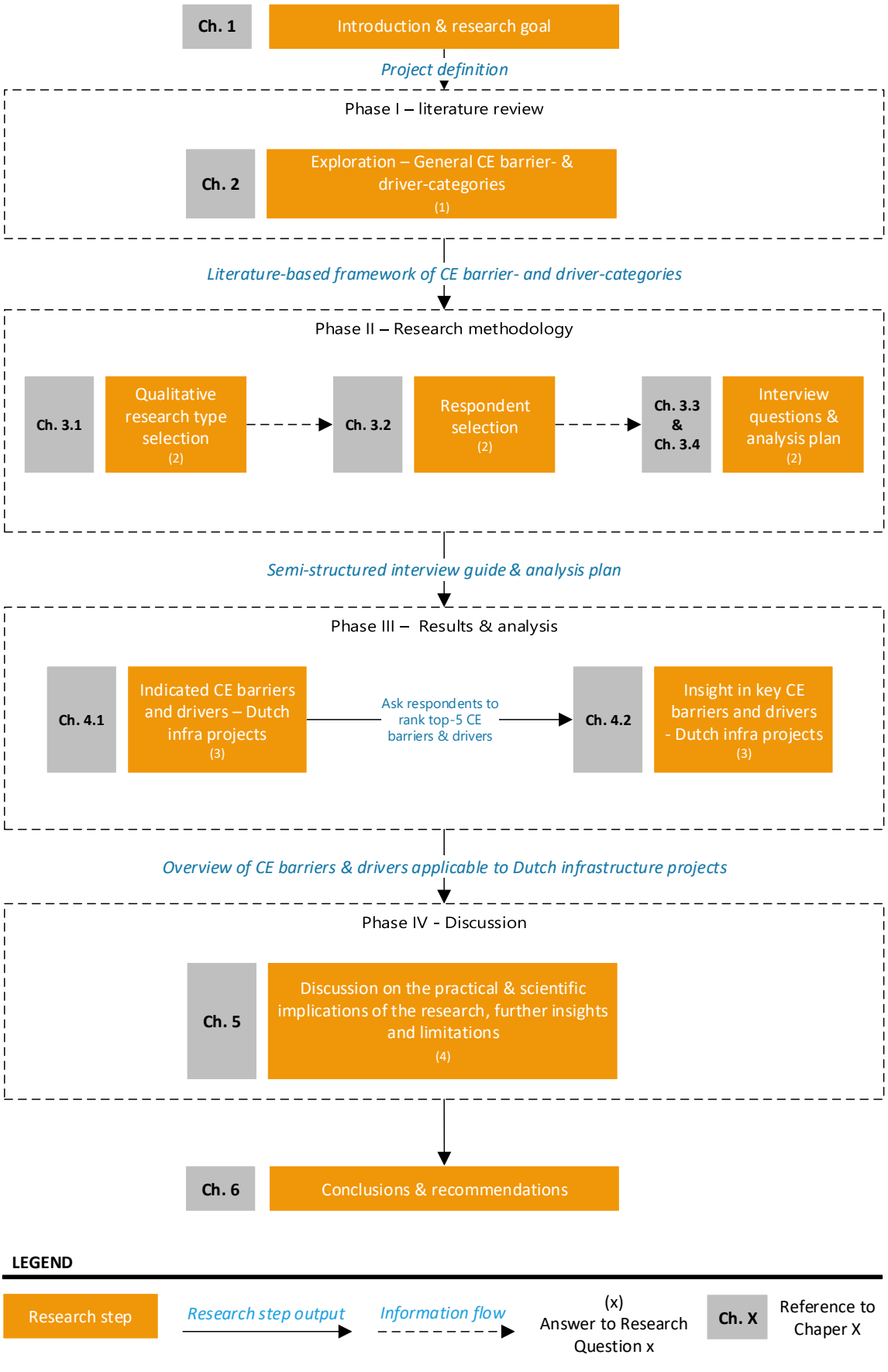

Figure 2 – Research design: Report structure and research steps. Source: own work

2. EXPLORATION

The goal of this part of the research is to identify the existing knowledge on the barriers to, and the drivers of the implementation of Circular Economy. The aim is to develop a literature-based framework of CE barriers and driver categories, required for conduction of the interviews (the approach of which will be discussed in Chapter 3). The framework will be developed based on the frequency with which certain CE barrier- and driver-categories are found in the literature. While it cannot be said that there is correlation between the frequency with which a certain CE barrier- or driver-category is mentioned and its importance, it is at least remarkable if certain categories are mentioned more frequently than others. This may be a reason to pay more attention during the interviews to certain categories than others.

In this chapter, sub-question 1: *"What are the general categories of barriers and drivers for the implementation of CE?"* will be answered. The definitions of the terms 'barriers', 'drivers', 'implementation' and 'Circular Economy' that are used in this report have been presented in Chapter 1.4. For this exploration, a desk research has been conducted, in the form of a literature review.

2.1. Literature review - approach

In order to gain an understanding of the state of knowledge regarding the barriers to, and the drivers of the implementation of Circular Economy, a literature review is conducted. For this literature review, data has been gathered by searching in Elsevier's Scopus. According to Falagas et al. (2008) Scopus has a wider subject and journal range than alternatives such as Google Scholar and Web of Science and is likely the best available tool for electronic literature search for articles published after 1995. The following search sensor has been used:

TITLE-ABS-KEY ("Circular Economy" AND barrier* OR challenge* OR driver* OR enabler*)

The search resulted in a total of 874 documents. No documents from earlier than 2005 exist. As can be seen in Figure 3, the amount of annually published articles on the topic has rapidly increased from the year 2014 onwards.

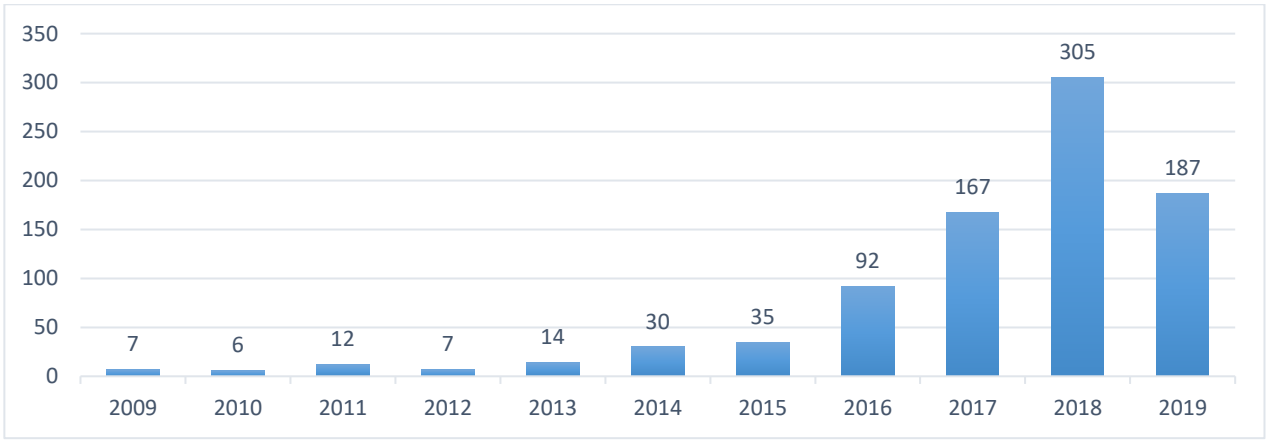

Figure 3 – Number of annually published documents in Scopus, based on search sensor. Source: own work

Due to the large amount of document results, several filters have been applied. Firstly, the subject area was limited to 'Engineering' and 'Environmental Science'. This was done under 'subject area' in Scopus and reduced the total body of documents from 874 to 639. The next step was to filter the document type. Only formal literature has been considered, document types such as books, research reports or editorials were left out of consideration, hereby decreasing the number of documents to 513. Thirdly, only documents written in the English language have been considered. 504 of the 513 documents are in English, the others in Chinese, Italian, Slovak and German. It was deemed too time-consuming to translate these documents, reason for which these non-English documents have been left out of consideration. Lastly, only post-2014 documents were studied. These filters resulted in a body of 469 documents. In the next step, the documents' abstract was read, asking the following question: *"Does the article address drivers of, or barriers to the Circular Economy in general, or in construction or infrastructure projects?"*.

If yes → keep document in sample
If no → exclude document from sample

This resulted in a total body of 26 relevant documents, which will be read entirely. An overview of these documents can be found in Appendix A – Literature review articles.

The 26 documents that are studied have the specific aim to determine the barriers to, and the drivers of the implementation of the Circular Economy in a particular sector or geographical region. Three types of sectors can be distinguished. The first sector type contains documents that address the barriers and drivers of the implementation of CE in general, so not specifically applying to a sector, which are 7 articles. The second sector type distinguishes documents that address the barriers and drivers of the implementation of CE in the Construction & Demolition sector. The documents that apply to the Buildings sector, Structural Steel and Cities have also been grouped in the Construction & Demolition sector, counting to a total of 16 documents in this sector type. The third sector type contains documents that address the barriers and drivers of the implementation of CE in a variety of sectors, a total of 3 documents are listed in this category. The articles in this sector type were considered too valuable to be left out of consideration, but could not be grouped in sector types 'general' or 'Construction & Demolition. Therefore a third sector type is distinguished, labelled as 'other'.

CE barrier- and driver-categories

Prior to presenting the identified CE barrier- and driver-categories per sector type, an overview of all the different categories that have been found in the 26 articles is provided. These categories are:

- Technological
- Economic/Market
- Financial
- Regulatory
- Legislative
- Social
- Cultural
- Attitudinal
- Supply Chain
- Organisational
- Environmental
- Structural
- Institutional
- Operational
- Managerial
- Information
- Political
- Governmental
- Performance indicators
- Customer
- CE definition/framework

In some cases, different authors used synonyms for the same type of categories. CE barrier- and driver categories may also overlap or lack a clear distinction. Several of these CE barrier- and driver categories will therefore be clustered.

The first clustering of categories is that of Technological and Information. From the results in Table 6 and Table 7 it can be seen that only one document distinguishes the Information category; the article by Tura et al. (2019). In their article, a literature-based framework of seven distinct categories is presented, of which one category is Technological and Information. The authors have 'grouped' these barrier categories, as both the lack of technologies and enhanced information management technologies (or platforms) may pose a barrier. Given the absence of a clear distinction between these categories, they will be combined and considered as one: Technological and Information.

The second clustering is of categories that are of financial, economic or market nature. The categories as identified in the literature are Economic/Market and Financial. These will be combined and named Economic/Financial/Market.

In some articles is spoken of CE barriers and/or drivers that are Social, Cultural, Attitudinal or Customer-related. The category Customer was only considered in the article by Araujo Galvão et al (2018), in which it was defined as the extent to which customers are interested in environmental issues and informed on environmental impacts. This highly overlaps with the definitions for Social/Cultural by Araujo Galvão et al. (2018) and de Jesus & Mendonça (2018), which can be found in Table 3. The same holds for Attitudinal, defined by Ritzén & Sandström (2017) as the *"perception of sustainability"* (p. 9). As these categories highly overlap they will be combined and named Sociocultural.

The fourth clustering of CE barrier- and driver categories is that of Operational, Organisational, Managerial and Structural. The category Structural has been distinguished in two articles. Ritzén & Sandström (2017) defined this as *"barriers [or drivers] identified as being of a more structural kind related to responsibilities and task division in the organizations"* (p. 9). Velenturf & Jopson (2019) have provided a largely similar definition, but make the distinction between both intra- and extra-organisational factors. In which the latter is defined as *"structural barriers external to companies such as renegotiating supply chain responsibilities, dependencies (more dependency makes change more difficult) and integrating perspectives of supply chain partners, and ability to change practices of suppliers"* (p. 1033). As this highly overlaps with the categories Organisational and Managerial, these will be combined and named Organisational/Managerial.

The last clustering of categories is that of Regulatory/Legislative, Political, Institutional and Governmental. The high overlap in these categories is the reason for clustering. The category will be named Institutional/Regulatory/ Governmental.

Having combined several of these barrier- and driver-categories, the final overview with which the literature will be reviewed is presented in Table 3, supplemented by a description of their definition.

Table 3 – CE barrier and driver category descriptions. Source: miscellaneous

CE barrier/driver category	Description
Technological/Information	Barriers or drivers related to the availability of (information management) technologies, knowledge, technical artefacts or know-how to implement circular solutions (Diaz Lopez, Bastein, & Tukker, 2019; Kirchherr et al., 2018)
Economic/Financial/Market	Barriers or drivers related to market conditions, economic climate, value network conditions and the financial profitability of CE (Diaz Lopez et al., 2019; Ritzén & Sandström, 2017)
Institutional/Regulatory/ Governmental	Barriers or drivers related to legal frameworks (regulations and laws), fiscal measures (i.e. taxes, subsidies) and conditions for investment (de Jesus & Mendonça, 2018; Diaz Lopez et al., 2019)
Sociocultural	Barriers or drivers related to the social sensitivity to environmental problems, customers' willingness to shift from ownership to service-models (de Jesus & Mendonça, 2018) and awareness/perception or willingness to commit to sustainable development (Araujo Galvão et al., 2018; Ritzén & Sandström, 2017)
Supply chain	Barriers or drivers related to the supply chain, such as supply dependence (availability of resources), transport distances and volatility of resource prices, management of (reverse) networks, (reverse) network support and collaboration, material 'market-places' (Tura et al., 2019)
Organisational/Managerial	Barriers and drivers related to organisational factors, both intra- and inter-organisational. *Intra-organisational* (within an organisation)*:* Organisations as social systems influenced by goals, routines, organisational structures, etc. The extent to which circularity is integrated in a company's strategy and goals, and the availability of skills and capabilities for CE. Structural within companies, such as balancing top-down direction-giving and allowing bottom-up experimenting, and integrating different departments (Diaz Lopez et al., 2019; Tura et al., 2019; Velenturf & Jopson, 2019)(Diaz Lopez et al., 2019) *Inter-organisational* (between organisations)*:* Related to supply chain responsibilities, dependencies between organisations (more dependency makes change more difficult) and the integration of supply chain partners' perspectives and the ability to change practices of suppliers
Environmental	Barriers or drivers related to resource constraints and the prevention of negative environmental impact (such as CO_2 emissions) (Tura et al., 2019)
Performance indicators	Barriers or drivers related to how circularity can be measured
CE definition/framework	Barriers or drivers related to the definition of the Circular Economy

In the next paragraphs, the literature will be reviewed per sector type, initially for articles on CE in general, then followed by articles on CE in the Construction & Demolition sector and lastly for articles on CE in other sectors. The frequency with which certain categories of barriers or drivers are mentioned in the literature is kept track of, after which an overview of the total number of times certain categories have been mentioned is presented.

2.2. Literature review on barriers and drivers for CE in general

Articles on barriers and drivers for CE in general were studied first, an overview of which can be found in Table 4.

Table 4 – Articles on the barriers and drivers for CE in general. Source: own work

Article written by	Sector type	Region
Diaz Lopez, Bastein, & Tukker (2019)	General	World
de Jesus & Mendonça (2018)	General	World
Araujo Galvão et al. (2018)	General	World
Ritzén & Sandström (2017)	General	World
Kirchherr et al. (2018)	General	European Union
Velenturf & Jopson (2019)	General	United Kingdom
Tura et al. (2019)	General	Finland

Diaz Lopez et al. (2019) have conducted a study in which 143 cases were studied in which different types of Resource Efficiency Measures (REMs) have been applied. The Circular Economy being such a life-cycle REM. From the total of 143 cases, three were on the topic of CE, for which the barrier categories *Organisational, Market* and *Technological* were identified. Diaz Lopez et al. (2019) state that there is only a limited amount of literature available that links business models to circularity, explaining why so few of the 143 studied case were on CE.

De Jesus & Mendonça (2018) conducted a meta-study in which 141 scholarly documents on the drivers of, and barriers to the CE were analysed. Their efforts resulted in an overview of both the most frequently mentioned CE barriers and drivers in academic literature (Figure 4). The four categories of CE barriers and drivers that have been identified by De Jesus & Mendonça (2018) are: *Technological, Economic/Financial/Market, Institutional/Regulatory* and *Social/ Cultural.*

Figure 4 – Most frequently mentioned CE barriers (left chart) and most frequently mentioned CE drivers (right chart) in academic literature (n=141). Source: de Jesus & Mendonça (2018)

Araujo Galvão et al. (2018) conducted a meta-study in which 195 articles on the barriers to the CE were analysed. Approximately 40% of the analysed articles involved case studies. The types of CE barriers that appeared most frequently in the 195 articles that were studied by Araujo Galvão et al. (2018) are: *Technological, Policy and Regulatory, Financial/Economic, Managerial, Performance Indicators, Customer* and *Social.* Actual barriers were not presented in the article; a limitation to this study. Araujo Galvão et al. (2018) state that another limitation is that specific barriers apply to different sectors. The categorization of barriers should therefore not be considered as a one-size-fits-all solution.

The study by Ritzén & Sandström (2017) involved the conduction of 18 semi-structured interviews in 2 case companies and resulted in 5 categories of barriers for CE. These 5 categories are: *Financial, Structural, Operational, Attitudinal* and *Technological.*

In an empirical study by Kirchherr et al. (2018), 47 experts have been interviewed and 208 surveys were taken with the aim to identify barriers for the CE in the European Union. Their efforts have resulted in an overview of 15 ranked barriers that are divided into the four categories as identified by de Jesus & Mendonça (2018) and can be found in Table 5. Drivers were not part of this study.

Table 5 – Barriers to the CE in the European Union (survey results, n=208). Source: Kirchherr et al. (2018)

Rank	Barrier description	Barrier category
1	Lacking consumer interest and awareness	Social/Cultural
2	Hesitant company culture	Social/Cultural
3	Low virgin material prices	Economic/Financial/Market
4	Operating in a linear system	Social/Cultural
5	High upfront investment costs	Economic/Financial/Market
6	Limited willingness to collaborate in the value chain	Social/Cultural
7	Obstructing laws and regulations	Regulatory/Legislative
8	Limited circular design	Technological
9	Lack of global consensus	Social/Cultural, Regulatory
10*	Limited funding for circular business models	Economic/Financial/Market
10*	Limited circular procurement	Regulatory/Legislative
10*	Too few large-scale demonstration projects	Technological
13	Lack of data, e.g. on impacts	Technological
14	Limited standardization	Regulatory/Legislative
15	Ability to deliver high quality remanufactured products	Technological

** Three barriers share a 10th place.*

Velenturf & Jopson (2019) conducted a study which focussed on the business case for resource recovery. Data was gathered during the *Resource Recovery from Waste* conference in the United Kingdom, in 2017 (which was attended by 68 experts from a variety of backgrounds). The authors identified 37 themes for the resource recovery business case, the most important themes covering the *Economic, Social, Environmental* and *Technical* value of resources and *Regulatory* change. Velenturf & Jopson (2019) state that *"focusing business cases on these is likely to deliver positive impacts regarding all identified themes"* (p. 1031). An overview of detailed barriers and drivers for companies to adopt circular practices is presented in the article.

Tura et al. (2019) developed a literature-based framework of CE barriers and drivers. Their framework consists of 7 categories of barriers and drivers and was subsequently used for more specific analysis, by means of 36 interviews in 4 case companies. The 7 categories that are distinguished are: *Environmental, Economic, Social, Political and Institutional, Technological and Informational, Supply Chain* and *Organisational.*

Summary of findings on literature review on barriers and drivers for CE in general

The authors that conducted studies with the aim to determine which types of barriers and drivers for CE in general exist, found a variety of categories. The only exception being Kirchherr et al. (2018), who adopted the four barrier categories as indicated by de Jesus & Mendonça (2018). The different categories of CE barriers and drivers are presented in respectively Table 6 and Table 7.

Table 6 – Categories of barriers for CE in general (non-sector specific)

Author(s)	Region	Technological/Information	Economic/Financial/Market	Institut./Regul./Government.	Sociocultural	Supply chain	Organisational/Managerial	Environmental	Performance indicators	CE definition/framework
Diaz Lopez et al. (2019)	World	X	X				X			
de Jesus & Mendonça (2018)	World	X	X	X	X					
Araujo Galvão et al. (2018)	World	X	X	X	X		X		X	
Ritzén & Sandström (2017)	World	X	X				X			
Kirchherr et al. (2018)	EU	X	X	X	X					
Velenturf & Jopson (2019)	UK	X	X	X	X		X			
Tura et al. (2019)	Finland	X	X	X	X	X	X	X		
	Totals:	**7**	**7**	**5**	**5**	**1**	**5**	**1**	**1**	**0**

As can be seen in Table 6, the most frequently mentioned CE barrier categories are Technological/Information,

Economic/Financial/Market, Sociocultural, Organisational/Managerial and Institutional/Regulatory/Governmental barriers.

Table 7 – Categories of drivers for CE in general (non-sector specific)

Author(s)	Region	Technological/Information	Economic/Financial/Market	Institut./Regul./Government.	Sociocultural	Supply chain	Organisational/Managerial	Environmental	Performance indicators	CE definition/framework
Diaz Lopez et al. (2019)	World					N/A*				
de Jesus & Mendonça (2018)	World	X	X	X	X					
Araujo Galvão et al. (2018)	World					N/A*				
Ritzén & Sandström (2017)	World					N/A*				
Kirchherr et al. (2018)	EU					N/A*				
Velenturf & Jopson (2019)	UK		X	X	X	X		X		
Tura et al. (2019)	Finland	X	X	X	X	X	X			
	Totals:	**2**	**3**	**3**	**3**	**2**	**1**	**1**	**0**	**0**

** Drivers were not part of these studies.*

When looking at the drivers for CE in general (Table 7), the first notable difference is that drivers for CE have been studied less frequently than CE barriers. Only three out of the seven studied documents focussed on the drivers for CE. In the cases that drivers were within the scope of the study, the most frequently appearing CE driver categories were Economic/Financial/Market and Sociocultural, followed by Technological/Information, Institutional/Regulatory/ Governmental and Supply chain. Organisational/Managerial and Environmental drivers were mentioned in only one out of three articles.

While the analysis so far does give some insight in the most frequently mentioned CE barrier- and driver-categories, Kirchherr et al. (2018) underline that their work only *"provides a helicopter view regarding CE barriers in the EU"* (p. 271) and that *"differences may exist regarding CE barriers from sector to sector"* (p. 271). Their statement does not solely applies to their article but to the other considered articles as well. It may therefore be worthwhile to narrow the focus from the general to the more specific; CE barriers and drivers in the Construction & Demolition sector. After analysis of the CE barrier- and driver-categories that apply to the Construction & Demolition sector, the results will be compared with that of sector type 'general'.

2.3. Literature review on barriers and drivers for CE in the Construction & Demolition sector

Having studied the articles that apply to the implementation of CE in general, the focus is narrowed to CE barriers and drivers in the Construction & Demolition sector. As mentioned in the introduction of this chapter, articles that apply to the Buildings sector and to Cities have been grouped under Construction & Demolition sector. Articles that specifically address the barriers and drivers for CE in the infrastructure sector are non-existent. The considered articles that had the aim to determine the barriers and drivers for the CE in the Construction & Demolition sector type are listed in Table 8.

As can be seen in Table 8, the articles that apply to either the World or European countries, have been listed first. They are followed by studies conducted in non-European countries. Ghisellini, Ripa & Ulgiati (2018) state that *"the environmental and economic sustainability of [a] CE framework is very site-specific and depends on several factors such as the type of material, building elements, transport distances, economic and political context"* (p. 618). It is therefore questionable that indicated barriers or drivers for CE that apply to the Construction & Demolition sector in for example China or Iran also apply to European countries, let alone to the Netherlands. Even within countries differences may exist from region to region. Therefore, two geographical areas are distinguished for this sector type. The first one is for articles of which the results apply on a global context (World) and European countries. The second type are non-European countries.

Table 8 – Articles on the barriers and drivers for CE in the Construction & Demolition sector. Source: own work

Article written by	Sector	Region
		World & European countries:
Ghisellini, Ripa, et al. (2018)	Construction & Demolition	World
Gálvez-Martos et al. (2018)	Construction & Demolition	Europe
Adams et al. (2017)	Construction & Demolition	United Kingdom
Nasir et al. (2017)	Construction & Demolition	United Kingdom
Sigrid Nordby (2019)	Construction & Demolition	Norway
Nußholz et al. (2019)	Building sector	Scandinavia
Eberhardt et al. (2019)	Building sector	Denmark
Densley Tingley et al. (2017)	Structural Steel	United Kingdom
Williams (2019)	Cities	World
		non-European countries:
Ghisellini, Ji, Liu, & Ulgiati (2018)	Construction & Demolition	China
Won & Cheng (2017)	Construction & Demolition	China
Huang et al. (2018)	Construction & Demolition	China
H. Yuan (2017)	Construction & Demolition	China
Mahpour (2018)	Construction & Demolition	Iran
Chang & Hsieh (2019)	Construction & Demolition	Taiwan
Esa, Halog, & Rigamonti (2017)	Construction & Demolition	Malaysia

Ghisellini, Ripa, et al. (2018) conducted a literature review with the aim to explore the environmental and economic costs and benefits of CE in the construction & demolition sector. Their efforts resulted in an overview of the main barriers to the 3R principles (reduce/re-use/recycle) of construction & demolition waste. The types of barriers that have been indicated are: *Economic, Political, Legislative, Informative* and *Managerial*. Drivers were not part of this study.

Gálvez-Martos et al. (2018) studied the best management practices of Construction & Demolition Waste recycling of 30 European countries. While the core focus of the study was not to provide an extensive overview of barriers and drivers for CE, some barriers and drivers have been mentioned, which can be found in Table 9 and Table 10.

Adams et al. (2017) studied the level of awareness of the CE concept and the relative importance of various barriers and drivers for CE in the UK construction sector. Data was gathered by an online survey (n=110) and a 'circular economy thinking' event (97 attendees). Adams et al. (2017) state that *"there is a significant body of literature on the drivers and benefits of circular economy [in general]; however, little research or wide- scale application has been undertaken within a construction context"* (p. 22)**.**

Sigrid Nordby (2019) studied the barriers for the CE in the Norwegian construction industry. The barriers that were indicated in this study are: *Technical, Organizational, Economic/Financial/Market, Information* and *Regulatory/ Legislative.* Only one driver for CE has been presented in this article: *Environmental*.

As for the studies conducted in non-European countries, the following findings have been found:

In the study by Ghisellini, Ji, Liu, & Ulgiati (2018) on the transition towards cleaner production in the Construction & Demolition sector in China, a total of 30 barriers have been indicated. Drivers were not part of this study. The identified barriers have been categorized as *Political and Market, Financial and Economic, Technical and Information* and *Managerial and Organizational.*

Mahpour (2018) conducted a study with the aim to prioritize the barriers for the adoption of CE in the Iranian construction & demolition waste sector. The author's efforts have resulted in an overview of 22 barriers. All these barriers can be categorised under Technological/Information, Institutional/Regulatory/Governmental and Sociocultural. However, the data was gathered from only six experts, a relatively small sample size. Moreover, all of these six experts work in the Iranian C&D sector, which makes it questionable whether these findings are also applicable to Dutch infrastructure projects.

Summary of findings on literature review on barriers and drivers for CE in construction & demolition sector

The frequency with which certain barrier categories appeared in the literature on the C&D sector types has been listed in Table 9. Searching for CE barriers has been part of all 16 articles in these sector types (9 for C&D World & European and 7 C&D non-European). Table 9 shows that the most frequently appearing categories of CE barriers in the Construction & Demolition sector types are Technological/Information, Economic/Financial/Market, Institutional/ Regulatory/Governmental and Organisational/Managerial. As mentioned in the previous paragraph, different CE barrier- and driver-frameworks may apply to specific geographical regions. Therefore, two different geographical regions have been distinguished. When comparing the results between these two different geographical regions (World & European countries versus non-European countries), differences in the frequency with which the barrier categories Economic/Financial/Market, Sociocultural and Supply chain appeared can be noted. While the frequency with which certain barriers were mentioned slightly varies, both geographical regions have the same categories of barriers in their top-6. These barrier categories are Technological/Information, Economic/Financial/Market, Institutional/Regulatory/ Governmental, Sociocultural, Supply chain and Organisational. However, in non-European countries, Both Economic/Financial/Market, Supply chain and Environmental barriers have been mentioned less frequently than in that of the World & European countries.

Table 9 – Categories of barriers for CE in Construction & Demolition sector

Author(s)	Region	Technological/Information	Economic/Financial/Market	Institut./Regul./Government.	Sociocultural	Supply chain	Organisational/Managerial	Environmental	Performance indicators	CE definition/framework
Ghisellini, Ripa, et al. (2018)	World	X	X	X			X			
Gálvez-Martos et al. (2018)	Europe		X	X						
Adams et al. (2017)	UK	X	X			X	X			
Nasir et al. (2017)	UK		X							
Sigrid Nordby (2019)	Norway	X	X	X			X	X		
Nußholz et al. (2019)	Scandinavia	X		X		X				
Eberhardt et al. (2019)	Denmark	X	X			X				X
Densley Tingley et al. (2017)	United Kingdom		X	X			X			
Williams (2019)	World	X	X	X	X			X		
World & European country totals:		**6**	**8**	**6**	**1**	**3**	**4**	**2**	**0**	**1**
Ghisellini, Ji, Liu, & Ulgiati (2018)	China	X	X				X			
Won & Cheng (2017)	China	X		X						
Huang et al. (2018)	China	X	X	X		X	X			
H. Yuan (2017)	China	X	X	X	X					
Mahpour (2018)	Iran	X		X	X					
Chang & Hsieh (2019)	Taiwan	X	X				X			
Esa, Halog, & Rigamonti (2017)	Malaysia	X		X	X					
Non-European country totals:		**7**	**4**	**5**	**3**	**1**	**3**	**0**	**0**	**0**
Totals:		**13**	**12**	**11**	**4**	**3**	**7**	**2**	**0**	**1**

Table 10 shows that, again, drivers for CE have been studied less frequently than CE barriers in the Construction & Demolition sector type (which was also the case for studies on CE barriers and drivers for sector type 'General'). In only four of the 16 articles, CE drivers were studied. None of the studies conducted on non-European countries focussed on determining the drivers for CE.

The most frequently appearing driver categories are Technological/Information, Economic/Financial/Market and Environmental. Institutional/Regulatory/Governmental and Organisational/Managerial drivers were mentioned both once, in two different articles. It can be noted that identifying CE drivers was not within scope of the studies that were conducted in non-European countries.

Table 10 – Categories of drivers for CE in Construction & Demolition sector

Author(s)	Region	Technological/Information	Economic/Financial/Market	Institut./Regul./Government.	Sociocultural	Supply chain	Organisational/Managerial	Environmental	Performance indicators	CE definition/framework
Ghisellini, Ripa, et al. (2018)	World					N/A*				
Gálvez-Martos et al. (2018)	Europe	X	X					X		
Adams et al. (2017)	UK	X	X				X			
Nasir et al. (2017)	UK					N/A*				
Sigrid Nordby (2019)	Norway							X		
Nußholz et al. (2019)	Scandinavia	X	X	X						
Eberhardt et al. (2019)	Denmark					N/A*				
Densley Tingley et al. (2017)	United Kingdom					N/A*				
Williams (2019)	World					N/A*				
World & European country totals:		**3**	**3**	**1**	**0**	**0**	**1**	**2**	**0**	**0**
Ghisellini, Ji, Liu, & Ulgiati (2018)	China					N/A*				
Won & Cheng (2017)	China					N/A*				
Huang et al. (2018)	China					N/A*				
H. Yuan (2017)	China					N/A*				
Mahpour (2018)	Iran					N/A*				
Chang & Hsieh (2019)	Taiwan					N/A*				
Esa, Halog, & Rigamonti (2017)	Malaysia					N/A*				
Non-European country totals:		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Totals:		**3**	**3**	**1**	**0**	**0**	**1**	**2**	**0**	**0**

** Drivers were not part of this study.*

Differences in results for CE drivers between the two geographical regions cannot be discussed, as there a no results on CE drivers for non-European countries.

2.4. Literature review on barriers and drivers for CE in other sectors

The third and last sector type contains articles that could not be grouped in sector types 'general' or 'Construction & Demolition', but were considered too valuable to be left out of consideration. An overview of the considered articles and the specific sectors they apply to can be found in Table 11.

Table 11 – Articles on the barriers and drivers for CE in other sectors. Source: own work

Article written by	Sector type	Region
de Mattos & de Albuquerque (2018)	Commercial refrigeration & electronic equipment sector	World
Bressanelli et al. (2018)	Supply Chain Management	World
Govindan & Hasanagic (2018)	Supply Chain Management	World

The article by de Mattos & de Albuquerque (2018) was considered relevant as it is one of the few studies that focussed solely on the enabling factors (drivers) for the transition towards a Circular Economy. Identifying barriers has not been part of this study. The authors developed a generally-applicable framework of drivers for circular business models, which they later applied to two companies in respectively the commercial refrigeration sector and electronic equipment sector. The authors distinguished both internal and external drivers. The internal drivers are: *Company culture, Team commitment, Networking* and *Support from the demand network*. External drivers are: *Local government support, legislation* and *Geographical proximity*. Covering the categories Economic/Financial/Market, Organisational/Managerial, Institutional/Regulatory/Governmental and Supply chain. The distinction of internal and external factors is interesting. Although the authors do not conclude on this particular topic, it could be argued that

both internal and external enablers need to be in place in order for a company to be able to adopt circular practices. Hereby meaning that although a company may be internally ready for the adoption of CE, as long as the landscape in which the company conducts its business is not ready for CE, they cannot make the transition. It is also worth mentioning that form the entire body of 26 documents, this is the only article that solely considered drivers. Barriers have not been part of this study.

Govindan & Hasanagic (2018) conducted a literature review on the barriers, drivers and practices towards CE from a supply chain perspective. A total of 60 articles have been considered, in which 5 clusters of CE drivers are distinguished. These 5 clusters are *Policy and Economy, Health, Environmental Protection, Society* and *Product Development*. Barriers have been grouped in 8 clusters: *Governmental issues, Economic issues, Technological issues, Knowledge and skills issues, Management issues, CE framework issues, Cultural and Social issues* and lastly, *Market issues.* For both the barriers and drivers the distinction between internal and external factors is made. Additionally, Circular Economy practices have been presented in the article which describe *how* CE should be adopted into a supply chain. These results will however not be presented as they are outside of the study's scope.

Summary of findings on literature review on barriers and drivers for CE in other sectors

The frequency with which certain barrier categories appeared in the literature applying to sector type 'other' is presented in Table 12. The most frequently appearing categories of CE barriers in this sector type are Technological/Information, Economic/Financial/Market, Institutional/ Regulatory/Governmental and Sociocultural.

Table 12 – Categories of barriers for CE in other sectors

Author(s):	Sector:	Region:	Technological/Information	Economic/Financial/Market	Institut./Regul./Government.	Sociocultural	Supply chain	Organisational/Managerial	Environmental	Performance indicators	CE definition/framework
de Mattos & de Albuquerque (2018)	Commercial refrigeration & electronic equipment sector	World	N/A*								
Bressanelli et al. (2018)	Supply Chain Management	World	X	X	X	X	X				
Govindan & Hasanagic (2018)	Supply Chain Management	Norway	X	X	X	X		X			X
		Totals:	**2**	**2**	**2**	**2**	**1**	**1**	**0**	**0**	**1**

** Barriers have not been part of this study.*

As can be seen in Table 13, drivers for CE have been studied in 2 out of 3 considered articles. The article by de Mattos & de Albuquerque (2018) is the only article from the entire body of 26 articles that solely considers drivers for the implementation of CE. The two most frequently mentioned driver categories are Economic/Financial/Market and Institutional/Regulatory/Governmental.

Table 13 – Categories of drivers for CE in other sectors

Author(s):	Sector:	Region:	Technological/Information	Economic/Financial/Market	Institut./Regul./Government.	Sociocultural	Supply chain	Organisational/Managerial	Environmental	Performance indicators	CE definition/framework
de Mattos & de Albuquerque (2018)	Commercial refrigeration & electronic equipment sector	World		X	X		X	X			
Bressanelli et al. (2018)	Supply Chain Management	World	N/A*								
Govindan & Hasanagic (2018)	Supply Chain Management	Norway	X	X	X				X		
		Totals:	**1**	**2**	**2**	**0**	**1**	**1**	**1**	**0**	**0**

** Drivers have not been part of this study.*

2.5. Identified CE barriers & drivers categories in literature

General findings

A variety of CE barrier- and driver-categories has been found in the literature. Given this variety, along with the fact that authors have questioned the direct adoption of a CE barrier- and driver-category framework to other sectors (due to region's different characteristics for material type, building elements, transport distances and the economic and political context (Ghisellini et al., 2018)), one-on-one adoption of an existing framework of CE barrier- and driver-categories from the literature for application to the Dutch infrastructure sector is not possible. Therefore, a literature-based framework of CE barrier- and driver-categories needs to be established, based on the findings from the 26 articles considered in the literature review. All 26 articles have been read and the types of CE barrier- and driver-categories that were indicated in these articles has been kept track of. The total number of articles in which a CE barrier- or driver-category appeared is presented in respectively Figure 5 and Figure 6.

It is important to realise that the number of times that a certain barrier- or driver-category appears in the literature does not necessarily say something about the actual importance of that specific barrier- or driver-category. However, looking at Figure 5, a barrier category being mentioned in only 1 out of 26 articles (Performance indicators) versus a barrier category that is mentioned in 22 out of 26 articles (Technological/Information) makes it logical to pay more attention during the interviews to the latter.

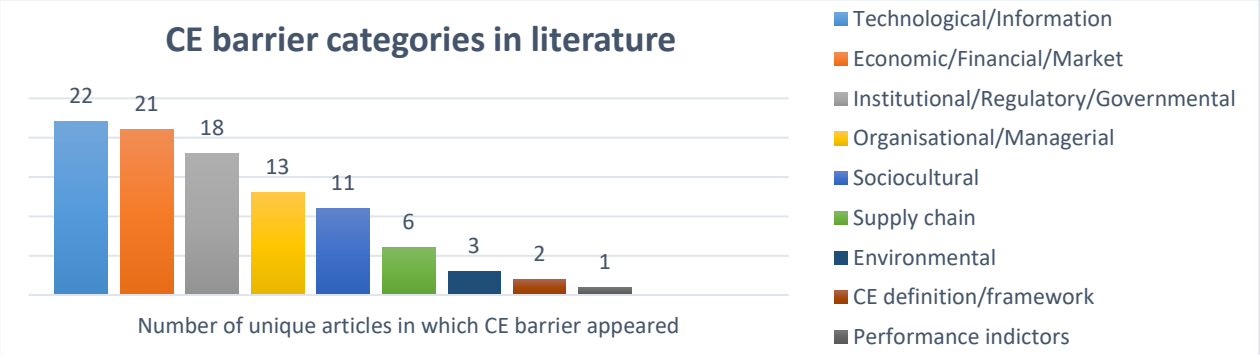

Figure 5 – Number of articles in which barrier category was mentioned (n=26 articles). Source: own work

As can be seen in Figure 5, the most frequently mentioned CE barrier categories are Technological/Information, Economic/Financial/Market and Institutional/ Regulatory/Governmental. These categories are followed by Organisational/Managerial, Sociocultural and Supply Chain. The least frequently mentioned CE barrier categories are Environmental, CE definition/framework and Performance indicators.

As can be concluded from Figure 5, the most frequently mentioned CE barrier categories are Technological/ Information (22 articles), Economic/Financial/Market (21 articles) and Institutional/Regulatory/Governmental (18 articles). The barrier categories Organisational/Managerial and Sociocultural were mentioned in respectively 13 and 11 articles. The least frequently mentioned CE barrier categories are Environmental (3 articles), CE definition/ framework (2 articles) and Performance Indicators (mentioned in only 1 article).

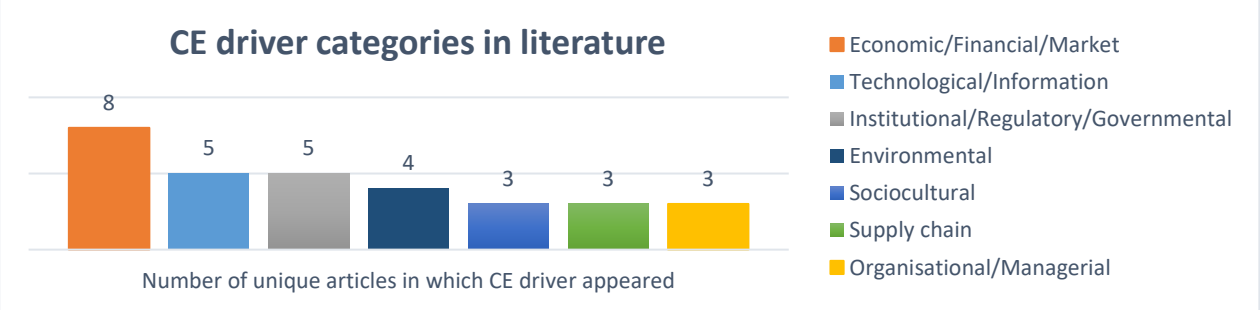

Figure 6 – Number of articles in which driver category was mentioned (n=26 articles). Source: own work

CE drivers on the other hand, have been studied less frequent than CE barriers and were within the scope of 9 out of 26 articles (35%). Figure 6 shows that the most frequently mentioned CE driver category is Economic/Financial/Market

(8 articles). Followed by CE driver categories Technological/Information (5 articles), Institutional/Regulatory/ Governmental (5 articles) and Environmental (4 articles). Sociocultural, Supply chain and Organisational/Managerial were all mentioned in 3 articles. The driver categories Performance Indicators and CE definition/framework have not been found to be CE driver categories.

Findings – per sector type

The categories of CE drivers and CE barriers have been studied in four different sector types. The goal of this part of the research is to compare the findings from the literature review for the four different sectors. An overview of the four different sector types and the geographical regions that the articles applied to can be found in Table 14.

Table 14 – Sector types & applicable geographical regions. Source: own work

Sector type name	Geographical region(s)	Number of articles
General	World, EU, UK, Finland	7
Construction & Demolition - World & Europe	World, UK, Scandinavia	9
Construction & Demolition - non-European	China, Iran, Taiwan, Malaysia	7
Other	World, Norway	3

For comparison of the frequencies with which certain CE barrier- and driver-categories are mentioned between the four sector types, the relative frequency with which CE barrier- and driver-categories are mentioned in the different sector types should be considered. This relative number is expressed in a percentage: the number of articles in which a CE barrier or driver category has been mentioned divided by the total number of articles in the sector type. These percentages can be found in Figure 7 and Figure 8.

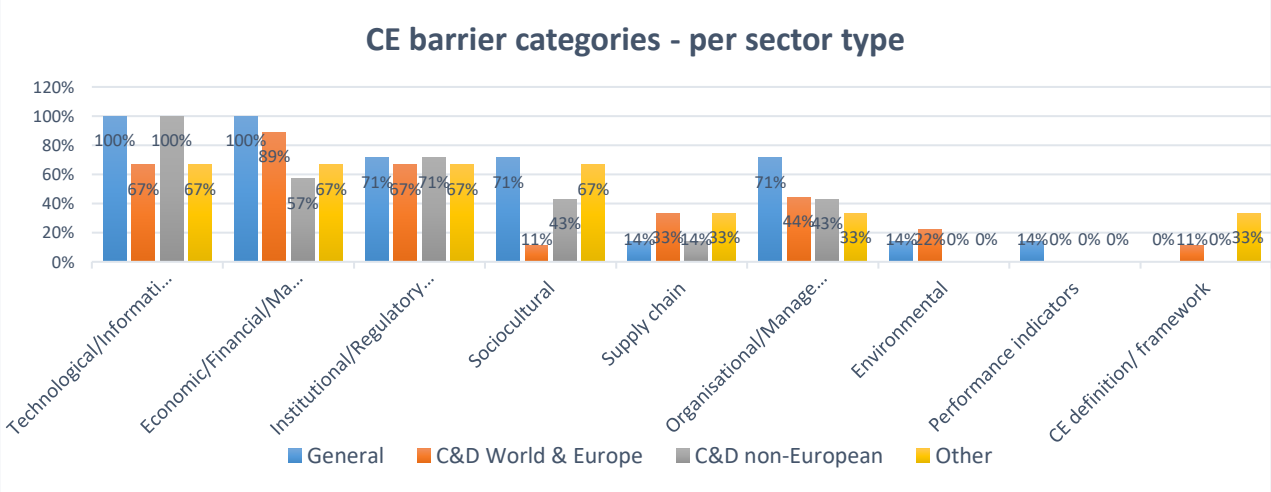

Figure 7 – Percentage of articles with which CE barrier categories have been mentioned in the different sector types

Differences in the frequencies with which certain CE barrier categories have been mentioned in the four sector types can be observed, the most notable differences applying to the barrier categories Technological/Information, Economic/Financial/Market, Sociocultural and Organisational/Managerial.

Whereas the Technological/Information barrier category has been mentioned in all articles of sector types 'General' and 'C&D non-European', it was mentioned in only 67 percent of the other sector types. Barrier category Economic/ Financial/Market was mentioned significantly less frequent in sector types 'C&D non-European' and 'other', compared to the other 2 sector types. Differences can also be observed for barrier category Sociocultural. While this category was mentioned in 5 out of 7 articles (71%) in sector type 'general', it only appeared in 1 out of 9 articles (11%) in 'C&D World & Europe. The Organisational/Managerial barrier category has been mentioned most frequently in sector type 'General' (5 out of 7 articles, or 71%), but was mentioned significantly less frequent in the three other sector types.

Given the economic, political and geographical differences between sector type 'C&D non-European' and 'C&D World and Europe', significant differences were expected. The decision on whether or not to take the results from sector type 'C&D non-European' into account should therefore be made. Especially for the category Institutional/Regulatory/

Governmental differences were expected, but this is not the case. Only the CE barrier categories Economic/Financial/ Market, Supply chain and Environmental were mentioned less frequently in sector type 'C&D non-European' than in 'C&D World and Europe'. Barrier categories Technological/Information and Sociocultural were mentioned more frequently in sector type 'C&D non-European' than 'C&D World and Europe'. All other categories were mentioned more or less as often in the two categories. The results from sector type 'C&D non-European' are considered to be valuable for this research and will therefore be included in the development of the literature-based framework of CE barriers and drivers. While it may seem that this decision is made before the differences in CE driver categories are discussed, none of the articles in sector type 'C&D non-European' focussed on CE drivers.

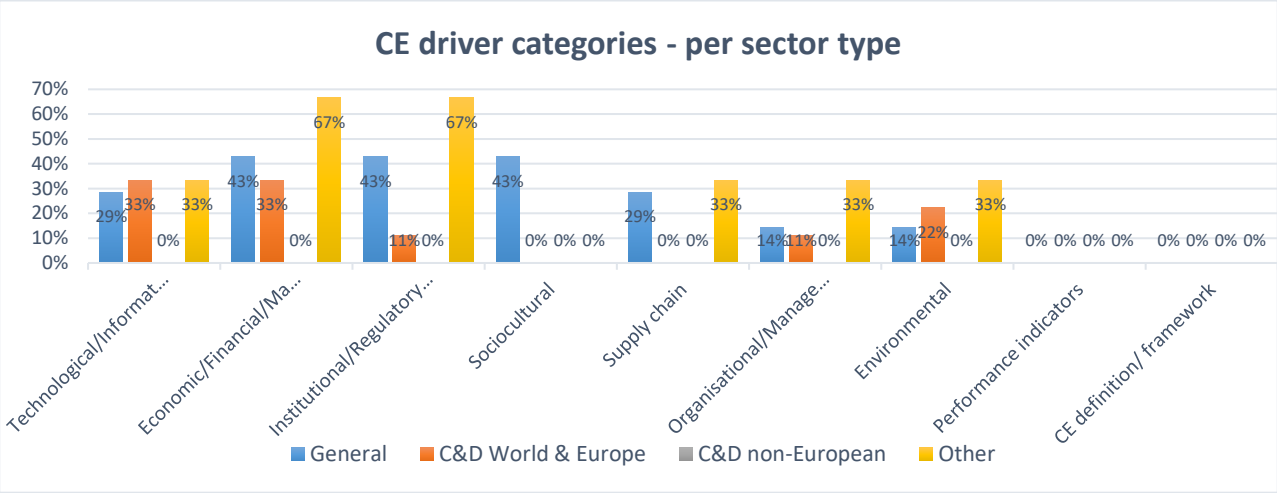

Figure 8 – Percentages of articles with which CE driver categories have been mentioned in the different sector types

Notable differences can also be observed in the mentioned CE driver categories in the considered body of literature. Firstly, none of the articles in sector type 'C&D non-European' aimed to identify CE drivers or CE driver categories. A comparison can therefore only be made between sector types 'general', 'C&D World & Europe' and 'Other'.

The largest differences in the frequency with which driver categories are mentioned amongst the different sector types applies to driver categories Institutional/Regulatory/Governmental, Economic/Financial/Market, Sociocultural and Supply chain. Whereas the Institutional/Regulatory/Governmental driver category appeared in 67% of the articles applying to sector type 'other'. It was mentioned in 43% of the articles on CE in general, but only in 1 out of 9 articles on CE in sector type 'C&D World & Europe'. Economic/Financial/Market drivers appeared most frequently in sector type 'other', but were mentioned significantly less frequent in sector types 'General' and 'C&D World & Europe'. Sociocultural drivers have only been mentioned in sector type 'General'.

2.6. Conclusion – SQ1

The goal of this part of the research was to provide an answer to sub-question 1:

"What are the general categories of barriers and drivers for the implementation of CE?"

The literature review has indicated that a high variety of CE barrier- and driver-categories can be distinguished. CE barriers have been studied in 25 out of 26 considered articles, nearly three times as often as CE drivers, which were studied in 9 out of 26 considered articles.

Several authors have questioned the one-on-one adoption of a CE barrier- and driver-category framework to other sectors, as the environmental and economic sustainability of a CE framework may be very site-specific and depends on several factors such as material type, building elements, transport distances and the economic and political context (Ghisellini, Ripa, et al., 2018; Kirchherr et al., 2018). For this reason, along with the fact that a wide variety of CE barrier- and driver-categories has been found in the literature, adoption of an existing CE barrier- and driver-category framework for application in Dutch infrastructure projects is deemed unsuitable. The aim of this part of the research therefore was to develop a literature-based framework of generally applicable CE barrier- and driver-categories (for application to the Dutch infrastructure sector).

A total of 26 articles across four different sector types have been analysed. The results from the sector types 'General', 'C&D World & Europe' and 'other' are considered relevant for the establishment of the literature-based framework of CE barrier- and driver-categories. However, given the economic, political and geographical differences between sector type 'C&D non-European' and the Netherlands, it has been considered whether or not the results from this sector type should be taken into account. It was found that the majority of categories mentioned in sector type 'C&D non-European' were mentioned at least as frequently as in the other sectors. The categories Technological/Information and Sociocultural were mentioned even more frequently in sector type 'C&D non-European' than in 'C&D World & Europe'. The decision has therefore been made to take the results from all the different sector types, -and therefore all 26 articles- into account in developing the literature-based framework of CE barrier- and driver-categories.

While the number of times a CE barrier- or driver-category appeared in the body of literature does not necessarily say something about its actual importance, it was considered the most feasible method for this research. The literature-based framework of CE barrier- and driver-categories is an adoption of the results in Figure 5 and Figure 6 (which depict the number of times a CE barrier- or driver-category appeared in the literature). The answer to the first sub-question can best be presented in the form of a table (Table 15), as it provides a clear and concise overview of the general categories of barriers and drivers for the implementation of CE. Please note that the categories are listed in order of most to least frequently appearing in the literature.

Table 15 – Literature-based framework of barrier- and driver-categories for the implementation of CE in general (listed in order of most to least frequently appearing in the literature)

Rank	CE barrier categories
1.	Technological/Information
2.	Economic/Financial/Market
3.	Institutional/Regulatory/Governmental
4.	Organisational/Managerial
5.	Sociocultural
6.	Supply chain
7.	Environmental
8.	CE definition/framework
9.	Performance indicators

Rank	CE driver categories
1.	Economic/Financial/Market
2.	Technological/Information
3.	Institutional/Regulatory/Governmental
4.	Environmental
5.	Sociocultural
6.	Supply chain
7.	Organisational/Managerial

At this point in the research insight has been attained regarding the categories of CE barriers and CE drivers. A literature-based framework of CE barrier- and driver-categories has been established, based on articles on CE in general, CE in the Construction & Demolition sector and CE in other sectors. However, the categories of barriers and drivers that apply specifically to the implementation of CE in Dutch infrastructure projects are still unknown. It is important to determine how these can be studied. The second sub-question of this research addresses this matter: "*How can the barriers and drivers for the implementation of CE in Dutch infrastructure projects be identified?".*

3. METHODOLOGY

In this part of the research, an answer is provided to sub-question 2: "*How can the barriers and drivers for the implementation of CE in Dutch infrastructure projects be identified*?". In other words, the research methodology has to be determined. This study involves qualitative research, for which a suitable research strategy needs to be selected. Several qualitative research strategies exist: experiments, surveys, archival analyses, history and case studies (Amaratunga et al., 2002). Whereas experiments, archival analyses, history and case studies are best applicable to 'how' and 'why' questions, survey research can provide answers to research questions in the 'who', 'what', 'where', 'how many' and 'how much' form (Amaratunga et al., 2002).

Due to the explorative nature of this research, in particular on 'what' the barriers and drivers for the implementation of CE in Dutch infrastructure projects are, survey research is considered an appropriate research strategy. According to Fowler Jr. (2013), survey research encompasses measurement procedures that involve asking questions of respondents and two types of survey research can be defined: questionnaires and interviews. Whereas questionnaires are best applied for quantitative research, interviews are best suited for qualitative research (Fowler Jr., 2013). Given the qualitative nature of this research, interviews are therefore the selected methodology.

3.1. Interview type selection

This paragraph describes what type of interviews will be conducted, followed by paragraphs on the criteria that the interviewees have to meet, how the interviews will be conducted and what will be done with the gathered data from the interviews.

First of all, a selection of the most suitable qualitative interview type needs to be made. Qualitative interviews have been categorised in a variety of ways. The categorization that is used most often is: unstructured, semi-structured and structured (DiCicco-Bloom & Crabtree, 2006).

Table 16 – Unstructured, structured and semi-structured interview type descriptions

Interview type	Description
Unstructured	Free-flowing and open conversation format, due to the absence of structured questions. The researcher relies on the interaction with the respondents to guide the interview process (Creswell et al., 2007).
Structured	Predetermined and structured approach. All interviewees are asked the same questions, but the questions are formulated such that responses are open-ended (Turner, 2010).
Semi-structured	Interview format which is organised around a set of predetermined open-ended questions. Supplementing questions may emerge from the dialogue between interviewee and interviewer (DiCicco-Bloom & Crabtree, 2006).

Structured interviews are best applied for situations in which complete knowledge about a topic is available and if the data that is to be gathered is precisely determined (Turner, 2010). Given the explorative nature of the research, in which drivers of, and barriers to the implementation of CE in Dutch infrastructure projects are searched for, the structured interview format is considered unsuitable for this research.

Unstructured interviews on the other hand, are not useful when a researcher already has a basic understanding of a phenomenon and pursues particular aspects of it (Wildemuth, 2016). As the latter is the case, unstructured interviews are not selected for this research. Due to the inconsistency of interview questions, coding of the data is difficult, for which many researchers consider the unstructured interview type as unreliable (Creswell et al., 2007).

According to DiCicco-Bloom & Crabtree (2006), the semi-structured interview combines the best features of both the structured and unstructured interview type. In semi-structured interviews, the guiding questions in the format ensure that the areas of focus are covered, while the possibility to developed the interview towards other directions of interest remains present. Moreover, semi-structured interviews allow for unbiased responses from the interviewees. The semi-structured interview type is the most widely used format for qualitative research and can either be conducted with a group or an individual. The semi-structured interview is deemed most suitable for this research and will therefore be selected.

3.2. Respondent selection

Having determined that semi-structured interviews are the appropriate research type, the next step involves selecting the respondents. This will be done based on several criteria. Firstly, the respondents should be working for organisations that are active in (or have experience) in realizing Dutch infrastructure project(s). Secondly, the respondents should be familiar with the concept of Circular Economy or sustainability. Thirdly, respondents working for a variety of stakeholders involved in Dutch infrastructure projects should be interviewed. In other words, the entire 'chain' should be represented. Abbasova (2018) distinguishes the following stakeholder types that are operating in the construction sector of the Dutch metropolitan area of Amsterdam (MRA): clients, engineering & consulting firms, architects, real estate developers, construction companies (contractors), suppliers of building materials, wholesalers of building materials, and recycling companies. However, as this study is limited to part of the construction sector; the infrastructure sector (not the building sector), the stakeholder types 'architects' and 'real estate developers' will not be taken into consideration. In a study by Adams et al. (2017) on the challenges and enablers for CE in the UK construction sector, stakeholder type 'demolition contractor' was also part of the group of respondents. Given the role of demolition contractors in a construction's end-of-life phase, this seems only logical. Demolition contractors are therefore added to the list of relevant stakeholders in Dutch infrastructure projects (listed in Table 17).

Table 17 – Stakeholder types & description. Source: own work

Stakeholder type	Description
Public clients	Governmental organisations that give the order to commission a project
Engineering & consulting firms	Organisations that provide consultancy and guidance for the realisation of technical projects
Contractor	Organisations that take responsibility for the realization and coordination of construction activities; a contractor provides, for a price specified in the contract and within an agreed period, the delivery of a fully completed structure
Demolition contractors	Organisations specialized in safely and efficiently tearing down buildings and other man-made structures
Suppliers of building material	Organisations that supply building or construction materials. These building- or construction materials may either origin from virgin or secondary materials
Wholesalers of building material	Organisations that fulfil the role of 'raw material banks' of used materials
Recycling companies	Organisations that recycle construction & demolition waste into new construction materials and objects. Organisations that fulfil R-strategies besides recycling (from the 10-R model as listed in Table 2) are also included

Different types of stakeholders are interviewed as it is assumed that they all have different views on the system. These different perspectives will likely result in differently perceived barriers and drivers for CE in the Dutch infrastructure sector. Regarding the group of respondents, two goals have been formulated. Firstly, the group of respondents should represent all relevant stakeholders and secondly, the group of respondents should be balanced (not focussing on only stakeholder type). In addition to these respondent criteria, a sample size should be determined. Malterud et al. (2016) have written an article on sample sizing in qualitative interviews studies. For explorative, broadly aimed studies, such as this research, a larger number of respondents is required for valid results than for more narrow aimed studies. Several researchers aimed to develop guidelines for qualitative sample sizing. According to (Bertaux, 1981), *"fifteen is the smallest acceptable sample size"* (p. 35). Green & Thorogood (2004) state that *"the experience of most qualitative researchers is that in interview studies little that is 'new' comes out of transcripts after you have interviewed 20 or so people"* (p. 120). The aim is therefore to conduct approximately 15 to 20 interviews.

3.3. Interview questions

Having determined the appropriate interview type and respondent criteria, the next step is to formulate effective interview questions. In order to do so the recommendations for constructing an effective interview by McNamara (2009) have been taken into consideration. These are:

1. Wording should be open-ended.
2. Questions should be as neutral as possible.
3. Questions should be asked one at a time.
4. Questions should be worded clearly.
5. Be careful asking "why" questions.

For the purposes of this research, and including the above recommendations, a semi-structured interview guide and questions have been developed, which can be found in Appendix B – Interview guide. The literature-based framework formed the basis in formulating the interview questions. Each interview will approximately take 1 hour.

Caution will be taken during the interviews to not steer the answers of the respondents in certain directions. The interview questions will be asked as open as possible. However, when respondents are no longer able to provide answers regarding the barriers and drivers for the implementation of CE in Dutch infrastructure projects, respondents will be asked if they recognise barriers or drivers in the categories as identified in the literature-based framework of CE barrier- and driver-categories. These more directed questions regarding the CE barrier and driver categories will be asked in different orders. Hereby preventing that no more time is available to ask respondents about the last CE barrier or driver-categories categories on the list.

3.4. Interview analysis & protocol

The interviews will transcribed from the audio-recordings. The transcriptions will allow for objective interpretation of the interview results and will be analysed using the literature-based framework of CE barriers and drivers, as established in Chapter 2. The interviews will be conducted in the Dutch language. In order to give a clear and concise description of the barriers or drivers that were mentioned by the respondent during the interview, some paraphrasing is necessary. Whereby care is taken not to change or alter the context of what the respondent said. Categorisation of the identified CE barriers or drivers will be done by the author. In order to objectively group a barrier or driver in a category, a categorisation protocol has been developed. This protocol describes the criteria that a barrier or driver should meet in order to be grouped in a certain category, which can be found in Table 18.

Table 18 – CE barrier and driver category criteria. Source: miscellaneous

CE barrier/driver category	Criterion
Technological/Information	Barrier or driver relates to the availability of: - Technologies (to deliver high quality remanufactured products or materials) - Information management technologies - Enhanced information sharing technologies - Knowledge to implement circular solutions - Technical artefacts to implement circular solutions (Diaz Lopez et al., 2019; Kirchherr et al., 2018; Tura et al., 2019)
Economic/Financial/Market	Barrier or driver relates to: - Economic climate - Financial profitability of CE - Market conditions - Value network conditions - How to value circular solutions in non-monetary units (Diaz Lopez et al., 2019; Ritzén & Sandström, 2017)
Institutional/Regulatory/ Governmental	Barrier or driver relates to: - Legal frameworks (laws and regulations) - Fiscal measures (i.e. taxes, subsidies) - The arrangement of appropriate conditions and measures by governments to enable the diffusion of new circular technologies or circular solutions (de Jesus & Mendonça, 2018; Diaz Lopez et al., 2019)
Sociocultural	Barrier or driver relates to: - Social sensitivity to environmental problems - Customers' willingness to shift from ownership to service-models - Awareness, perception and willingness to commit to sustainable development (Araujo Galvão et al., 2018; de Jesus & Mendonça, 2018; Ritzén & Sandström, 2017)
Supply chain	Barrier or driver relates to: - Availability of resources (supply dependency) - Transport distances and volatility of resource prices - Management of (reverse) networks - (reverse) network support and collaboration - Material 'market-places' (Tura et al., 2019)
Organisational/Managerial	Barrier or driver relates to organisational factors, either internal or external. Intra-organisational (inside organisations): - Organisations as social systems influenced by goals, routines, organisational structures, etc. (Diaz Lopez et al., 2019) - The extent to which circularity is integrated in a company's strategy and goals - The availability of skills and capabilities for CE (Tura et al., 2019) - Structural within companies, such as balancing top-down direction-giving and allowing bottom-up experimenting, and integrating different departments (Velenturf & Jopson, 2019)

	Inter-organisational (between different organisations): - Related to supply chain responsibilities - dependencies between organisations (more dependency makes change more difficult) - the integration of supply chain partners' perspectives and the ability to change practices of suppliers
Environmental	Barrier or driver relates to: - Resource constraints - The prevention of negative environmental impact (CO_2 emissions) (Tura et al., 2019)
Performance indicators	Barrier or driver relates to: - How circularity should be measured (Araujo Galvão et al., 2018)
CE definition/framework	Barrier or driver relates to: - The definition of the Circular Economy

After completion of the overview of CE barriers and drivers that were identified during an interview, it will be send to the respondent by e-mail for verification and ranking. The respondent is asked to verify the results and to indicate the top-5 barriers and top-5 drivers (in which 1 is the most important one). After verification of the results, the entire overview of barriers and drivers can be established, which allows for further analysis.

3.5. Conclusion – SQ2

The goal of this part of the research was to provide an answer to sub-question 2:

"How can the barriers and drivers for the implementation of CE in Dutch infrastructure projects be identified?"

The answer to this sub-question is that semi-structured interviews are the most appropriate methodology for this research. For these purposes, an interview guide was developed to provide some structure during the (semi-structured) interviews, which can be found in Appendix B – Interview guide. The interview guide also encompasses the questions that will be asked during the interviews, in which the literature-based framework of CE barrier- and driver-categories provided the basis for the interview questions. Given the explorative nature of this research, a sample group of 15 respondents has been selected from a balanced and diverse set of stakeholder types. These measures were taken to ensure that the resulting data from respondents would generalise as well as possible to Dutch infrastructure projects. A schematic depiction of the aforementioned research methodology is presented in Figure 9.

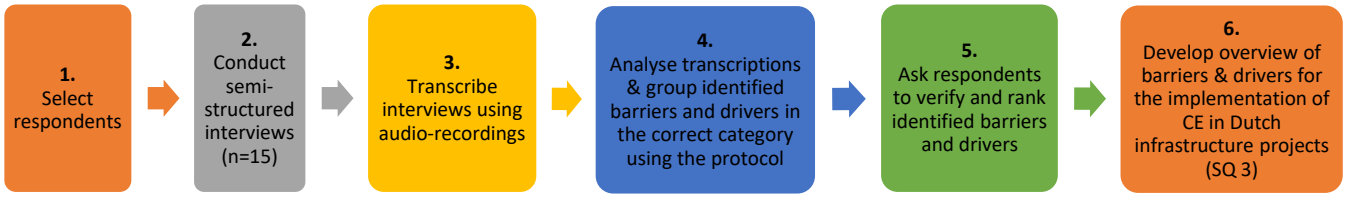

Figure 9 – Schematic flow of research methodology. Source: own work

4. RESULTS

In this part of the research an answer is provided to sub-question 3*: "What barriers and drivers for the implementation of CE in Dutch infrastructure projects are experienced by practitioners of the sector?"*.

In order to provide an answer to this sub-question, the interviews have been analysed using the methodology as described in Chapter 3.4. A total of 15 interviews were conducted in 13 different organisations. All interviews had a duration of approximately one hour and were taken in the months May and June of 2019. Interview number 7 and 12 were both conducted with two respondents, so a total of 17 respondents were interviewed. An overview of the interviewed organisations, supplemented by a description of the organisation and the organisation size can be found in Table 19. For the organisation size description, the bandwidths of the Dutch SME Servicedesk have been used (MKB Servicedesk, 2019), which are:

- Large: more than 250 employees
- Medium: less than 250 employees
- Small: less than 50 employees
- Micro: less than 10 employees

Table 19 – Overview organisations in which interviews were conducted. Source: own work

ID	Stakeholder type	Description of organisation	Organisation size
1	Contractor	Contractor specialised in a variety of infrastructural disciplines	Medium
2	Contractor	Contractor specialised in road infrastructure	Large
3	Client	Public client operating in infrastructure sector	Large
4	Client	Regional water authority	Large
5	Client	Regional water authority	Large
6	Supplier of building materials	Supplier of circular, bio-based concrete solutions	Micro
7	Contractor	Infrastructural construction company (interview with 2 respondents)	Medium/Large
8	Client	Public client operating in infrastructure sector	Large
9	Client	Municipality of medium-sized city	Large
10	Recycling company/ Wholesaler of building materials	Organisation specialised in selling of re-used construction- and dredging materials	Small
11	Engineering & Consulting firm	Organisation specialised in supporting organisations in transitioning towards a CE	Micro
12	Client	Province (interview with 2 respondents)	Large
13	Engineering & Consulting firm	Organisation specialised in supporting organisations in implementing CE and sustainable solutions	Small
14	Demolition contractor/ recycling company	Demolition company that is a frontrunner in working circular and sustainably	Medium
15	Engineering & Consulting firm	Interview conducted with the consultancy department of this organisation, more specifically the sustainability/circularity consultancy department	Medium/Large

Whereas the distinction between the stakeholder types clients, engineering & consulting firms and contractors was clear, this was not the case for organisations that had to be labelled as demolition contractors, recycling companies or wholesaler of building materials. Organisations 10 and 14 fulfil multiple roles and were therefore grouped in two stakeholder types.

For the selection of respondents, the aim was to safeguard that the group of respondents represented all the different stakeholder types involved in Dutch infrastructure projects and that the group of respondents was balanced. A total of 6 interviews with public organisations (all of which are clients) have been conducted. Nine interviews were conducted with respondents working for private organisations. Three with respondents working for engineering & consulting firms, three with respondents working for contractors, one interview with a supplier of (circular) building material, one interview with a demolition contractor/recycling company and one interview with a recycling company/wholesaler of building materials.

The main goal of the interviews was to identify barriers and drivers for the implementation of CE in Dutch infrastructure projects. Using the audio-recordings, the interviews were transcribed. The transcriptions allowed for objective interpretation of the interview results, which have been analysed using the literature-based framework of CE barriers and drivers as established in Chapter 2 and the methodology as described in Chapter 3.4.

The transcriptions have been analysed and were subsequently coded using the literature-based framework of CE barrier and drivers. Whereas the framework only provides insight in the types of CE barrier- and driver-categories and how often they appeared in the body of literature, the interviews were an opportunity to ask respondents for specific barriers and drivers for the implementation of Circular Economy in Dutch infrastructure projects.

4.1. Identified barriers & drivers – per category

A total of 135 barriers to, and 72 drivers of the implementation of CE in Dutch infrastructure projects were identified during the interviews. As described in the Methodology (Chapter 4) of this research, respondents were asked what they see as barriers or drivers for the implementation of CE in Dutch infrastructure projects. These questions were initially asked in an open manner. Hereafter, the question was formulated more specifically, by asking respondents whether they recognise barriers or drivers in a certain category. As it is important to objectively interpret what the respondents said, a protocol (Table 18) has been developed by which the identified barriers and drivers can objectively be grouped in the correct category. Based on the criteria as provided in this protocol, the identified barriers and drivers have been grouped in the corresponding categories of the literature-based framework.

Prior to presenting the identified barriers and drivers, an overview of the number of CE barriers and CE drivers per category that were identified during the interviews is provided (respectively Figure 10 and Figure 11).

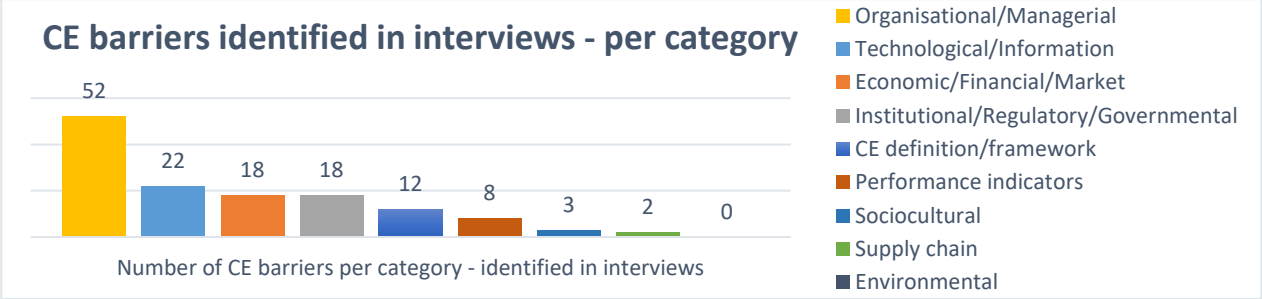

Figure 10 – Number of CE barriers per category – identified during the interviews. Source: own work

As can be seen in Figure 10, Organisational/Managerial CE barriers were mentioned most frequently during the interviews. CE barriers in the categories Technological/Information, Institutional/Regulatory/Governmental and Economic/Financial/Market nature were mentioned second and third most frequently. These are followed by barriers that can be categorised in CE definition/framework, Performance indicators, Sociocultural barriers and Supply chain. Environmental barriers have not been identified during the interviews.

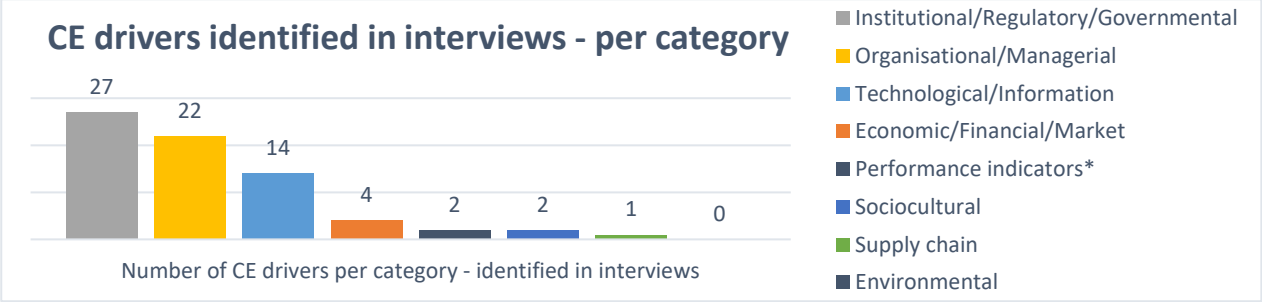

Figure 11 – Number of CE drivers per category – identified during the interviews. Source: own work

Figure 11 shows that the most frequently mentioned CE drivers are Institutional/Regulatory/Governmental, followed by Organisational/Managerial. The third most frequently mentioned CE drivers are Technological/Information. Drivers in the categories Economic/Financial/Market, Performance indicators, Sociocultural and Supply chain were mentioned significantly less frequently. However, whereas Performance indicators was not mentioned as a driver category in the literature it was in fact mentioned as a driver two times during the interviews. Drivers in the categories CE definition/framework and Environmental have not been identified during the interviews. While this section has provided some insight in the number of barriers and drivers per category, the actual value of the results lies on a deeper level; of the identified barriers and drivers instead of the categories. These are presented in the following two sections 4.2 and 4.3).

4.2. Identified barriers for the implementation of CE in Dutch infrastructure projects

In this section, the barriers for the implementation of CE in Dutch infrastructure projects mentioned most often by the respondents are presented. The entire overview of barriers can be found in Appendix C.1. Identified barriers for the implementation of CE in Dutch infrastructure projects Given the overlap in several of the 135 identified barriers a more concise overview of barriers has been developed (Table 20). The description of the most frequently mentioned barriers as presented in this section was made based on Table 20.

One of the most frequently mentioned barriers is of Organisational/Managerial nature and relates to the procurement of infrastructure projects. Circularity or the implementation of CE is a requirement in only a limited number of infrastructure tenders. In the tenders that are labelled as 'circular', awarding of the tender is still often largely based on lowest price and minimisation of traffic hindrance, not on circularity. This poses a barrier for the implementation of CE in infrastructure projects.

Another frequently mentioned Organisational/Managerial barrier relates to the aversion of risks. Safety is paramount In Dutch infrastructure projects as structural (or premature) failure of infrastructure assets can result in fatalities and enormous economic costs. Clients are therefore hesitant in adopting circular innovations or solutions in their projects and prefer to stick to the conventional, 'known' way of working. Whereas the Dutch infrastructure sector is often labelled as being conservative, this can more likely be ascribed to the aversion of risks.

A barrier in the category Economic/Financial/Market that was indicated several times relates to the costs of circular or secondary materials. Due to the additional costs for transportation and possible processing of secondary materials, along with the lack of economies of scale for secondary materials, the costs for the use of secondary materials are often higher than for 'primary' or virgin materials. From a financial point of view, using primary or virgin materials in infrastructure projects is therefore the preferred option.

Several respondents mentioned that the absence of a clear, unambiguous definition for 'Circular Economy' is a barrier. As there are different perceptions on what is meant by the implementation of a CE in the Dutch infrastructure sector, it is unclear what goal is worked to towards. Two barriers in the category Performance indicators were mentioned. The first barrier is that it is unclear how circularity should be measured. Secondly, there is no consensus on the level of circularity of the different R-strategies (as introduced in Table 2).

Several respondents mentioned Organisational/Managerial barriers. The most frequently mentioned barrier is that organisations are unable to adopt circularity due to the unavailability of the resources time and money, or because other departments within the organisation are unwilling to cooperate as they need to change the way they work.

Standards and guidelines, such as the Eurocode and the *'Standaard RAW bepalingen 2015'* have been mentioned to obstruct or prevent the use of circular or secondary materials. One of the respondents gave an example in which a circular asphalt could not be applied. In this circular asphalt, bitumen was no longer used as the binding agent, but an alternative. Due to the different composition of this circular asphalt, it could no longer be classified as asphalt and the material could therefore not be applied. Another example was of structural nature, in which a circular asphalt did not meet the entry requirements for roughness, while it was proven that the roughness of this circular asphalt remains significantly higher than the conventional asphalt type in the long term.

The overview of barriers for the implementation of CE in Dutch infrastructure projects per category that were mentioned less frequently is presented in Table 20. Please note that in some cases, the categories have been split up into themes and that the number in brackets [x] indicates during which interview the barrier has been identified.

Table 20 – Identified barriers for the implementation of CE in Dutch infrastructure projects

Category	Theme	Description of identified barriers
Organisational/ Managerial	Procurement	- Implementation of CE or circularity is a requirement in only a limited number of infrastructure tenders. In the tenders that are labelled as 'circular', awarding of the tender is still often largely based on lowest price and minimisation of traffic hindrance, not on circularity. This hampers the implementation of CE [2] [5] [6] [7] [10] [11] [13] [15] - In several tenders in which circularity should be incorporated, the specifications requirements are formulated so specific that it is impossible for contractors to implement circular solutions (i.e. by specifying that the applied materials should be new, or by specifying which materials should be used in a certain type of concrete or asphalt; preventing the application of a circular type of concrete or asphalt) [6] [10]
	Risk-aversion	- Risk aversion is paramount In Dutch infrastructure projects as structural (or premature) failure of infrastructure assets can result in fatalities and enormous economic costs. Clients are therefore hesitant in adopting circular innovations or solutions for their projects and prefer to stick to the conventional, 'known' way of working (this is sometimes also labelled as 'conservative', but is strongly related to the aversion of risks) [1] [2] [6] [7] [8] [11] [12] [15] - Specifications of materials are deliberately not provided, as providing incorrect information in the past has led to contractors suing the client. This impedes the high-grade reuse of materials and therefore circularity [3]
	Intra-organisational	- Organisations are unable to adopt circularity, due to the fact that the required resources (time & money) are not made available, or because other departments are not willing to cooperate [1] [7] [9] [11] - Organisations do not realise that change *within* the organisation is required for the implementation of circularity in their projects [11]
	Inter-organisational	- The implementation of CE in Dutch infrastructure projects requires different forms of collaboration *between* organisations [3] [10]
Technological/ Information	Technological	- Due to weathering and erosion, materials can only be high-grade re-used once or twice [12] [15] - Production of materials: the lower production speeds of circular materials or products make it impossible to compete with conventional materials (both in economic terms and in the restricted time in which for example highways need to be repaired) [2] [3] - Demolition: the existing infrastructure has not been 'designed for demolition' or 'designed for re-use', which impedes high-grade reuse of materials and therefore circularity [14] - The absence of a central platform in which information of materials is stored means that circularity cannot be implemented [3]
	Information	- For the majority of infrastructure assets there is no information about the materials' specifications, preventing high-grade re-use of materials [3] [8] - There is uncertainty on the lifespan of circular materials (i.e. materials or products made out of secondary materials) [6]
Economic/ Financial/ Market		- Costs for circular materials are often higher than for 'primary' or virgin materials, due to the additional costs for transportation or processing of the materials and the lack of an economy of scale for circular materials (therefor the costs of circular projects are higher than that of conventional projects) [2] [6] [9] [10] [14] [15] - Circular projects have a longer return on investment (> 1 year) than conventional projects [2] - The 'production chains' for construction materials are primarily designed for use with virgin materials [6] - Whereas in many other sectors, scarcity of materials drives up the price of primary materials and thus acts as an incentive to use secondary materials, primary materials required for the realisation of Dutch infrastructure projects are abundantly available [11]
Institutional/ Regulatory/ Governmental		- Standards and guidelines (such as the Eurocode and the 'Standaard RAW bepalingen 2015') may obstruct or prevent the use of secondary materials, due to different compositions (i.e. specifying that asphalt *must* contain bitumen, while a circular asphalt may contain an alternative binding agent) or specifications (a circular asphalt may not meet the entry requirements for roughness, but may wear less and have a higher roughness coefficient after 5 years than a conventional asphalt). By which these standards and guidelines hamper the implementation of CE [1] [2] [7] - The Procurement law impedes the innovations that are required for the implementation of CE. (For these innovations, extensive communication and collaboration between client and contractor is required in an early stage. However, the strict rules of the public procurement law is in contrast to this idea of cooperation as they prescribe rather compellingly how the contacts and communication between the client and take place and there is no room for experimentation. Although the new Public Procurement Act 2016 provides for new forms of public procurement: competition procedure & innovation partnership, this is proving to be difficult in practice.) [2] [10] - The lack of legislation and regulation that obligates the use and application of circular materials in Dutch infrastructure projects is considered a barrier, as there currently is no incentive to realise circular projects [3] - While the Dutch government is developing plans and goals to implement CE in all economic sectors, so far they have not specifically ordered their subordinate organisations involved in the infrastructure sector to implement CE in their projects [3]
CE definition/ framework		- There is no clear, unambiguous definition for 'Circular Economy', let alone for CE in specifically the (Dutch) infrastructure sector. The term is therefore often misused, but more importantly, it is unclear towards what goal is worked to [3] [7] [9] [12] [13] [14] - There is no consensus on which R-strategies (as introduced in Table 2) can be labelled as circular [10] [14] [15]

Performance indicators		- It is unclear how circularity should be measured [3] [7] [15] - Circularity is still predominantly measured in monetary values, hereby preventing the implementation[12]
Sociocultural		- There seems to be a tendency that every viaduct/lamppost/etc. in the Dutch infrastructure sector should have an unique design, while many assets can be standardized (which makes high-grade reuse easier) [2] - If the term Circular Economy is not embedded more structurally in the short term, it will blow over again; the Donut Economy is already gaining ground [13]
Supply chain		- The volume of required materials for new constructions is greater than the volume of available secondary materials [1]
Environmental		N/A*

* no barriers in this category were identified

4.3. Identified drivers for the implementation of CE in Dutch infrastructure projects

In this section, the drivers for the implementation of CE in Dutch infrastructure projects that were mentioned most often by the respondents are described. Due to the overlap in several of the 72 identified drivers (of which the entire overview can be found in Appendix C.2. Identified drivers for the implementation of CE in Dutch infrastructure projects), a more concise overview of drivers has been developed (Table 21). The description of the most frequently mentioned drivers as presented in this section has been made based on Table 21.

Many of the drivers that were mentioned by the respondents require the government to take action. One of the most frequently mentioned drivers is that the government should develop more binding legislation and regulations on the use and application of circular materials (at least to an extend) in infrastructure projects.

Moreover, respondents mentioned that the government should provide more room for circular innovations or pilot projects. Doing so may act as a catalyser for CE, as respondents also indicated that the successful application of circular construction materials (such as circular concrete or asphalt) or the realisation of circular projects (such as the circular viaduct in Kampen) resulted in a noticeable increase in demand for such materials or projects. A perceived risk or 'fear of the unknown' seems to be taken away. The government providing more room for circular innovations or pilot projects can therefore be considered an important driver for the implementation of CE in Dutch infrastructure projects.

Another frequently mentioned driver is that the government should provide more financial support (in the form of tax regulations or subsidies) to finance circular innovations in Dutch infrastructure projects, which can help accelerate the implementation of CE. In relation to procurement, awarding of infrastructure tenders should weigh more heavily on circularity. Tenders are still often predominantly awarded on the lowest bid and minimisation of traffic hindrance instead of circularity. Additionally, in the tenders that are circular or in which CE is central, formulating more specific requirements (as opposed to leaving them vague and hoping that the bids will be circular) has been mentioned to act as a driver for the implementation of CE.

Another driver that has been mentioned by multiple respondents is on the standardisation of infrastructural assets. The current lack of standardisation of components or materials applied in infrastructure hampers high-grade re-use.

Sharing of knowledge and information on the implementation of CE, both within organisations and between organisations has been mentioned as a driver. While sharing of knowledge may seemingly undermine the competitiveness of private parties, the puzzle of implementing CE in infrastructure projects is too big to be solved by one organisation. This requires that all the organisations in the infrastructure sector that are working on solving part of this puzzle should share their knowledge so that the sector can collectively solve the entire puzzle. While private parties might be wary in doing so, it should at least be done by the public clients in the sector.

The overview of barriers for the implementation of CE in Dutch infrastructure projects is listed per category in Table 21. Please note that some categories have been split up into themes and that the number in brackets [x] indicates during which interview the barrier has been identified.

Table 21 – Identified drivers for the implementation of CE in Dutch infrastructure projects. Source: own work

Category	Theme	Description of identified drivers
Organisational/ Managerial	Procurement	- Infrastructure tenders should be awarded more based on circularity (tenders are still often awarded based on lowest price and minimisation of traffic hindrance, not on circularity). Additionally, in the tenders that are 'circular', the requirements should be made more specific (instead of leaving them vague and hoping that the bids will be circular) [1] [14] [15] - Procurement of both construction and maintenance of infrastructure assets in the same contract creates an incentive for contractors to deliver high quality (long lifespan, little maintenance) [13]
	Risk-aversion	- Clients need to accept the shorter guarantee period for the lifespan of circular concrete or asphalt [12] - Public clients need to show courage by fulfilling the role of launching customer more frequently [10] [12]
	Intra-organisational	- Organisations themselves need to think of circular solutions for released secondary materials or assets in an early stage (instead of leaving this up to the market) [5] [8] - Organisations should make money available for the implementation of CE in their projects [9] - In order to realise circular projects, it is important that circularity is in the DNA of organisations (so circularity should be central in all layers of the organisation; no waste, emissions-free vehicles, etc.) [9]
	Inter-organisational	- Agreements such as *'Green Deal Duurzaam GWW 2.0', 'Betonakkoord'* and *'Asfalt impuls'* enable organisations to commit to circular goals and are also being developed for the materials steel and wood [5] [8]
Technological/ Information	Technological	- Standardise infrastructural assets so components/materials works can be more easily re-used in secondary applications [8] [11] [13] - Instead of outsourcing circular construction innovations to 'the market', public clients should do more research themselves (and test these innovations in pilots) [7] - Develop a model compared to Steward Brand's *'Shearing Layers'* model to distinguish the different lifespans of infrastructure assets [13]
	Information	- Information regarding secondary materials (i.e. 'passports') should be made available so that a market for secondary materials can develop [4] [15] - A fully functioning platform on which material information can be stored (i.e. Madaster) can accelerate the transition towards CE [8]
	Knowledge	- Sharing of knowledge and information on the implementation of CE, both within organisations and between organisations. While this may undermine private parties their competitiveness, this should at least be done by public clients [5] [8] [13]
Economic/ Financial/ Market		- Financial incentives are strong incentives for organisations to develop new technologies or innovations: 1. During the times in which oil prices peaked, it was economically beneficial to separate all the different layers of asphalt and bitumen (a by-product of oil). This enabled developing new, high-grade asphalt from these secondary materials (achieving maximum circularity). The high price of oil has been an incentive for the market to make high-grade new asphalt from old asphalt (the technology to do so is available, but when the oil price is normal this is too costly) [3] [7] 2. The high costs of dumping dredging material has always been reason for Water Authorities to find new applications of dredging materials (i.e. in dykes) [4]
Institutional/ Regulatory/ Governmental		- The government should develop more binding legislation and regulations on the use and application of circular materials (at least to an extend) in infrastructure projects. This creates a level-playing field for all private parties [1] [2] [4] [6] [7] [10] [11] [14] - The government should provide more room for circular innovations/pilot projects [1] [6] [10] [15] - The government should provide more support (i.e. in the form of tax regulations/subsidies) to finance circular innovations in Dutch infrastructure projects, which can help accelerate the implementation of CE [2] [8] [11] - Non-binding agreements or guidelines both in the infrastructure sector (*'Asfalt-Impuls'* and *'Betonakkoord'*) and in other sectors (*'Milieu-Prestaties Gebouwen'* and *'BREEAM',* both from the buildings sector) have given sustainability and circularity a noticeable boost [1] [10] [14]
CE definition/ framework		N/A*
Performance indicators		- The quality of materials should not only be expressed in terms of strength or lifespan, but also on its ability for circular applications (reuse, recycle etc.) [11] - Provide clarity on *how* circularity should be measured [15]
Sociocultural		- The successful application of circular construction materials (i.e. circular concrete) or the realisation of the circular viaduct in Kampen have resulted in a noticeable increase in demand for such materials or products (a perceived risk or fear seems to be taken away). This stresses the need for more of such pilot projects in which technologies can prove successful [6] [8]
Supply chain		- Re-use materials on a regional level so that the costs and environmental impact as a result of transportation is minimised [15]
Environmental		N/A*

*no drivers in this category were identified

4.4. Ranked barriers & drivers for CE in Dutch infrastructure projects

In the previous paragraph (4.1), the indicated barriers and drivers for CE in Dutch infrastructure were presented. As described in the methodology, in addition to identifying barriers and drivers, respondents were asked to rank them, in the form of a top-5 (with number 1 being the most important barrier or driver). The decision to ask respondents for a top-5 ranking was made because this provides clear enough insight in the top barriers and drivers, but is a small enough request to likely be carried out by all respondents. Based on the respondents' ranking, points are rewarded to the identified barriers and drivers. A relatively straightforward scoring system has been selected, in which the number 1 barrier or driver is rewarded 5 points, number 2 is rewarded 4 points, number 3 is rewarded 3 points, etcetera.

The ranking of the identified barriers and drivers for the implementation of CE in Dutch infrastructure projects from 9 out of 15 interviews has been received. The entire overviews of ranked barriers and drivers can be found in respectively in Appendix D – Overview of ranked barriers and drivers for CE in Dutch infrastructure projects. The sum of the total scores of ranked barriers by the respondents per category is presented (Figure 12). As can be concluded from this figure, barriers in the category Organisational/Managerial scored highest. The second highest scoring barriers are Economic/Financial/Market, followed by barriers in the categories Institutional/Regulatory/ Governmental and Technological/Information.

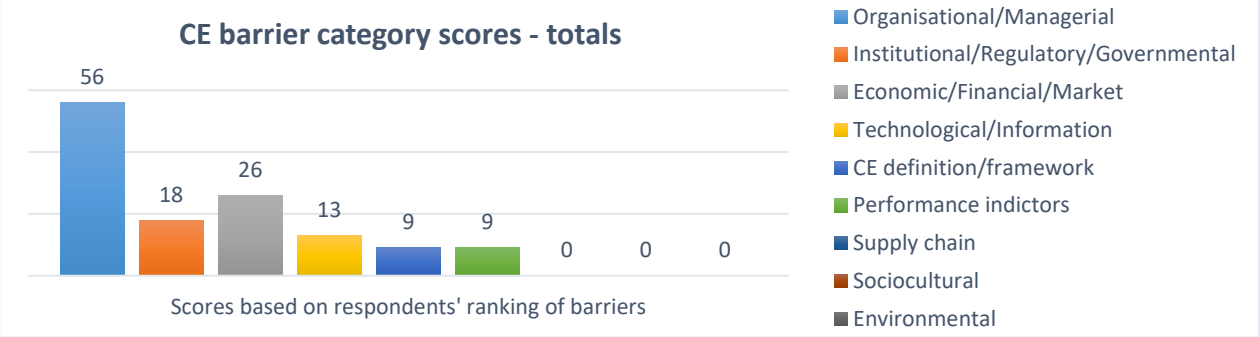

Figure 12 – Scores of barriers for the implementation of CE in Dutch infrastructure projects, as indicated by respondents. Source: own work

The sum of the drivers as ranked by the respondents is presented in Figure 13. As can be concluded from the figure, drivers in the category Institutional/Regulatory/Governmental scored highest. The second most important drivers fall in the category Organisational/Managerial, followed by Technological/Information and Economic/Financial/Market drivers.

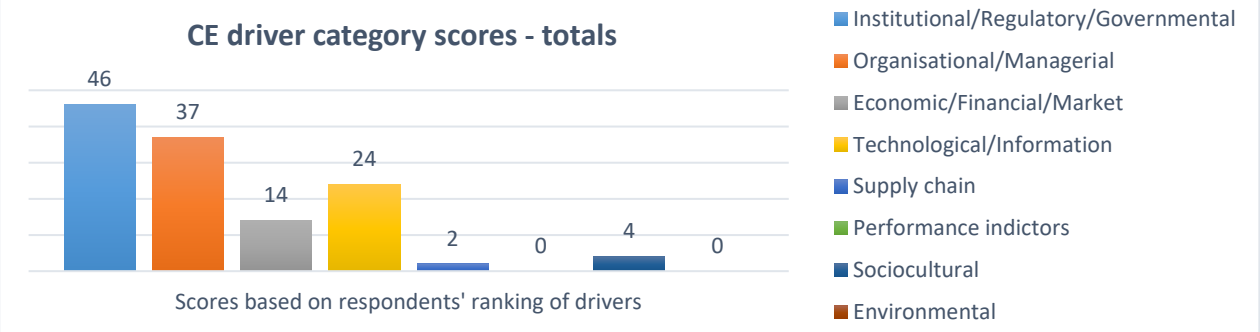

Figure 13 – Scores of drivers for the implementation of CE in Dutch infrastructure projects, as indicated by respondents. Source: own work

4.5. Conclusion – SQ3

The goal of this part of the research was to provide an answer to sub-question 3: *"What barriers and drivers for the implementation of CE in Dutch infrastructure projects are experienced by practitioners of the sector?".*

In a total of 15 interviews, 17 respondents were asked for their view on the barriers and drivers for the implementation of Circular Economy in Dutch infrastructure projects. This resulted in a total of 135 barriers and 72 drivers, which could be divided in the categories as identified in the literature-based framework of CE barriers and drivers. The number of

CE barriers and CE drivers per category has been presented in Figure 10 and Figure 11, but the actual value of these results lies on the barriers and drivers themselves.

The barriers mentioned most frequently by practitioners of the infrastructure sector relate to the procurement of infrastructure projects, the aversion of risks, the higher costs of secondary or circular materials as compared to 'virgin' materials (and therefore, circular projects). Moreover, the lack of a clear and unambiguous definition for CE, the lack of consensus on the level of circularity of the different R-strategies and how circularity should be measured were found to be barriers. Intra-organisational barriers were also mentioned and relate either to the unavailability of resources for the implementation of CE or to certain departments of organisations being unwilling to change or cooperate. Lastly, respondents indicated that the current standards and guidelines are unfit and sometimes even obstruct the use of secondary or circular materials.

The drivers that were mentioned most frequently often require the government to take steps. The most frequently mentioned driver was that the government should develop more binding legislation and regulation on the use and application of circular materials (at least to an extend) in infrastructure projects. As the commissioner of the majority of infrastructure projects in the Netherlands, the government providing more room for circular innovations or pilot projects was mentioned as a driver. Doing so may act as a catalyst for CE; the successful application of circular materials or projects takes away a perceived risk or 'fear of the unknown' and has already proven to increase the demand for such materials or projects. Another frequently mentioned driver is financial support by the government for the development of circular innovations. Additionally, sharing of knowledge and information on the implementation of CE by both public and private organisations has been indicated to be a driver. Drivers that do not comprise solely of actions for the government are related to standardisation of infrastructural assets.

In addition to identifying the barriers and drivers, respondents were asked to indicate the top-5 barriers and top-5 drivers that were identified during the interview. This has been done for the barriers and driver of 9 out of 15 interviews, the scores of which are depicted in Figure 12 and Figure 13. The sum of the ranked barriers was highest for barriers in the category Organisational/Managerial, followed by Economic/Financial/Market barriers, and barriers in the categories Institutional/Regulatory/Governmental, Technological/Information and CE definition and Performance indicators. The sum of the ranked drivers on the other hand, was highest for drivers in the category Institutional/Regulatory/Governmental, Organisational/Managerial, Technological/Information and Economic/ Financial/Market.

In the next section, a discussion in relation to the finding of this research is presented.

5. DISCUSSION

This chapter contains a discussion on the findings in this research. The scientific implications of this research are presented in section 5.1. In section 5.2 the practical implications of this research are discussed. Further insights are discussed in section 5.3, followed by the conclusion on sub-question 4, in section 5.4. The limitations to this research are discussed in the last section of this chapter; section 5.5.

The goal of this chapter is to answer sub-question 4: *"To what extend are the identified barriers and drivers applicable to the implementation of CE in infrastructure projects in other European countries?".*

5.1. Scientific implications of research

In the beginning of this thesis, a knowledge-gap was defined: between the theoretical concept of the CE and its actual implementation into practice. Adams et al. (2017) stated that *"there is a significant body of literature on the drivers and benefits of circular economy [in general]; however, little research or wide- scale application has been undertaken within a construction context"* (p. 22). After conduction of the literature review, this statement could be confirmed. The body of literature on the barriers and drivers for the implementation of CE within the context of construction is limited. Academic literature on the implementation of CE in part of the construction sector; the infrastructure sector had so far been non-existent. This study has contributed to this knowledge gap and is novel in the sense that it is the first to provide an overview of the barriers and drivers for the implementation of CE in the context of infrastructure projects.

Scientific applicability of literature-based framework on Dutch infrastructure projects

In this paragraph, the applicability of the literature-based framework of CE barrier- and driver-categories to Dutch infrastructure projects is discussed. The basis for doing so is by making a comparison on how frequently CE barriers and CE drivers appeared in the literature and compare this with the frequency they were mentioned in the interviews. In order to make this comparison, the relative frequencies were calculated. How these calculations were done, as well as the overviews in which these relative frequencies are presented and compared can be found in Appendix E.

With the majority of the CE barrier- and CE driver categories from the literature-based framework being mentioned in the interviews, it can be concluded that the literature-based framework of CE barrier- and driver-categories is applicable to Dutch infrastructure projects. In which it should be noted that neither barriers nor drivers in the category Environmental were identified during the interviews, while this category was in fact part of the literature-based framework. Remarkable was that drivers in the category Performance indicators were identified in three interviews whereas the literature review did not indicate this to be a driver category (and therefore was not part of the literature-based framework). For the framework to be applicable to Dutch infrastructure projects, the driver category Performance indicators should be added.

The literature-based framework provides a good basis for further studies in the context of infrastructure projects, under the conditions that the driver category Performance indicators is added and that extra attention is paid on the presence of barriers and drivers that can be categorised as Environmental. It is therefore recommended to use this framework as the basis for other studies on the barriers and drivers of the implementation of CE within the context of infrastructure projects. Caution should however be taken when using this framework for studies on these barriers and drivers in the context of other sectors or project types.

5.2. Practical implications of research

This research contributes to the practical knowledge on the implementation of CE in infrastructure projects both in the geographical context of the Netherlands and other European countries. Exactly how this research contributes is discussed in the following paragraphs.

5.2.1. Practical applicability of literature-based framework in Dutch infrastructure projects

In the previous section, the scientific implications of the literature-based framework have been discussed. While the literature-based framework can provide the basis for further application in the scientific field, it can also be practically applied. Applying small changes to the framework (as described in section 5.1), it can be useful for both policy makers and practitioners in the Dutch infrastructure sector.

Generalisability of results to infrastructure projects in other European countries

Whereas the aim of this research has been to identify barriers and drivers that apply specifically to the implementation of CE in infrastructure projects in the Netherlands, some of the results may be generalizable to other geographical areas. In this part of the research the generalisability of the results to infrastructure projects in other European countries is discussed. Ghisellini, Ripa, & Ulgiati (2018) and Kirchherr et al. (2018) stated that their findings on CE barriers and drivers may be very sector- or region-specific. Moreover, the environmental and economic sustainability of a CE framework is very site-specific and depends on several factors such as material type, building elements, transport distances, economic and political context (Ghisellini et al., 2018). This should also be taken into account with to the findings of this research.

In this part of the research, the applicability of barriers and drivers that were mentioned by at least two different respondents is discussed. This threshold level is selected, as the identified barriers and drivers in this research have not been validated. The validity of a barrier or driver for CE in Dutch infrastructure projects that is mentioned by only one respondent is uncertain. In the case a barrier or driver has been mentioned by two or more respondents, it is fair to assume that this these findings are valid. The generalisability of barriers and drivers that were mentioned by two (or more) different respondents will be discussed per category. All categories except Environmental and Supply chain contain a barrier or driver that was mentioned by at least two respondents.

Technological/Information

Characterising for infrastructure projects are the long life cycles, which pose challenges for information management technologies in which material specifications are stored (which is crucial for high-grade reuse of materials). This challenge is not limited to infrastructure projects in the Netherlands, but will apply to infrastructure projects in other European countries as well.

Another technical barrier related to weathering and erosion is that the number of times materials can be high-grade reused is limited. Respondents indicated that this mainly applies to stony materials (asphalt and concrete), as over time the roughness of the material changes. As this barrier is related to the technical properties of these materials, it is not limited to certain geographical areas and will apply to infrastructure projects in other European countries as well.

Sharing of knowledge and information on the implementation of CE, both within organisations and between organisations has been identified as a driver for at least the geographical context of the Netherlands. Within the European Union, knowledge attained by countries may be shared. Additionally, the development of information management technologies in which the specifications of materials (i.e. information passports) can be stored can act as a driver not in only in the Netherlands, but throughout all of Europe.

Economic/Financial/Market

In the Netherlands, the costs for secondary or circular materials are higher than for virgin (or primary) materials. While there is no material scarcity for the materials used in infrastructure projects in the Netherlands, this might be the case in other geographical areas, driving up the costs and making secondary materials a more attractive alternative. The lack of economies of scale for secondary materials makes it difficult to compete with virgin (or primary) materials. Given that the Netherlands is considered a pioneer in circularity (van Buren et al., 2016), but the scale of the economy for secondary materials is still too small to compete with virgin (or primary) materials, it is fair to assume that these challenges also apply to infrastructure projects outside of the Netherlands.

Institutional/Regulatory/Governmental

In order to ensure safety in infrastructure projects, strict standards and guidelines have been developed. For infrastructure assets in the Netherlands these are formulated in the ‘Standaard RAW bepalingen 2015’. Similar standards and guidelines such as the Eurocode apply to infrastructure projects in other European countries. Whereas the Eurocode provides requirements on the structural safety in, amongst other sectors, the infrastructure sector, it is unknown which more specific requirements as formulated in standard and guidelines such as the ‘Standaard RAW bepalingen 2015’ apply to other European countries. The applicability of this barrier to other European countries is therefore uncertain.

Given that the Procurement law applies to all public procurement contracts in the EU, the identified barriers mentioned related to this theme will also apply to other European countries. At least in the countries in which infrastructure projects are predominantly commissioned by public clients.

Drivers in this category predominantly require the government to take action. The first driver is that the government should develop more binding legislation and regulation on the use and application of circular materials in infrastructure projects as this creates a level-playing field for all private parties. Secondly the government should provide more room for circular innovations or pilot projects. Thirdly, the government should provide more support (such as tax regulation or subsidies) to finance circular innovations in Dutch infrastructure projects, which can help accelerate the implementation of CE. With the government being the commissioner of the majority of infrastructure project in European countries, these drivers likely also apply outside the Netherlands.

Organisational/Managerial

Given the high societal impact (consequences in terms of loss of life and economic costs) for structural failure in infrastructure projects, safety is paramount in the sector. Clients in the Netherlands are doing everything they can to ensure safety in their infrastructure projects. However, this makes these clients rather hesitant in embracing circular solutions (or any other solution that deviates from what is known). This hesitance of organisations in the adoption of circular solutions will not only apply to infrastructure projects in the Netherlands, but to these types of projects throughout Europe.

Sociocultural

Several respondents indicated that the successful application of a circular construction material or project has resulted in a noticeable increase in demand for such materials or projects in the Netherlands. The perception of society on such projects seems to have shifted. Despite cultural differences, the same effect is assumed to happen for other European countries.

CE definition/framework

The lack of a clear and unambiguous definition for 'Circular Economy' and the fact that it is unclear what this exactly entails for the infrastructure sector is a barrier that is not bounded by the borders of the Netherlands. Academics and practitioners throughout the world have not yet reached consensus on this matter, so this barrier will likely apply to other European countries as well.

Performance indicators

Besides the absence of a clear definition for CE, it is yet uncertain how circularity should be measured. This barrier will therefore likely also apply to other European countries.

5.2.2 Application in Dutch infrastructure projects: overcoming the barriers and enhancing the drivers

This section functions as a step-up in questioning the research question. The central aim of this research is to determine what barriers need to be overcome and what drivers need to be enhanced in order to accelerate the implementation of CE in Dutch infrastructure projects. A large number of barriers have been identified. Despite that several of these barriers overlap and could therefore be grouped, a lot of unique barriers can still be distinguished (Table 20). The same applies to the drivers; after grouping of overlapping drivers, a considerate amount of drivers remains present (Table 21). A selection therefore has to be made, which will be based on the number of respondents that have indicated a certain factor to be a barrier or driver. The three most frequently mentioned barriers and the three most frequently mentioned drivers will therefore be considered.

5.3. Further insights

Remarkable was that the majority of the identified drivers for the implementation of CE in Dutch infrastructure projects require the government to take certain actions. To summarize, these actions entail that the Dutch government should:

- develop more binding legislation and regulations on the use and application of circular materials
- provide more room for circular innovations or pilot projects
- provide more financial support (in the form of tax regulations/subsidies) to finance circular innovation;
- weigh circularity more heavily in awarding of infrastructure tenders.

Whether the Dutch government sees itself as the designated stakeholder to execute these actions is up for debate.

Whereas stakeholders in the Dutch infrastructure sector are often labelled as being conservative, several of the respondents ascribed this to the aversion of risks. Risk aversion is an important pillar in any sector, but since structural or premature failure of infrastructure assets may result in fatalities or enormous economic costs (or both) it is understandable that clients are hesitant in adopting circular innovations or solutions in their projects and prefer to stick to the conventional, 'known' way of working.

5.4. Conclusion – SQ4

The goal of this part of the research was to find an answer to sub-question 4: "*To what extend are the identified barriers and drivers applicable to the implementation of CE in infrastructure projects in other European countries?*"

It can be concluded that the majority of identified barriers and drivers that are applicable to the implementation of CE in infrastructure projects in the Netherlands can also be applied to other European countries. With the Netherlands being considered a pioneer in circularity (van Buren et al., 2016), it seems fair to state that barriers for CE as experienced by the Netherlands have neither been overcome in other European countries. However, this does not mean that all the barriers and drivers applicable to other European countries have been identified. Due to economic and political differences in other European countries, barriers and drivers additional to the ones identified in this research may apply for infrastructure projects in other European countries, for which further studies are required. Moreover, despite being labelled as a frontrunner, the Netherlands can potentially still learn from other European countries.

5.5. Limitations of research

Several limitations apply to this research. What these limitations are is described in this section of the report. Evaluation of the research limitations is important to determine the actual value of the conclusions of the study. In this section, the limitations regarding the research methodology, the obtained data, limitations in general and the limitations regarding the generalisability of the results are discussed.

Limitations of research methodology

Given the explorative nature of this research, the external validity of the results is under pressure. While the respondents were asked to verify the barriers and drivers identified during their interview, the selected research methodology offered no room for external validation of the results. For more valuable and trustworthy research results, the barriers and drivers for the implementation of CE in Dutch infrastructure as identified by the different respondents should have been validated by other respondents as well.

Limitations of obtained results

One of the limitations regarding the obtained data relates to the limited number of circular infrastructure projects. With respect to the transition towards a CE in the infrastructure sector, we are only at the foot of the mountain, still having a long climb ahead. A large part of the debate therefor is on why circular infrastructure projects are not realised at all, instead of finding factors that possibly hinder the intended realisation of a circular project.

The role of the researcher in the interpretation of the qualitative research results was anticipated prior to conducting the semi-structured interviews. However, despite safeguarding paying attention to asking interview questions that are as neutral as possible, along with a protocol which describes what criteria have to be met in order for a barrier or driver to be group in a certain category, the acquired results have been subject to the interpretation of the researcher.

General limitations

Care has been taken to interview a balanced and diverse group of stakeholder. These measures were taken to ensure that the resulting data from respondents would generalise as well as possible. Despite the conduction of 15 interviews, from some stakeholder types only one respondent was interviewed.

Furthermore, time constraints have limited this research. Time constraints applied to both the general process of conducting this research, as well as during the interviews. One hour was found to be the maximum amount of time respondents were able to make free for the interview. In practice, from this hour, significantly less time is available for conduction of the actual interview, as a lot of time is spend on formalities or things like getting coffee. However, even for the interviews in which time was limited, it is fair to assume that respondents share what they think are the most important barriers and drivers it is assumed that the most important.

Limitations of generalisation of results

While the research results can be applied to geographical regions other than the Netherlands; European countries, the results specifically apply to infrastructure projects. It is uncertain whether these results can be adopted to sectors other than the infrastructure sector.

6. CONCLUSION

This study addressed the problem of the slow implementation of a Circular Economy in Dutch infrastructure projects. It focussed on identifying the barriers that hamper this transition, as well as identifying the drivers that may stimulate the implementation of CE in Dutch infrastructure projects. The following research question was formulated:

"What are the barriers and drivers that respectively need to be overcome and enhanced in order to accelerate the implementation of a Circular Economy in Dutch infrastructure projects?"

By means of a literature study and 15 semi-structured interviews, an answer has been found to the formulated research question. The literature study was required for the development of a literature-based framework of CE barrier- and driver-categories. As no off-the-shelf framework of CE barrier- and driver-categories for application in Dutch infrastructure projects exists, it had to be developed. This literature-based framework provided the basis for the formulation of the interview questions.

This thesis has been written in the structure of the sub questions, which were introduced in Chapter 1. Each succeeding chapter was dedicated to answering one of the four sub-questions. In the following section, the research sub-questions will be answered. This paragraph is followed by a section on the strengths and limitations of this study. Lastly, recommendations for future research are presented.

6.1. Answers to the research sub-questions

In order to provide an answer to the main research question, this study was divided into four phases. In each phase, one sub-question was answered.

SQ1: What are the general categories of barriers and drivers for the implementation of CE?

The literature review has indicated that a high variety of CE barrier- and driver-categories can be distinguished. CE barriers have been studied in 25 out of 26 considered articles, nearly three times as often as CE drivers, which were studied in 9 out of 26 considered articles.

Several authors have questioned the one-on-one adoption of a CE barrier- and driver-category framework to other sectors, as the environmental and economic sustainability of a CE framework may be very site-specific and depends on several factors such as material type, building elements, transport distances and the economic and political context (Ghisellini, Ripa, et al., 2018; Kirchherr et al., 2018). For this reason, along with the fact that a wide variety of CE barrier- and driver-categories has been found in the literature, adoption of an existing CE barrier- and driver-category framework for application in Dutch infrastructure projects is deemed unsuitable. The aim of this part of the research therefore was to develop a literature-based framework of generally applicable CE barrier- and driver-categories (for application to the Dutch infrastructure sector).

A total of 26 articles across four different sector types have been analysed. The results from the sector types 'General', 'C&D World & Europe' and 'other' are considered relevant for the establishment of the literature-based framework of CE barrier- and driver-categories. However, given the economic, political and geographical differences between sector type 'C&D non-European' and the Netherlands, it has been considered whether or not the results from this sector type should be taken into account. It was found that the majority of categories mentioned in sector type 'C&D non-European' were mentioned at least as frequently as in the other sectors. The categories Technological/Information and Sociocultural were mentioned even more frequently in sector type 'C&D non-European' than in 'C&D World & Europe'. The decision has therefore been made to take the results from all the different sector types, -and therefore all 26 articles- into account in developing the literature-based framework of CE barrier- and driver-categories.

While the number of times a CE barrier- or driver-category appeared in the body of literature does not necessarily say something about its actual importance, it was considered the most feasible method for this research. The literature-based framework of CE barrier- and driver-categories is an adoption of the results in Figure 5 and Figure 6 (which depict the number of times a CE barrier- or driver-category appeared in the literature). The answer to the first sub-question can best be presented in the form of a table (Table 15), as it provides a clear and concise overview of the general categories of barriers and drivers for the implementation of CE. Please note that the categories are listed in order of most to least frequently appearing in the literature.

SQ2: How can the barriers and drivers for the implementation of CE in Dutch infrastructure projects be identified?

The answer to this sub-question is that semi-structured interviews are the most appropriate methodology for this research. For these purposes, an interview guide was developed to provide some structure during the (semi-structured) interviews, which can be found in Appendix B – Interview guide. The interview guide also encompasses the questions that will be asked during the interviews, in which the literature-based framework of CE barrier- and driver-categories provided the basis for the interview questions. Given the explorative nature of this research, a sample group of 15 respondents has been selected from a balanced and diverse set of stakeholder types. These measures were taken to ensure that the resulting data from respondents would generalise as well as possible to Dutch infrastructure projects. A schematic depiction of the aforementioned research methodology is presented in Figure 9.

SQ3: What barriers and drivers for the implementation of CE in Dutch infrastructure projects are experienced by practitioners of the sector?

In a total of 15 interviews, 17 respondents were asked for their view on the barriers and drivers for the implementation of Circular Economy in Dutch infrastructure projects. This resulted in a total of 135 barriers and 72 drivers, which could be divided in the categories as identified in the literature-based framework of CE barriers and drivers. The number of CE barriers and CE drivers per category has been presented in Figure 10 and Figure 11, but the actual value of these results lies on the barriers and drivers themselves.

The barriers mentioned most frequently by practitioners of the infrastructure sector relate to the procurement of infrastructure projects, the aversion of risks, the higher costs of secondary or circular materials as compared to 'virgin' materials (and therefore, circular projects). Moreover, the lack of a clear and unambiguous definition for CE, the lack of consensus on the level of circularity of the different R-strategies and how circularity should be measured were found to be barriers. Intra-organisational barriers were also mentioned and relate either to the unavailability of resources for the implementation of CE or to certain departments of organisations being unwilling to change or cooperate. Lastly, respondents indicated that the current standards and guidelines are unfit and sometimes even obstruct the use of secondary or circular materials.

The drivers that were mentioned most frequently often require the government to take steps. The most frequently mentioned driver was that the government should develop more binding legislation and regulation on the use and application of circular materials (at least to an extend) in infrastructure projects. As the commissioner of the majority of infrastructure projects in the Netherlands, the government providing more room for circular innovations or pilot projects was mentioned as a driver. Doing so may act as a catalyst for CE; the successful application of circular materials or projects takes away a perceived risk or 'fear of the unknown' and has already proven to increase the demand for such materials or projects. Another frequently mentioned driver is financial support by the government for the development of circular innovations. Additionally, sharing of knowledge and information on the implementation of CE by both public and private organisations has been indicated to be a driver. Drivers that do not comprise solely of actions for the government are related to standardisation of infrastructural assets.

In addition to identifying the barriers and drivers, respondents were asked to indicate the top-5 barriers and top-5 drivers that were identified during the interview. This has been done for the barriers and driver of 9 out of 15 interviews, the scores of which are depicted in Figure 12 and Figure 13. The sum of the ranked barriers was highest for barriers in the category Organisational/Managerial, followed by Economic/Financial/Market barriers, and barriers in the categories Institutional/Regulatory/Governmental, Technological/Information and CE definition and Performance indicators. The sum of the ranked drivers on the other hand, was highest for drivers in the category Institutional/Regulatory/Governmental, Organisational/Managerial, Technological/Information and Economic/ Financial/Market.

SQ4: To what extend are the identified barriers and drivers applicable to the implementation of CE in infrastructure projects in other European countries?

It can be concluded that the majority of identified barriers and drivers that are applicable to the implementation of CE in infrastructure projects in the Netherlands can also be applied to other European countries. With the Netherlands being considered a pioneer in circularity (van Buren et al., 2016), it seems fair to state that barriers for CE as experienced by the Netherlands have neither been overcome in other European countries. However, this does not mean that all the barriers and drivers applicable to other European countries have been identified. Due to economic and political differences in other European countries, barriers and drivers additional to the ones identified in this research may apply for infrastructure projects in other European countries, for which further studies are required.

Moreover, despite being labelled as a frontrunner, the Netherlands can potentially still learn from other European countries.

6.2. Answer to the research question

The answers to the four sub-questions provided the basis for answering the main research question. At this point, the four sub-questions have been answered and an answer can be given to the research question:

"What are the barriers and drivers that respectively need to be overcome and enhanced in order to accelerate the implementation of a Circular Economy in Dutch infrastructure projects?"

In section 5.2 the selection criteria for the barriers and drivers that respectively need to overcoming and enhancing to accelerate the implementation of a Circular Economy in Dutch infrastructure projects were determined. These are the top-3 most frequently mentioned barriers and the top-3 most frequently mentioned drivers.

The barriers that were mentioned most frequently mentioned by the respondents relate to the procurement of infrastructure projects, the aversion of risks, the high costs of circular or secondary materials as compared to primary or 'virgin' materials and the lack of a clear, unambiguous definition for CE (a total count of four, as two barriers share the third place).

The barrier related to procurement prevents the implementation of CE in an early stage. Circularity or the implementation of CE is a requirement in only a limited number of infrastructure tenders. In the tenders that are labelled as 'circular', awarding of the tender is still often largely based on lowest price and minimisation of traffic hindrance, not on circularity. This poses a barrier for the implementation of CE in infrastructure projects. Risk aversion is paramount in Dutch infrastructure projects as structural (or premature) failure of infrastructure assets can result in fatalities and enormous economic costs. Clients are therefore hesitant in adopting circular innovations or solutions in their projects and prefer to stick to the conventional, 'known' way of working. Whereas the Dutch infrastructure sector is often labelled as being conservative, this can more likely be ascribed to the aversion of risks.

The costs of circular or secondary materials as compared to primary or 'virgin' materials was often mentioned as a barrier. These costs results from the additional costs for transportation and possible processing of secondary materials, along with the lack of economies of scale for secondary materials. Given the higher costs for secondary or circular materials, using primary or virgin materials in infrastructure projects is the preferred option from a financial point of view. Moreover, the lack of a clear, unambiguous definition for CE has also been considered an important barrier as it prevents the clear dialogue and a common goal which is worked towards.

The majority of drivers that were mentioned most frequently by the respondents require the Dutch government to take the lead. These drivers are relate to the Dutch government developing more binding legislation and regulations on the use and application of circular materials in infrastructure projects, providing more room for circular innovations or pilot projects, providing more financial support to finance circular innovations, the government in taking the lead in establishing non-binding agreements (i.e. 'Asfalt-Impuls' and 'Betonakkoord'). Moreover, the government should award its tenders more heavily on circularity. The final driver on the third place (the third place is shared by a total of five drivers) relates to standardisation of infrastructural assets, in which the government does not necessarily have to take the lead.

6.3. Recommendations

In this section, the recommendations for future research are presented. These recommendations are partly based on the limitations of this research (section 5.5) and can be divided into scientific and practical recommendations.

6.3.1. Scientific recommendations

This study is one of the first attempts to determine the barriers and drivers for the implementation of Dutch infrastructure projects. Further studies into the following matters within this topic are therefore highly recommended in order to gain a better breadth and depth within this field of knowledge. These recommendations are:

1. Study potential differences in the barriers and drivers as perceived by different types of stakeholders

As mentioned in section 3.2, different types of stakeholders are interviewed as it was assumed that they all have different views on the barriers and drivers for the implementation of CE in Dutch infrastructure projects. During the interviews, I noticed that private organisations often pointed their finger at the public sector (and vice versa) as being

responsible for restraining the implementation of CE in infrastructure projects. However, this observation is based on intuition. Further research on whether this actually is the case and moreover, what the trends are regarding the perceived barriers and drivers as experienced by the different stakeholders would be a highly interesting topic for further research. In such a study however, it is recommended to gather data based on a larger number of each stakeholder type.

Additionally, the selection for the different types of stakeholders in this study was based largely on the distinction as made by Abbasova (2018). It would be interesting to study whether the selection of stakeholders based on the distinction by for example Adams et al. (2017) or other authors results in different outcomes.

2. Study how to overcome barriers and enhance drivers for the implementation of CE in Dutch infrastructure projects

The focus of this study has been to search for the barriers and drivers of the implementation of CE in Dutch infrastructure projects. *How* these barriers may be overcome and *how* these drivers may be enhanced has not been part of this study, but would be a highly interesting topic for further research.

This could either be studied by looking at best practices from other sectors. More progress on the implementation of CE has been made in Dutch buildings projects than in Dutch infrastructure projects. Best practices in how to overcome certain barriers as well as how to enhance certain drivers may be adopted from other sectors for application in Dutch infrastructure projects.

Another way to study how to respectively overcome and enhance these barriers and drivers would be to determine the views of the relevant stakeholders in Dutch infrastructure projects.

A third suggestion is to conduct case studies on circular infrastructure projects to study how certain barriers have been overcome in the realisation of such projects, as well as looking at which driving factors have been enhanced to implement the circular ambitions or goals. However, as mentioned earlier in this report, as of today only one circular infrastructure project in the Netherlands has been realised (Circular Viaduct in Kampen). Once more circular infrastructure projects are realised in the Netherlands such case studies can be conducted.

3. Study the barriers and drivers for the implementation of CE in infrastructure projects in other countries

In section 5.2 a discussion was presented regarding which of the barriers and drivers identified in this research will also apply to other European countries. This however does not mean that the results as identified in this research cover all barriers and drivers applicable to infrastructure projects in European countries other than the Netherlands. Further research on barriers and drivers for the implementation of a CE in infrastructure projects these countries would be highly interesting. The literature-based framework of CE barrier- and driver categories as developed in this research provides a good basis for such studies.

4. Applicability of literature-based framework in other sectors

The applicability of the literature-based framework of CE barrier- and driver-categories in Dutch infrastructure projects has been discussed in section 5.1. Whether this framework also extends to sectors other than the construction industry is uncertain. Studies on this topic would be valuable.

6.3.2. Practical recommendations

In addition to the scientific recommendations, practical recommendations have been formulated.

1. Organise session with stakeholders from the Dutch infrastructure sector

Over the course of this research I noticed that there was a lack of understanding of the challenges regarding the implementation of CE in infrastructure projects that different stakeholders face. Therefore, organising a session in which the identified barriers and drivers for the implementation of CE in Dutch infrastructure projects are discussed with practitioners from the field would be highly valuable and may result in more mutual understanding and possibly serve as the first step in finding ways to overcome barriers or enhance drivers. During the interviews, the majority of respondents indicated that they would be more than willing to attend such an event. Given the explorative nature of this research it is important that this session is not solely attended by the respondents that were interviewed for this research. Attendance of respondent besides the ones who were interviewed in this research is paramount for validation of the research results.

2. Incentivise organisations to reflect on the barriers and drivers they experience in implementing CE in Dutch infrastructure projects

Having conducted this research act as a first step towards implementing CE in Dutch infrastructure projects. However, organisations themselves should determine which barriers they are experiencing and which of these barriers are within their power to be overcome. The same applies to drivers, for which the first step would be to identify them. Secondly, organisations must determine which of these drivers are within their control. Further studies conducted by organisations on the barriers and drivers for the implementing of CE in Dutch infrastructure projects are therefore highly recommended. The literature-based framework as developed in this research may be used in such endeavours.

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Appendix A – Literature review articles

This Appendix is an elaboration of section 2.1 and contains an overview of all the articles that were studied for the literature review. Information on the authors, the study's topic, focus area and the country or geographical region it applies to can be found in Table 22 below.

Table 22 – Overview of articles that were studied

#	Author(s)	Description of study	Focus area, CE in:	Country or region
1	**Nußholz, Nygaard Rasmussen, & Milios (2019)**	3 case studies of pioneering Scandinavian companies that produce circular building materials. Policies that could remove barriers were also studied.	Building sector	Scandinavia
2	**Velenturf & Jopson (2019)**	Study on which types of values and costs considered for resource recovery business cases (besides economic) should be taken into account. Additionally, governmental aspects (such as regulatory change and policy integration) that should change in order to implement CE is also part of the study.	General	World
3	**Williams (2019)**	Literature analysis and expert workshop to identify the main (58) challenges for looping actions in cities, across eight themes.	Cities	World
4	**Eberhardt, Birgisdottir, & Birkved (2019)**	Literature review & case study on the potential of CE in sustainable buildings. Identifying key challenges and potentials was also part of study.	Building sector	Denmark
5	**Diaz Lopez, Bastein, & Tukker (2019)**	Study of 143 cases in which the implementation barriers of certain Resource Efficiency Measures (such as the CE) have been searched for.	General	World
6	**Tura et al. (2019)**	Development of CE barriers and drivers framework based on literature review. The appearance and content of this framework in practice was then examined in 4 case companies, by conducting 36 semi-structured interviews.	General	Finland
7	**Sigrid Nordby (2019)**	Study on barriers and opportunities for reuse of building materials in the Norwegian construction sector.	Construction & Demolition sector	Norway
8	**Chang & Hsieh (2019)**	Case studies and interviews to gain insight in the current development, barriers and future potentials of CE in Taiwan's building sectors and its related BIM applications.	Construction & Demolition sector	Taiwan
9	**Mahpour (2018)**	Ranking of barriers for CE in Iran's C&D sector by experts (n=6), that were identified in a literature review	Construction & Demolition sector	Iran
10	**Ghisellini, Ripa & Ulgati (2018)**	Literature review (n=70 articles) with the aim to explore environmental and economic costs and benefits of CE in the Construction & Demolition Sector.	Construction & Demolition sector	World
11	**de Mattos & de Albuquerque (2018)**	The study aims to identify and analyse the enabling factors and strategies for the structuring and diffusion of a circular business model.	Commercial refrigeration and Electronic equipment sector	World
12	**Bressanelli, Perona, & Saccani (2018)**	Literature review on the challenges towards a circular supply chain that companies face on the micro-level	Supply Chain Management	World

13	**Gálvez-Martos, Styles, Schoenberger, & Zeschmar-Lahl (2018)**	Comparison of circular C&D Waste Management practices between 30 European countries.	Construction & Demolition sector	Europe
14	**Kirchherr et al. (2018)**	Study on the barriers to the CE in the European Union (208 surveys and 47 expert interviews).	General	European Union
15	**Ghisellini, Ji, Liu, & Ulgiati (2018)**	Literature review (n=52 articles) on the barriers towards alternative C&D Waste Management strategies (as opposed to landfilling).	Construction & Demolition sector	China
16	**Huang et al. (2018)**	Study consisting of a literature review and 40 expert interviews on the challenges for adoption of the 3R principles in C&D Waste Management.	Construction & Demolition sector	China
17	**de Jesus & Mendonça (2018)**	Literature review (n=141 articles) on the drivers and barriers in the Eco-innovation Road to the CE.	General	World
18	**Govindan & Hasanagic (2018)**	Literature review (n=60 articles) on drivers, barriers and practices towards CE in Supply Chain Management.	Supply Chain Management	World
19	**Araujo Galvão et al. (2018)**	Literature review (n=195 articles) on the barriers towards CE.	General	World
20	**Densley Tingley, Cooper, & Cullen (2017)**	Study with the aim to understand and propose measure to overcome the barriers for structural steel reuse in the UK.	Structural Steel	United Kingdom
21	**Adams et al. (2017)***	Study consisting of surveys (n=110) and a workshop (n=97 attendees) to determine the current level of awareness regarding CE in construction, as well as overviews of the most pressing challenges and enablers for CE.	Construction & Demolition sector	United Kingdom
22	**Nasir, Genovese, Acquaye, Koh & Yamoah (2017)**	Study in which linear and circular supply chain in the construction industry are compared.	Construction & Demolition sector	United Kingdom
23	**Won & Cheng (2017)**	Literature review to study the potential opportunities of BIM for C&D Waste Management and minimization.	Construction & Demolition sector	World
24	**Esa, Halog, & Rigamonti (2017)**	Study on the development of strategies for C&D Waste based on the CE concept.	Construction & Demolition sector	Malaysia
25	**H. Yuan (2017)**	Study on the barriers and countermeasures for C&D Waste Management by means of literature review, semi-structured interviews (n=10) and group discussion (n=10 attendees).	Construction & Demolition sector	China
26	**Ritzén & Sandström (2017)**	Study in which barriers towards the CE have been identified by means of 18 semi-structured interviews (in 2 companies).	General	World

Appendix B – Interview guide

This Appendix is an elaboration of section 3.3 and contains the interview guide and question that have been used for conduction of the interviews. The structure of the interviews is as following:

I. Introduction

In this introductory part of the interview, the following topics will be discussed:

- Introduce myself, communicate goal & duration of interview (approximately 1 hour), discuss respondents requirements regarding confidentiality, ask permission for audio-recording of the interview and communicate that transcription of interviews will be shared with respondents

II. Introduction questions

In this part of the interview, questions are asked that enable the respondent to introduce him/herself. The following questions will be asked:

- Can you give a brief description of the company you work?
- What is the role that you fulfil in the company?
- What is your view on the of Circular Economy?

III. Questions on CE barriers and drivers

In this part of the interview, the respondent is ask on his/her view on the current state of the CE in Dutch infrastructure projects. The respondent will then be asked which factors (barriers) he/she thinks hinder the implementation of a CE in Dutch infrastructure projects. This question has deliberately been formulated in an 'open' manner. If the respondent is unable to think of barriers, the respondent will be asked whether he/she can think of CE factors that relate to the CE barrier categories from the literature-based framework.

After discussing the CE barriers, the respondent will then be asked which factors he/she thinks stimulate or accelerate the implementation of CE in Dutch infrastructure projects. Again, the questions will be asked in an 'open' manner. If the respondent is unable/no longer able to give answers regarding these drivers, the respondent will be asked whether he/she recognises the indicated CE drivers from the literature-based framework. It should be noted here that preferable all CE barrier and CE drivers categories from the literature-based framework are asked for. To summarize, the following questions will be asked in this phase of the interview:

- To your understanding, what is the current state regarding the Circular Economy in Dutch infrastructure projects?
    - What do you think is/are the reason(s) for this?
- What do you think are the factors that hinder the implementation of CE in Dutch infrastructure projects?
- Can you think of any factors that impede the implementation of CE in Dutch infrastructure projects, in relation to:
    - Technological/Information
    - Economic/Financial/Market
    - Institutional/Regulatory/Governmental
    - Organisational/Managerial
    - Sociocultural
    - Supply chain
    - Environmental
    - CE definition/framework
    - Performance indicators
- What do you think are the factors that stimulate/accelerate the implementation of CE in Dutch infrastructure projects?
- Can you think of any factors that stimulate/accelerate the implementation of CE in Dutch infrastructure projects, in relation to:
    - Economic/Financial/Market

- Technological/Information
- Institutional/Regulatory/Governmental
- Environmental
- Sociocultural
- Supply chain
- Organisational/Managerial

IV. Interview closure

At this stage, the interview has ended. The respondent is thanked for his/her time and will be informed that in a few weeks, a copy of the transcripts along with the CE barriers and CE drivers for the implementation of CE in Dutch infrastructure projects that were identified during the interview will be sent to him/her. In this e-mail, the respondent will be asked to rank the top-5 CE barriers and top-5 CE drivers.

V. Post-interview actions

- Transcribe interviews
- Analyse & code transcriptions
- Develop overview of CE barriers and CE drivers identified by respondent
- Send interview transcription and CE barrier and CE driver overview to respondent and ask him/her to:
  - verify results
  - rank top-5 barriers for implementation of CE in Dutch infrastructure projects
  - rank top-5 barriers for implementation of CE in Dutch infrastructure projects

Appendix C – Overview of identified barriers and drivers

This Appendix is an elaboration of section 4.1 and contains all 135 barriers and 72 drivers for the implementation of CE in Dutch infrastructure that were identified during the interviews. The appendix consists of two sections. In the first part of this appendix, the overviews of barriers identified in each category are presented. In the second part, the identified drivers per category are presented.

C.1. Identified barriers for the implementation of CE in Dutch infrastructure projects

The entire overviews of barriers for the implementation of CE in Dutch infrastructure projects that were identified during the interviews can be found in respectively Table 23 until Table 31.

Table 23 – Identified Organisational/Managerial barriers. Source: own work

Identified barriers	Stakeholder type	ID
M.b.t. sloopwerken in opdracht van een grote publieke opdrachtgever staat in het contract opgenomen dat 'vrijkomende materialen verblijven aan de aannemer', zonder dat enige informatie m.b.t. kwaliteit wordt verstrekt (Dit wordt bewust gedaan, ter voorkoming van het risico dat deze informatie incorrect is en een aannemer hierover een rechtszaak start, hetgeen in het verleden is voorgekomen)	Client	3
De huidige supply chain is een lineaire keten, hier verandering in aanbrengen vraagt niet alleen om een andere werkwijze binnen organisaties, maar ook tussen organisaties onderling	Client	3
Onduidelijkheid over hoe partijen met elkaar moeten samenwerken t.b.v. circulariteit	Client	3
Aanbestedingen werden voornamelijk beoordeeld op prijs, in plaats van circulariteit/duurzaamheid	Client	5
Ondanks dat er m.b.t.. het beleggen van duurzaamheid/circulariteit binnen het waterschap enorme stappen zijn gemaakt, is het waterschap nog niet volledig in staat om circulair te werken. Voor deze interne transitie is nog meer tijd nodig	Client	5
Een poging van een publieke opdrachtgever om een stalen boogbrug te herbruiken is mislukt (men wil gewoon liever een nieuwe brug/opdrachtnemers zijn niet bereid de brug ergens op te slaan als er geen gegarandeerde afzet voor is)	Client	8
Uit het oogpunt van 'voldoen aan de richtlijn' worden richtlijnen door opdrachtnemers dusdanig zwart-wit geïnterpreteerd dat dit innovaties belemmerd	Client	8
Het doorgaans risicomijdende karakter van publieke opdrachtgevers (wat goed is voor het garanderen van veiligheid en doorstroming) staat circulaire innovaties in de weg	Client	8
Binnen gemeente [9] wordt te weinig aandacht besteed aan de vertaling van beleid m.b.t. circulariteit naar daadwerkelijke uitvoering	Client	9
Doordat veel taken en verantwoordelijkheden (binnen gemeente [9]) zijn gesplitst kunnen geen circulaire oplossingen gerealiseerd worden (de taak van het verdelen van het geld, het bepalen wat aan projecten nodig is en het uitvoeren hiervan liggen verspreid binnen de organisatie)	Client	9
Er wordt onvoldoende geld beschikbaar gesteld binnen gemeente [9] om circulair te worden	Client	9
De contracten van gemeente [9] zijn dusdanig dichtgetimmerd (lees: er worden nog steeds vooral veel contracten voorzien van bestekken opgesteld) dat aannemers geen innovaties (circulaire) oplossingen kunnen inbrengen.	Client	9
De sterke drang naar veilig werken (binnen de gemeente [9] staat circulariteit in de weg; men wil niet afwijken van de standaard manieren)	Client	9
Zowel opdrachtgever als opdrachtnemer zijn niet bereid het risico te dragen dat de garantietermijn van een circulair materiaal (bijv. asfalt) niet gehaald wordt.	Client	12
De belangen van het garanderen van veiligheid en doorstroming wegen dusdanig zwaar dat er geen ruimte is voor circulaire experimenten/innovaties	Client	12
In de transitie naar CE stuit men binnen organisaties op weerstand van vooral de asset beheerders (tegenstrijdige belangen)	Client	12
Interne organisatie van project- en beheersafdeling bij (met name) gemeentes leent zich niet voor het realiseren van circulaire/as-a-service oplossingen. Projectafdeling wil vernieuwen, echter beheersafdeling werkt via LIOR (Leidraad Inrichting Openbare Ruimte) en heeft moeite met hiervan afwijken	Contractor	1
Alleen ‘proven technologies’ worden door opdrachtgevers geaccepteerd	Contractor	1
Opdrachtgevers zijn doorgaans niet bereidt de hogere kosten voor de eerste paar circulaire aanbestedingen te betalen (zowel opdrachtgever als opdrachtnemer zullen moeten betalen aan de kosten voor innovaties richting CE), waarna de prijs zeer waarschijnlijk gestaag zakt.	Contractor	1
Huidige beheerders kritieke GWW assets willen niet overstappen naar as-a-service omdat dan bijv. het onderhouden van primaire waterkeringen bij commerciële partijen komt te liggen (welke overgekocht kunnen worden/failliet kunnen gaan)	Contractor	1
Constructies in de GWW zijn van hoog maatschappelijk belang (verkeersveiligheid & doorstroming) waardoor men huiverig is met innovaties (risico-mijding)	Contractor	1
De markt zit op slot door gewoontes in wat wordt toegepast als wegconstructie	Contractor	2

Circulariteit wordt in slechts zeer weinig aanbestedingen uitgevraagd (en in de uitzonderlijke gevallen dat circulariteit wordt uitgevraagd, is niet helder omschreven hoe aan deze eis invulling gegeven moet/kan worden)	Contractor	2
Aanbestedingen voor grootschalige weg-infrastructuur projecten worden nog voornamelijk beoordeeld op de punten prijs en beschikbaarheid (zo kort mogelijke bouwperiode t.b.v. garanderen doorstroming) en niet op circulariteit	Contractor	2
Er wordt te veel vastgehouden aan de punten veiligheid en doorstroming, hetgeen innovatie/alternatieve bouwmethodes in de weg staat	Contractor	2
Aanbestedingen van publieke opdrachtgevers worden hoofdzakelijk nog op tijd, prijs & kwaliteit beoordeeld. Niet op circulariteit/duurzaamheid (door EMVI/BPKV)	Contractor	7
Opdrachtgevers staan niet erg open voor vernieuwingen/innovaties in grootschalige projecten (bouw is traditioneel)	Contractor	7
Opdrachtgevers zijn niet bereid om extra kosten te betalen voor circulaire projecten	Contractor	7
Het risicomijdende karakter binnen de GWW staat circulariteit in de weg	Engineering & Consulting firm	11
Er wordt vaak naar wet- & regelgeving gewezen zijnde een barrière. Echter, de overheid heeft hiervoor een loket ingericht, juist om casuïstiek te bespreken (Loket Ruimte en Regels van Min. EZ & IenW), echter krijgen zij weinig cases binnen. Daardoor lijkt het alsof organisaties zich achter wet- & regelgeving 'verschuilen'	Engineering & Consulting firm	11
De vertaling van circulair beleid naar daadwerkelijke uitvoering blijft uit	Engineering & Consulting firm	11
Circulariteit wordt in te weinig aanbestedingen goed uitgevraagd	Engineering & Consulting firm	11
Organisaties beseffen niet goed dat om circulair te worden, de organisatie intern moet veranderen	Engineering & Consulting firm	11
De benodigde organisatieverandering om circulair te worden vraagt om een ander type mensen op de inkoopafdeling. Waar inkopers van oudsher voornamelijk controleurs waren, worden er nu meer faciliterende/regisserende taken vereist	Engineering & Consulting firm	11
Individuen binnen organisaties willen graag dat deze circulair worden, maar stuiten op inter-organisatorische barrières (bijv. werkwijzen van bepaalde afdelingen) die circulariteit in de weg staan	Engineering & Consulting firm	11
Rechtmatigheid en doelmatigheid zijn binnen (GWW) aanbestedingen de speerpunten. Echter gaat nu 98% van de discussie over rechtmatig. Een groter deel van deze discussie zou moeten gaan over doelmatigheid; het realiseren van een maatschappelijke doelstelling (circulair/duurzaam GWW project)	Engineering & Consulting firm	13
(Publieke) organisaties geven in GWW aanbestedingen nog een (te) zware weging aan prijs ten opzichte van kwaliteit.	Engineering & Consulting firm	13
Veel (grote) bouwbedrijven in de GWW maken zelden langetermijnstrategieën. Er wordt slechts een aantal jaren vooruit gekeken (op een termijn vele malen korter dan de levensduur van de objecten die ze realiseren en ook korter dan de onderhoudscontracten die deze organisaties aangaan)	Engineering & Consulting firm	13
De zwart-wit interpretatie van de aanbestedingswet voorkomt dat OG en ON in GWW aanbestedingen de dialoog met elkaar aangaan, wat zorgt voor wantrouwen, onduidelijkheid over wat op circulair gebied mogelijk is. Hetgeen circulariteit belemmerd	Engineering & Consulting firm	13
In de spoorwegbouw is men zeer huiverig met de toepassing van gebruikte/secundaire materialen (vanuit oogpunt veiligheid)	Engineering & Consulting firm	15
Duurzaamheid/circulariteit wordt bij aanbestedingen vooralsnog vaak zijdelings ingebracht, in plaats van dat het een centraal staand thema is	Engineering & Consulting firm	15
Doordat de overheid vooralsnog voornamelijk aanbesteed o.b.v. laagste prijs zit de bouwsector gevangen in huidige werkwijzen/methodieken	Recycling company; Wholesaler of building materials	10
Om daadwerkelijk circulair te werken zullen materialen uit de regio moeten komen, hetgeen om andere vormen van samenwerking vraagt	Recycling company; Wholesaler of building materials	10
Circulariteit in aanbestedingen wordt vaak platgeslagen doordat alsnog moet worden voldoen aan zeer specifieke bestek eisen (voor bijv. asfalt)	Recycling company; Wholesaler of building materials	10
In sommige aanbestedingen die als circulair worden bestempeld is alsnog 90% van de EMVI waarde verkeershinder en slechts 10% circulariteit)	Recycling company; Wholesaler of building materials	10
Bedrijven zijn huiverig met het doen van de investeringen die benodigd zijn voor innovaties t.b.v. circulariteit	Recycling company; Wholesaler of building materials	10
Binnen publieke opdrachtgevers is een gebrek aan kennis over hoe de EMVI-methodiek wordt geïnterpreteerd door aannemers, waardoor nu alsnog veel partijen voor een zo laag mogelijke inschrijving gaan	Recycling company; Wholesaler of building materials	10
In contracten staan soms zowel eisen m.b.t. materiaalspecificaties (waar een secundair materiaal aan voldoet), maar vervolgens was er óók in opgenomen dat er *nieuwe* materialen moeten worden toegepast	Recycling company; Wholesaler of building materials	10
De circulaire ambities op politiek niveau worden niet door de uitvoerende organisaties doorvertaald in circulaire projecten	Supplier of building materials	6
Opdrachtgevers zijn terughoudend met toepassing van circulaire betonsoort (wat als de vereiste levensduur niet gehaald wordt?!)	Supplier of building materials	6
Veel organisaties maken gebruik van vaste bestekteksten die de toepassing van circulaire materialen in de weg staan	Supplier of building materials	6
In overheidsaanbestedingen wordt het toepassen van circulaire materialen zelden tot nooit gunstiger beoordeeld (er wordt dus geen CO2 prestatieladder / MKI score meegenomen in de uitvraag)	Supplier of building materials	6

Table 24 – Identified Technological/Information barriers. Source: own work

Identified barriers	Stakeholder type	ID
Een grote publieke opdrachtgever beschikt voor een groot deel van het areaal niet over de juist informatie m.b.t. materiaalspecificaties	Client	3
Bestaande areaal is nooit gebouwd met inachtneming van demontage/hergebruik van de toegepaste materialen. Ontwerpen voor demontage/hergebruik staat nog in de kinderschoenen.	Client	3
Waar Rijkswaterstaat vroeger nog beschikte over een materialen laboratorium waar zo'n 20 mensen werkten om materiaalinnovaties te ontwikkelen, is RWS nu afhankelijk van innovaties uit de markt	Client	3
Afwezigheid van een centraal platform (bijv. BIM) waar informatie m.b.t. materialen bijeenkomt maakt dat cirkel niet gesloten kan worden; circulair inkopen zou volgens respondent dan nu ook (nog) geen zin hebben	Client	3
Onduidelijkheid over hoe bouwwerken circulair ontworpen moeten worden	Client	3
I.v.m. de minimaal gestelde levensduur voor nieuwe werken is toepassing van hergebruikt staal in nieuwe oeverconstructies van waterschappen vaak niet mogelijk	Client	4
Veel materialen in GWW-bouwwerken hebben geen identiteit (specificaties m.b.t. kwaliteit etc.), wat deze materialen tot afval maken	Client	8
Publieke opdrachtgevers hebben geen tot nauwelijks materiaalexperts in dienst, waardoor innovatie dus vooral vanuit de markt de organisatie in moet stromen	Client	8
Binnen een grote publieke opdrachtgever zit veel kennis in de mensen, niet in de organisatie. Voor pilots/innovaties zijn geen werkwijzers	Client	8
Er wordt door verschillende organisaties gewerkt aan standaardisatie t.b.v. circulariteit binnen de bouw, echter is er nog geen éénduidige standaard	Client	8
Zelfs al zou de Provincie [12] circulairder willen aanbesteden, ze weten nu simpelweg nog niet welke harde eisen ze zouden moeten formuleren	Client	12
Veel bouwmaterialen zijn slechts 1 tot 2 maal her te gebruiken	Client	12
Opdrachtgevers zijn niet goed op de hoogte van wat opdrachtnemers aan circulaire oplossingen kunnen leveren	Contractor	2
Voor circulair asfalt valt de productiesnelheid terug naar de helft van die van conventioneel asfalt, waarmee de tijdsduur van onbeschikbaarheid van een weg toeneemt	Contractor	2
Productiesnelheden van conventionele bouwmaterialen vs circulaire zijn dusdanig veel hoger dat de business case niet sluitend te krijgen is	Contractor	2
Opdrachtgevers zijn niet goed in staat om duidelijke eisen m.b.t. circulariteit te formuleren in hun aanbestedingen (hoewel de term 'circulariteit' in veel aanbestedingen staat vermeld, ontbreken specifieke eisen; niet SMART)	Contractor	7
Bouwwerken die momenteel worden gesloopt zijn nooit gebouwd met hergebruik van materialen na sloop in achterhoofd	Demolition contractor; Recycling company	14
Doordat de levenscycli in de GWW en het onderscheid tussen de verschillende materialen/elementen waaruit bouwwerken bestaan niet duidelijk is, zijn de CE principes over hoogwaardigheid van hergebruik (binnenste cycli EMF vlinder) zijn in GWW projecten minder sterk van toepassing dan voor sommige producten of gebouwen	Engineering & Consulting firm	13
Door verwering/erosie/degeneratie van materialen zijn deze niet meer geschikt voor hoogwaardig hergebruik	Engineering & Consulting firm	15
Het is onduidelijk wat de meest geschikte aanbestedingsvorm is om circulaire oplossingen uit te vragen	Recycling company; Wholesaler of building materials	10
Er is een gebrek aan kennis over hoe we onze lineaire consumptiepatronen circulair kunnen maken	Supplier of building materials	6
Er is een gebrek aan informatie m.b.t. de levensduur/kwaliteit/toepassing van circulaire materialen	Supplier of building materials	6

Table 25 – Identified Economic/Financial/Market barriers. Source: own work

Identified barriers	Stakeholder type	ID
Huidige verdienmodellen recyclingbedrijven staan circulariteit in de weg, omdat deze nu berusten op het oplossen van een afvalprobleem, in plaats van een circulair probleem	Client	3
Circulaire oplossingen zijn nu doorgaans nog duurder dan conventionele oplossingen	Client	9
Circulaire initiatieven hebben langere terugverdientijd dan standaardoplossingen (Return on Investment circulaire alternatieven doorgaans > 1 jaar)	Contractor	1
Bedrijven wachten op elkaar wachten met innoveren door *'winner-takes-all'* principe	Contractor	1
De toenemende vraag naar secundaire bouwmaterialen (bijv. betonpuin) zorgt voor prijsstijging. De kosten van secundaire bouwmaterialen wordt daarmee nóg hoger dan die van primaire bouwmaterialen.	Contractor	1
Er zijn nog geen *economies of scale* voor circulaire betonsoorten, wat maakt dat circulaire betonsoorten nu nog duurder zijn dan conventionele betonsoorten.	Contractor	2
Volledig circulair asfalt is technisch mogelijk (door de asfaltlagen apart te vrezen), echter wordt dit niet gedaan omdat het duurder is	Contractor	7

De prijs van secundaire materialen is hoger dan die van primaire/nieuwe bouwmaterialen	Demolition contractor; Recycling company	14
Omdat betonproducten ook zelf leveranciers van toeslagmaterialen zijn, zijn zij niet gebaat bij het toepassen van alternatieve (secundaire) materialen in hun beton	Demolition contractor; Recycling company	14
Circulariteit moet altijd plaatsvinden binnen de huidige financiële kaders (om te voorkomen dat je als bedrijf failliet gaat), hetgeen de mogelijkheden om grote stappen m.b.t. circulariteit te zetten beperkt	Demolition contractor; Recycling company	14
In de GWW is materiaalschaarste geen prikkel om circulair te worden (In veel andere sectoren is materiaalschaarste wél een sterke prikkel)	Engineering & Consulting firm	11
De huidige manier van financiële waardering voorkomt duurzaamheid op de lange termijn	Engineering & Consulting firm	13
Het vlinder model voor de Circulaire Economie (van de EMF) is een materiaalstromen-model, wat betekent dat de CE als concept nu dan ook nog niet praktisch implementeerbaar is. De economische kant van CE is vooralsnog niet duidelijk/onbelicht (omdat we toe moeten naar een ander soort waardering van stromen, ander soort waardering van grondstoffen en een anders soort niet-waardering van afval.	Engineering & Consulting firm	13
Volgens de huidige systematiek zijn de waardes van materialen in slooprijpe bouwwerken momenteel 0 euro	Engineering & Consulting firm	15
Veel basismaterialen zoals zand en grind zijn primair economisch gunstiger dan gerecycled materiaal. Dit gezien de hoge transportkosten	Engineering & Consulting firm	15
De lage prijs van conventioneel beton maakt dat de business case voor circulair beton moeilijk te sluiten is	Recycling company; Wholesaler of building materials	10
Doordat een deel van het zand in beton wordt vervangen door miscanthus is het uiteindelijke betonproduct zo'n 10 à 15 procent duurder. Dit maakt concurrentie met standaard betonproducten moeilijk	Supplier of building materials	6
Huidige productieketens beton zijn volledig ingesteld op standaard betonsoorten. De vraag naar 'conventionele' betonsoorten is momenteel al dusdanig hoog, dat het voor betonleveranciers niet gunstig is om de circulaire betonsoorten te maken (tijdelijk aanpassen workflow). Reden dat ze dit doen is voornamelijk omdat ze bijv. persoonlijk het milieu belangrijk vinden (niet zozeer vanuit economisch oogpunt)	Supplier of building materials	6

Table 26 – Identified Institutional/Regulatory/Governmental barriers. Source: own work

Identified barriers	Stakeholder type	ID
Er is een gebrek aan regulering voor de toepassing van secundaire materialen	Client	3
Huidige technische regelgeving (normeringen, voorschriften) staan circulariteit in de weg	Client	3
Duurzaamheid is geen eis in de opdracht van Min IenW aan Rijkswaterstaat, waardoor het nu afhankelijk is van of een projectmanager duurzaamheid wel/niet belangrijk vind of dit wordt meegenomen	Client	3
Aanbestedende diensten mogen alleen circulariteit als eis opnemen in hun aanbestedingen als ze intern ook beleid op circulariteit voeren	Client	4
Het is voorgekomen de doorlooptijd voor het aanvragen van een vergunning voor tijdelijke opslag van grond (waarmee een duurzame/circulaire oplossing kon worden gerealiseerd) dusdanig lang was dat projectteams besloten hier van af te zien.	Client	5
Bepaalde contractvormen staan circulariteit in de weg (DBFM is kwalitatief doorgaans hoog. Echter, in prestatiecontracten zit een perverse prikkel om als aannemer zo vaak mogelijk te moeten onderhouden. Contracten met eigenaarschap willen opdrachtgevers niet aan beginnen, omdat de verantwoordelijkheid voor kritieke primaire infrastructuur dan bij bedrijven komt te liggen welke failliet kunnen gaan of kunnen worden overgekocht door buitenlandse partijen)	Client	8
Voor nog lang niet alle onderhoudscontracten is DuboCalc met een MKI-score berekening verplicht gesteld	Client	8
Voor het hoogwaardiger hergebruiken van materialen moet het voldoen aan strenge eisen, die moeilijk haalbaar zijn	Client	12
Aanbestedingswet staat innovatie in de weg en biedt geen ruimte voor aannemers om mee te denken over ontwerpen/innoveren	Contractor	1
Secundaire bouwmaterialen passen niet binnen huidige certificeringen	Contractor	1
Door voorschriften over wat wel/niet mag worden toegepast als wegconstructie zit de markt op slot	Contractor	2
Circulair asfalt wordt niet toegepast omdat het de 'instap-eis' voor stroefheid nét niet haalt maar wel bewezen langer stroef blijft (t.o.v. conventioneel asfalt)	Contractor	2
Circulaire oplossingen voor beton/asfalt komen de markt niet op omdat deze niet passen binnen de Eurocode en binnen de voorschriften van ‘wat is beton/asfalt’. (Bijv. de afwezigheid van bitumen in het asfalt maakt dat het niet als ‘asfalt’ geclassificeerd kan worden, terwijl de structurele eisen wel gehaald worden.)	Contractor	2
Publieke opdrachtgevers hebben dusdanig veel regelgeving ontwikkeld om te voldoen aan de pijler veiligheid dat circulaire producten niet kunnen worden toegepast	Contractor	2
Het is niet duidelijk aan welke normen/eisen secundaire bouwmaterialen moeten voldoen	Contractor	7
De eisen in de standaard RAW bepalingen 2015 staan circulair materiaalgebruik in de weg	Contractor	7
Vrijkomende materialen hebben nu vaak de 'afval-status' omdat onduidelijk is wat de voorwaarden/eisen hiervoor zijn (het is niet duidelijk welke vervuiling er wel/niet in mag zitten, hoe het getest moet worden, etc.)	Engineering & Consulting firm	15

Europese aanbestedingen staan het op de markt krijgen van circulaire innovaties in de weg	Recycling company; Wholesaler of building materials	10

Table 27 – Identified CE definition/framework barriers. Source: own work

Identified barriers	Stakeholder type	ID
Het is onduidelijke wat een publieke opdrachtgever nou precies bedoeld met de doelstelling om per 2030 'circulair te werken'	Client	3
Het gebrek aan een eenduidige definitie voor Circulaire Economie maakt zowel het gesprek als de transitie lastig	Client	9
In de term Circulaire Economie zit het woord 'economie', wat al gelijk de link naar geld legt. Streven naar 'circulariteit' zou een beter doel zijn	Client	12
Projecten worden soms als 'circulair' bestempeld terwijl dit aantoonbaar niet mogelijk is	Client	12
Volgens de huidige definitie van CE binnen de Provincie [12] wordt reeds 80% circulair ingekocht, wat een veel hoger getal is dan in de praktijk daadwerkelijk circulair is	Client	12
Het inkoopbeleid van de Provincie [12] is dat 10% circulair wordt ingekocht. Deze definitie is echter zo ruim gesteld dat nu 80% van de infra werken in de Provincie [12] aan deze definitie voldoen (in de praktijk is de mate van circulariteit aanzienlijk lager)	Client	12
Er is onduidelijkheid over wat nou precies met de term 'Circulaire Economie' (en andere duurzaamheids-begrippen) wordt bedoeld; een (overheids)loket hiervoor ontbreekt	Contractor	7
Er is onduidelijkheid over wat nou precies bedoelt wordt met Circulaire Economie of wat 'hoogwaardig' hergebruik is	Demolition contractor; Recycling company	14
Er is geen eenduidige/uniforme definitie voor Circulaire Economie	Engineering & Consulting firm	13
De transitie naar de CE is een onhaalbaar doel (wensbeeld), men kan beter spreken over/toewerken naar het toepassen van circulaire principes	Engineering & Consulting firm	13
Het is onduidelijk welke toepassingen van materialen binnen de GWW als 'hoogwaardig hergebruik' kunnen worden bestempeld	Engineering & Consulting firm	15
Het is onduidelijk over wat nou laag- of hoogwaardige toepassing van materialen is	Recycling company; Wholesaler of building materials	10

Table 28 – Identified Performance indicators barriers. Source: own work

Identified barriers	Stakeholder type	ID
Betongranulaat wordt onterecht bestempeld als laagwaardig, terwijl het een functioneel materiaal is waarvoor alternatieven (zoals steen) in NL niet voorhanden is (onduidelijkheid over positie op R-ladder)	Client	3
Respondent is van mening dat R-ladder in hiërarchische vorm niet bestaat	Client	3
Onduidelijkheid over hoe circulariteit gemeten moet worden	Client	3
Iedereen redeneert uiteindelijk naar euro's. Zolang er geen andere verdienmodellen/meetmethodes voor circulariteit komen gaat er niets veranderen.	Client	12
De huidige manier van rekenen aan kosten (alleen in euro's) belemmeren circulariteit	Client	12
MKI (Milieukosten Indicator) staat circulariteit in de weg, want is alleen gericht op CO2 emissies en kijkt enkel binnen de grenzen van 1 project.	Contractor	1
Het is onduidelijk hoe circulariteit te meten is	Contractor	7
Het is momenteel nog onduidelijk hoe circulariteit gemeten moet worden	Engineering & Consulting firm	15

Table 29 – Identified Sociocultural barriers. Source: own work

Identified barriers	Stakeholder type	ID
De cultuur van de GWW sector is dat voor veel inrichtingselementen/objecten (viaducten/geleiderails/lichtmasten/prullenbakken enz.) een unieke (in plaats van een gestandaardiseerde) oplossing gerealiseerd lijkt te moeten worden.	Contractor	2
ER zijn decennia nodig om het besef van de urgentie van het implementeren van een Circulaire Economie bij mensen te laten indalen (vergelijk het met roken)	Contractor	7
Als de term Circulaire Economie niet op korte termijn structureler wordt ingebed waait deze weer over	Engineering & Consulting firm	13

Table 30 – Identified Supply chain barriers. Source: own work

Identified barriers	Stakeholder type	ID
Aanbod secundaire materialen is lager dan de vraag die nodig is om alle nieuwe bouwwerken te realiseren (maw: er wordt meer gebouwd dan gesloopt)	Contractor	1
Leverancier van verkeersborden van een alternatief materiaal (kunststof) is niet in staat om op korte termijn te leveren.	Contractor	1

Table 31 – Identified Environmental barriers. Source: own work

Identified barriers	Stakeholder type	ID
N/A*		

*No environmental barriers were identified during the interviews

C.2. Identified drivers for the implementation of CE in Dutch infrastructure projects

The identified drivers for the implementation of CE in Dutch infrastructure projects have been listed per category in Table 32 until Table 40.

Table 32 – Identified Organisational/Managerial drivers. Source: own work

Identified drivers	Stakeholder type	ID
Organisaties moeten vóór het slopen van werken bepalen welke materialen geschikt zijn voor toepassing in nieuwe werken	Client	4
Richtlijnen zoals de Green Deal Duurzaam GWW 2.0 zorgen voor commitment in realiseren duurzame/circulaire oplossingen	Client	5
Toepassen van circulair werken kan bevorderd worden wanneer de interne opdrachtgever bij opdrachten voorschrijft dat circulariteit toegepast moet worden door de interne opdrachtnemer	Client	5
Het waterschap heeft in het voortraject van een aantal opdrachten al nagedacht over slimme duurzame/circulaire oplossingen voor de vrijkomende materialen	Client	5
Het ontwikkelen van gezamenlijke visies voor alle materiaalketens zorgt ervoor dat organisaties iets hebben waarop ze zich kunnen committeren (Betonakkoord, Asfaltimpuls zijn er al. Die voor staal en hout zijn in ontwikkeling)	Client	8
Voor kortlopende contracten moeten publieke opdrachtgevers meer (en vooral: specifiekere) duurzaamheidseisen stellen (omdat daar in de contractvorm op zichzelf geen prikkel in zit om te verduurzamen)	Client	8
Bij het hergebruiken van bijvoorbeeld en stalen boogbrug moeten opdrachtgevers zelf in de planfase al over alternatieve toepassingslocaties nadenken (in plaats van dit aan de markt overlaten)	Client	8
De top binnen gemeente [9] moet circulariteit meer gaan dragen, zodat de rest van de organisatie vanzelf wel manieren vindt om 'circulairder' te worden	Client	9
Binnen gemeente [9] is een duurzaamheidspotje beschikbaar gesteld	Client	9
De circulaire ambitie op alle lagen binnen de gemeente [9] laten doorstromen (dus van het scheiden van afval, zuinig omgaan met koffiekopjes, energie neutrale voertuigen tot het uitvoeren van projecten), zodat circulariteit in het DNA komt te zitten en de transitie in een versnelling belandt.	Client	9
Als opdrachtgevers een circulair beton of asfalt willen zullen ze genoegen moeten nemen met de garantietermijnen die daarvoor worden aangeboden.	Client	12
Bestuurlijke moed tonen door circulaire innovatieprojecten uit te voeren	Client	12
Circulariteit zwaarder laten wegen als criterium in aanbestedingen (dus minder zwaar beoordelen op prijs zoals nu veelal het geval is)	Contractor	1
Op basis van innovatief partnerschap aanbesteden, waarbij veel ruimte is voor innovaties	Contractor	1
Opdrachtgevers zouden sloopbedrijven eerder moeten betrekken om te kijken welke materialen zich in een te slopen werk bevinden en welke materialen hiervan hoogwaardig hergebruikt kunnen worden	Demolition contractor; Recycling company	14

Het feit dat bepaalde opdrachtgevers circulariteit belangrijk zorgt ervoor dat Beelen meer ruimte (en vooral ook: extra tijd) krijgt om te experimenteren (opdrachtgever werkt/denkt mee en biedt zelfs locaties aan voor tijdelijke opslag materialen)	Demolition contractor; Recycling company	14
Aannemers zullen circulair moeten gaan uitvragen (en dit ook specifiek maken). Gezien de 'u vraagt, wij draaien' cultuur binnen de aannemerij in de GWW is dit de enige manier om naar een CE te gaan	Demolition contractor; Recycling company	14
Versimpelen van het type bouwwerken in de GWW door onderscheid te maken tussen 'unieke' en 'standaard' GWW bouwwerken.	Engineering & Consulting firm	11
Aanbestedingen op de markt zetten waarin zowel aanleg als onderhoud (voor een langere periode) in 1 contract vallen (hier zit een prikkel in om op de lange termijn kwaliteit te leveren)	Engineering & Consulting firm	13
Opdrachtgevers moeten duidelijker weten wat ze vragen, dat vertalen in goede contracten/besteken (dus niet met het idee van 'laat het maar aan de markt over'.)	Engineering & Consulting firm	15
Creatieveling/out-of-the-box-denkers van buiten de GWW uitnodigen om mee te denken over de transitie naar de CE binnen de GWW	Engineering & Consulting firm	15
Publieke opdrachtgevers moeten vaker de rol van *launching customers* vervullen om zodanig bij te dragen aan het op de markt krijgen van innovaties/projecten met nieuwe werkwijzen	Recycling company; Wholesaler of building materials	10

Table 33 – Identified Technological/Information drivers. Source: own work

Identified drivers	Stakeholder type	ID
Platform ontwikkelen zodat informatie over het eigenaarschap, de kwaliteit en volumes van materialen beschikbaar zijn	Contractor	1
Informatie m.b.t. vrijkomende materialen beschikbaar stellen zodat de markt het aanbod op de vraag kan afstemmen	Client	4
Het waterschap is bezig met interne kennisdeling van voorbeeldprojecten op gebied van duurzaamheid	Client	5
Het waterschap deelt (en verkrijgt) kennis en praktische ervaringen via de Unie van Waterschappen (landelijk) en via de regio	Client	5
Rijkswaterstaat moet als een van de grootste opdrachtgevers in de Nederlandse infrastructuur sector zelf meer gaan experimenteren met nieuwe bouwmethodes en deze testen in proeftuinen, om zodanig materiaalinnovaties sneller te kunnen valideren en opschalen	Client	8
Een gezamenlijk platform voor het opslaan van de informatie van bouwwerken ontwikkelen (i.e. Madaster)	Client	8
Onderdelen (van beweegbare bruggen) standaardiseren, modulair maken en nieuwe bouwmethodieken ontwikkelen	Client	8
SBIR (Small Business Innovation Request) in de GWW implementeren om zodanig de opgedane kennis m.b.t. circulariteit te delen (deze opgave is namelijk te groot om door 1 organisatie te kunnen worden opgelost)	Client	8
Het afstemmen van vraag- en aanbod van materialen aan de markt overlaten	Client	9
Personen die succesvol circulaire projecten hebben uitgevoerd of gerealiseerd inzetten als vliegende brigade om zodanig andere mensen of organisaties te begeleiden in het realiseren van circulaire projecten/kennisdeling	Engineering & Consulting firm	11
Veel bouwwerken in de GWW zijn na 30 tot 50 jaar functioneel verouderd, terwijl de technische levensduur van GWW bouwwerken tussen de 50 tot 100 jaar ligt, hetgeen volgens respondent het belang onderstreept voor het ontwerpen met aanpasbaarheid, demontabiliteit en circulariteit.	Engineering & Consulting firm	13
Het ontwikkelen van een shearing layers/lagen-model voor toepassing in de GWW (o.b.v. die van Stuart Brandt). Het ontwikkelen van een model à la Brand is namelijk een manier om anders na te denken over de verschillende levensduren waaruit een constructie is opgebouwd	Engineering & Consulting firm	13
Het standaardiseren van afstanden tussen landhoofden en verbindingspunten voor (beweegbare) bruggen bevorderd de mogelijkheid tot hoogwaardig hergebruik	Engineering & Consulting firm	13
Paspoorten gaan bijdragen aan CE in GWW doordat duidelijk wordt waar materialen zijn, wat de kwaliteit is, de leeftijd/levensduur. Hier kan dan voor bepaalt worden welke vervolgtoepassingen mogelijk zijn	Engineering & Consulting firm	15

Table 34 – Identified Economic/Financial/Market drivers. Source: own work

Identified drivers	Stakeholder type	ID
De toenemende prijs van olie (bitumen is een olie restproduct), heeft ervoor gezorgd dat de business case voor gerecycled asfalt interessant werd. Dit is tevens een stimuli geweest voor de markt om het PIM (Pavement Information Model) te ontwikkelen.	Client	3
De hoge kosten voor het storten van bagger (25€/kuub) heeft ervoor gezorgd dat waterschap [4] altijd slimme en duurzame toepassingen voor hun bagger realiseerde (kan/moet nog scherper geformuleerd)	Client	4

Hogere olieprijs (hierdoor loont het plotseling wel om de verschillende asfaltlagen apart te vrezen en het bitumen terug te winnen) zorgt voor toepassing 100% circulair asfalt	Contractor	7
Organisaties moeten zelf actief markten creëren voor materialen om leveranciers en afnemers bij elkaar te krijgen [10] doet dit zo)	Recycling company; Wholesaler of building materials	10

Table 35 – Identified Institutional/Regulatory/Governmental drivers. Source: own work

Identified drivers	Stakeholder type	ID
Heldere regulering voor het gebruik van secundaire materialen kan voor een boost in de toepassing hiervan zorgen	Client	3
Geld beschikbaar stellen voor het ontwikkelen/bekostigen van duurzame innovaties	Client	3
Voor GWW projecten met een aanneemsom hoger dan €500.000 (ex. BTW) verplicht stellen dat deze aan de afspraken in de Green Deal Duurzaam GWW moeten voldoen	Client	4
Het door het Ministerie van Infrastructuur en Waterstaat beschikbaar stellen van budget voor innovaties geeft circulariteit een boost	Client	8
De opdrachtbrief vanuit het Ministerie van Infrastructuur en Waterstaat m.b.t. duurzaamheid richting RWS heeft er toe geleide dat Rijkswaterstaat concreet gaat focussen op energiebesparing, CO2 reductie en circulariteit. Onderstreept de noodzaak voor meer top-down benadering t.b.v. implementatie CE	Client	8
Innovatieve projecten zoals het Circulaire Viaduct vormen een boost om knelpunten in de huidige richtlijnen (bijv. Richtlijn Ontwerpen Kunstwerken) bloot te leggen	Client	8
Verandering van bovenaf doorvoeren. Top-down benadering gaat de transitie naar CE in GWW op gang krijgen. Dus door andere wet- en regelgeving.	Client	12
De overheid moet concreter beleid ontwikkelen m.b.t. circulariteit	Contractor	1
Overheid moet meer ruimte bieden voor innovaties	Contractor	1
Toepassing bepaalde circulaire bouwmaterialen als eis stellen in aanbestedingen	Contractor	1
Certificering vergelijkbaar met BREEAM voor B&U ontwikkelen voor GWW	Contractor	1
Publieke opdrachtgevers moeten meer eisen stellen m.b.t. circulariteit in de uitvragen/aanbestedingen (voorbeeld van het verbod op teer werd hierbij aangehaald, wat er zeer snel voor heeft gezorgd dat er alleen nog maar bitumen in asfalt wordt toegepast. Met het stellen van deze eis is tevens een 'level playing field' gecreëerd)	Contractor	2
De overheid moet wet- en regelgeving opstellen waarmee circulariteit verplicht wordt gesteld om zodanig een 'level playing field' te creëren.	Contractor	2
De overheid moet extra geld investeren om innovaties te bekostigen en zodanig de transitie naar een Circulaire Economie op te starten	Contractor	2
Regelgeving m.b.t. circulariteit in de GWW kan een enorme versnelling veroorzaken (als voorbeeld werd het Bouwbesluit aangehaald, een wet die voor enorme verandering binnen de bouw heeft gezorgd)	Contractor	7
In aanbestedingen minimum-percentages opnemen m.b.t. hergebruik materialen	Demolition contractor; Recycling company	14
Het invoeren van de MPG (Milieuprestaties Gebouwen) heeft er toe geleid gebouwen steeds energiezuiniger gebouwd zijn. Een vergelijkbare eenduidige norm voor de milieu-impact van materialen zou ook in de GWW toegepast moeten/kunnen worden	Demolition contractor; Recycling company	14
Het verbod op het storten van bouw- en sloopafval fungeert als incentive voor sloopbedrijven om zo hoogwaardig mogelijke toepassingen te zoeken	Demolition contractor; Recycling company	14
Overheid zou meer subsidies aan organisaties die innoveren op het gebied van circulariteit moeten verstrekken zodat deze extra mensen in dienst te kunnen nemen en hen meer kennis laten opslurpen (door o.a. desk research). Deze opgedane kennis m.b.t. Circulaire Economie kan vervolgens de GWW in stromen	Engineering & Consulting firm	11
Kleine aanpassingen in wet- of regelgeving m.b.t. circulariteit kunnen al grote positieve gevolgen hebben	Engineering & Consulting firm	11
Publieke opdrachtgevers moeten meer ruimte bieden voor circulaire pilotprojecten	Engineering & Consulting firm	15
Meer dwingende eisen/regelgeving m.b.t. circulair gebruik van materialen gaat voor een versnelling zorgen	Recycling company; Wholesaler of building materials	10
Initiatieven zoals het Betonakkoord/Asfaltimpuls geven de markt een boost en maken deze meer stabiel doordat publieke opdrachtgevers nu de percentages zoals overeengekomen in deze akkoorden opneemt/uitvraagt in hun contracten	Recycling company; Wholesaler of building materials	10
Publieke opdrachtgevers moeten de markt meer ruimte geven om nieuwe ontwikkelingen toe te passen	Recycling company; Wholesaler of building materials	10

In overheidsuitvragen zou het verplicht stellen van toepassen van circulaire betonsoorten er voor kunnen zorgen dat de hele keten wordt meegetrokken, waardoor betonleveranciers wellicht gaan investeren in betonmixers t.b.v. circulaire betonsoorten, hetgeen de markt een impuls zou geven (en prijzen zou doen dalen)	Supplier of building materials	6
Publieke opdrachtgevers zouden voor niet-kritieke onderdelen infrastructuur in elk geval al circulaire betonsoorten kunnen toepassen om zodanig de markt voor circulaire bouwmaterialen een impuls te geven. Zelfs een klein percentage circulair uitvragen kan al voor een enorme verandering in de markt zorgen	Supplier of building materials	6
Publieke opdrachtgevers kunnen door meer circulaire uitvragen de markt een impuls geven (de markt reageert namelijk op wat gevraagd word)	Supplier of building materials	6

Table 36 – Identified CE definition/framework drivers. Source: own work

Identified drivers	Stakeholder type	ID
N/A*		

* No drivers in the category CE definition/framework were identified during the interviews.

Table 37 – Identified Performance Indicator drivers. Source: own work

Identified drivers	Stakeholder type	ID
De hoogwaardigheid van materialen niet enkel op technische eisen (zoals sterkte/levensduur) beoordelen, maar ook op circulariteit	Engineering & Consulting firm	11
Duidelijkheid verschaffen in hoe circulariteit gemeten kan worden in de GWW	Engineering & Consulting firm	15

Table 38 – Identified Sociocultural drivers. Source: own work

Identified drivers	Stakeholder type	ID
Het circulaire viaduct heeft voor een merkbare toename in het aantal circulaire projecten gezorgd.	Client	8
Doordat het beton van een circulaire betonleverancier nu steeds vaker aantoonbaar succesvol is toegepast neemt de vraag toe	Supplier of building materials	6

Table 39 – Identified Supply chain drivers. Source: own work

Identified drivers	Stakeholder type	ID
Hergebruik van materialen moet regionaal beschouwd worden om zodanig de kosten en milieu-impact als gevolg van transport laag te houden	Engineering & Consulting firm	15

Table 40 – Identified Environmental drivers. Source: own work

Identified drivers	Stakeholder type	ID
N/A*		

*No drivers in the category CE definition/framework were identified during the interviews.

Appendix D – Overview of ranked barriers and drivers for CE in Dutch infrastructure projects

D.1 Ranked barriers for CE in Dutch infrastructure projects

The top-5 barriers as indicated by the respondents have been listed in Table 41. Please note that the top-5 barriers have been listed per stakeholder type.

Table 41 – Top-5 barriers as indicated by respondents. Source: own work

ID	Stakeholder type	Barrier description	Barrier category
1	Contractor	1. Aanbestedingswet staat innovatie in de weg en biedt geen ruimte voor aannemers om mee te denken over ontwerpen/innoveren	Institutioneel/Wet- en Regelgeving/Overheid
		2. Interne organisatie van project- en beheersafdeling bij (met name) gemeentes leent zich niet voor het realiseren van circulaire/as-a-service oplossingen. Projectafdeling wil vernieuwen, echter beheersafdeling werkt via LIOR (Leidraad Inrichting Openbare Ruimte) en heeft moeite met hiervan afwijken	Organisatorisch/Management
		3. Alleen 'proven technologies' worden door opdrachtgevers geaccepteerd	Organisatorisch/Management
		4. Circulaire initiatieven hebben langere terugverdientijd dan standaardoplossingen (Return on Investment circulaire alternatieven doorgaans > 1 jaar)	Economisch/Financieel/Markt
		5. Opdrachtgevers zijn doorgaans niet bereidt de hogere kosten voor de eerste paar circulaire aanbestedingen te betalen (zowel opdrachtgever als opdrachtnemer zullen moeten betalen aan de kosten voor innovaties richting CE), waarna de prijs zeer waarschijnlijk gestaag zakt.	Organisatorisch/Management
2	Contractor	1. Door voorschriften over wat wel/niet mag worden toegepast als wegconstructie zit de markt op slot	Institutioneel/Wet- en Regelgeving/Overheid
		2. De markt zit op slot door gewoontes in wat wordt toegepast als wegconstructie	Organisatorisch/Management
		3. Circulair asfalt wordt niet toegepast omdat het de 'instap-eis' voor stroefheid nét niet haalt maar wel bewezen langer stroef blijft (t.o.v. conventioneel asfalt)	Institutioneel/Wet- en Regelgeving/Overheid
		4. Er zijn nog geen economies of scale voor circulaire betonsoorten, wat maakt dat circulaire betonsoorten nu nog duurder zijn dan conventionele betonsoorten.	Economisch/Financieel/Markt
		5. De cultuur van de GWW sector is dat voor veel inrichtingselementen/objecten (viaducten/geleiderails/lichtmasten/prullenbakken enz.) een unieke (in plaats van een gestandaardiseerde) oplossing gerealiseerd lijkt te moeten worden.	Socio-cultureel
3	Client	1. *no ranking of results by respondent	
		2.	
		3.	
		4.	
		5.	
4	Client	1. *no ranking of results by respondent	
		2.	
		3.	
		4.	
		5.	
5	Client	1. Ondanks dat er m.b.t.. het beleggen van duurzaamheid/circulariteit binnen het waterschap enorme stappen zijn gemaakt, is het waterschap nog niet volledig in staat om circulair te werken. Voor deze interne transitie is nog meer tijd nodig	Organisatorisch/Management
		2. Aanbestedingen werden voornamelijk beoordeeld op prijs, in plaats van circulariteit/duurzaamheid	Organisatorisch/Management
		3. Het is voorgekomen de doorlooptijd voor het aanvragen van een vergunning voor tijdelijke opslag van grond (waarmee een duurzame/circulaire oplossing kon worden gerealiseerd) dusdanig lang was dat projectteams besloten hier van af te zien.	Institutioneel/Wet- en Regelgeving/Overheid
		4.	
		5.	
6	Supplier of building materials	1. *no ranking of results by respondent	
		2.	

		3.	
		4.	
		5.	
7	Contractor	1. *no ranking of results by respondent	
		2.	
		3.	
		4.	
		5.	
8	Client	1. Veel materialen in GWW-bouwwerken hebben geen identiteit (specificaties m.b.t. kwaliteit etc.), wat deze materialen tot afval maken	Technologisch/Informatie
		2. Een poging van een publieke opdrachtgever om een stalen boogbrug te herbruiken is mislukt (men wil gewoon liever een nieuwe brug/opdrachtnemers zijn niet bereid de brug ergens op te slaan als er geen gegarandeerde afzet voor is)	Organisatorisch/Management
		3. Uit het oogpunt van 'voldoen aan de richtlijn' worden richtlijnen door opdrachtnemers dusdanig zwart-wit geïnterpreteerd dat dit innovaties belemmerd	Organisatorisch/Management
		4. Bepaalde contractvormen staan circulariteit in de weg (DBFM is kwalitatief doorgaans hoog. Echter, in prestatiecontracten zit een perverse prikkel om als aannemer zo vaak mogelijk te moeten onderhouden. Contracten met eigenaarschap willen opdrachtgevers niet aan beginnen, omdat de verantwoordelijkheid voor kritieke primaire infrastructuur dan bij bedrijven komt te liggen welke failliet kunnen gaan of kunnen worden overgekocht door buitenlandse partijen)	Institutioneel/Wet- en Regelgeving/Overheid
		5. Publieke opdrachtgevers hebben geen tot nauwelijks materiaalexperts in dienst, waardoor innovatie dus vooral vanuit de markt de organisatie in moet stromen	Technologisch/Informatie
9	Client	1. Binnen gemeente [9] wordt te weinig aandacht besteed aan de vertaling van beleid m.b.t. circulariteit naar daadwerkelijke uitvoering	Organisatorisch/Management
		2. Circulaire oplossingen zijn nu doorgaans nog duurder dan conventionele oplossingen	Economisch/Financieel/Markt
		3. Doordat veel taken en verantwoordelijkheden (binnen gemeente [9]) zijn gesplitst kunnen geen circulaire oplossingen gerealiseerd worden (de taak van het verdelen van het geld, het bepalen wat aan projecten nodig is en het uitvoeren hiervan liggen verspreid binnen de organisatie)	Organisatorisch/Management
		4. Er wordt onvoldoende geld beschikbaar gesteld binnen gemeente [9] om circulair te worden	Organisatorisch/Management
		5. Het gebrek aan een eenduidige definitie voor Circulaire Economie maakt zowel het gesprek als de transitie lastig	CE definitie
10	Recycling company/ Wholesaler of building materials	1. De lage prijs van conventioneel beton maakt dat de business case voor circulair beton moeilijk te sluiten is	Economisch/Financieel/Markt
		2. Doordat de overheid vooralsnog voornamelijk aanbesteed o.b.v. laagste prijs zit de bouwsector gevangen in huidige werkwijzes/methodieken	Organisatorisch/Management
		3. Om daadwerkelijk circulair te werken zullen materialen uit de regio moeten komen, hetgeen om andere vormen van samenwerking vraagt	Organisatorisch/Management
		4. Circulariteit in aanbestedingen wordt vaak platgeslagen doordat alsnog moet worden voldoen aan zeer specifieke bestekseisen (voor bijv. asfalt)	Organisatorisch/Management
		5. In sommige aanbestedingen die als circulair worden bestempeld is alsnog 90% van de EMVI waarde verkeershinder en slechts 10% circulariteit)	Organisatorisch/Management
11	Engineering & Consulting firm	1. *no ranking of results by respondent	
		2.	
		3.	
		4.	
		5.	
12	Client	1. Iedereen redeneert uiteindelijk naar euro's. Zolang er geen andere verdienmodellen/meetmethodes voor circulariteit komen gaat er niets veranderen.	CE prestatie-indicatoren
		2. De huidige manier van rekenen aan kosten (alleen in euro's) belemmeren circulariteit	CE prestatie-indicatoren
		3. In de term Circulaire Economie zit het woord 'economie', wat al gelijk de link naar geld legt. Streven naar 'circulariteit' zou een beter doel zijn	CE definitie

		4. Zelfs al zou de Provincie [12] circulairder willen aanbesteden, ze weten nu simpelweg nog niet welke harde eisen ze zouden moeten formuleren	Technologisch/Informatie
		5. Zowel opdrachtgever als opdrachtnemer zijn niet bereid het risico te dragen dat de garantietermijn van een circulair materiaal (bijv. asfalt) niet gehaald wordt.	Organisatorisch/Management
13	Engineering & Consulting firm	1. Rechtmatigheid en doelmatigheid zijn binnen (GWW) aanbestedingen de speerpunten. Echter gaat nu 98% van de discussie over rechtmatig. Een groter deel van deze discussie zou moeten gaan over doelmatigheid; het realiseren van een maatschappelijke doelstelling (circulair/duurzaam GWW project)	Organisatorisch/Management
		2. De huidige manier van financiële waardering voorkomt duurzaamheid op de lange termijn	Economisch/Financieel/Markt
		3. (Publieke) opdrachtgevers geven in GWW aanbestedingen nog een (te) zware weging aan prijs ten opzichte van kwaliteit/circulariteit	Organisatorisch/Management
		4. Er is geen eenduidige/uniforme definitie voor Circulaire Economie	CE definitie
		5. Doordat de levenscycli in de GWW en het onderscheid tussen de verschillende materialen/elementen waaruit bouwwerken bestaan niet duidelijk is, zijn de CE principes over hoogwaardigheid van hergebruik (binnenste cycli EMF vlinder) zijn in GWW projecten minder sterk van toepassing dan voor sommige producten of gebouwen	Technologisch/Informatie
14	Demolition contractor / recycling company	1. De prijs van secundaire materialen is hoger dan die van primaire/nieuwe bouwmaterialen	Economisch/Financieel/Markt
		2. Bouwwerken die momenteel worden gesloopt zijn nooit gebouwd met hergebruik van materialen na sloop in achterhoofd	Technologisch/Informatie
		3. Er is onduidelijkheid over wat nou precies bedoelt wordt met Circulaire Economie of wat 'hoogwaardig' hergebruik is	CE definitie
		4. Omdat betonproducten ook zelf leveranciers van toeslagmaterialen zijn, zijn zij niet gebaat bij het toepassen van alternatieve (secundaire) materialen in hun beton	Economisch/Financieel/Markt
		5. Circulariteit moet altijd plaatsvinden binnen de huidige financiële kaders (om te voorkomen dat je als bedrijf failliet gaat), hetgeen de mogelijkheden om grote stappen m.b.t. circulariteit te zetten beperkt	Economisch/Financieel/Markt
15	Engineering & Consulting firm	1. *no ranking received from respondent	
		2.	
		3.	
		4.	
		5.	

D.2. Ranked drivers for CE in Dutch infrastructure projects

The top-5 drivers as indicated by the respondents have been listed in Table 42. Please note that the top-5 barriers have been listed per stakeholder type.

Table 42 – Top-5 drivers as indicated by respondents. Source: own work

ID	Stakeholder type	Driver description	Driver category
1	Contractor	1. Circulariteit zwaarder laten wegen als criterium in aanbestedingen (dus minder zwaar beoordelen op prijs zoals nu veelal het geval is)	Organisatorisch/Management
		2. De overheid moet concreter beleid ontwikkelen m.b.t. circulariteit	Institutioneel/Wet- en Regelgeving/Overheid
		3. Overheid moet meer ruimte bieden voor innovaties	Institutioneel/Wet- en Regelgeving/Overheid
		4. Toepassing bepaalde circulaire bouwmaterialen als eis stellen in aanbestedingen	Institutioneel/Wet- en Regelgeving/Overheid
		5. Op basis van innovatief partnerschap aanbesteden, waarbij veel ruimte is voor innovaties	Organisatorisch/Management
2	Contractor	1. Publieke opdrachtgevers moeten meer eisen stellen m.b.t. circulariteit in de uitvragen/aanbestedingen (voorbeeld van het verbod op teer werd hierbij aangehaald, wat er zeer snel voor heeft gezorgd dat er alleen nog maar bitumen in asfalt wordt toegepast. Met het stellen van deze eis is tevens een 'level playing field' gecreëerd)	Institutioneel/Wet- en Regelgeving/Overheid
		2. De overheid moet wet- en regelgeving opstellen waarmee circulariteit wordt verplicht om zodanig een 'level playing field' te creëren.	Institutioneel/Wet- en Regelgeving/Overheid
		3. De overheid moet extra geld investeren om innovaties te bekostigen en zodanig de transitie naar een Circulaire Economie op te starten	Institutioneel/Wet- en Regelgeving/Overheid
		4.	
		5.	
3	Client	1. *no ranking of results by respondent	
		2.	
		3.	
		4.	
		5.	
4	Client	1. *no ranking of results by respondent	
		2.	
		3.	
		4.	
		5.	
5	Client	1.Het waterschap is bezig met interne kennisdeling van voorbeeldprojecten op gebied van duurzaamheid	Technologisch/Informatie
		2. Toepassen van circulair werken kan bevorderd worden wanneer de interne opdrachtgever bij opdrachten voorschrijft dat circulariteit toegepast moet worden door de interne opdrachtnemer	Organisatorisch/Management
		3. Het waterschap deelt (en verkrijgt) kennis en praktische ervaringen via de Unie van Waterschappen (landelijk) en via de regio	Technologisch/Informatie
		4. Het waterschap heeft in het voortraject van een aantal opdrachten al nagedacht over slimme duurzame/circulaire oplossingen voor de vrijkomende materialen	Organisatorisch/Management
		5. Richtlijnen zoals de Green Deal Duurzaam GWW 2.0 zorgen voor commitment in realiseren duurzame/circulaire oplossingen	Organisatorisch/Management
6	Supplier of building materials	1. *no ranking of results by respondent	
		2.	
		3.	
		4.	
		5.	
7	Contractor	1. *no ranking of results by respondent	
		2.	
		3.	
		4.	
		5.	
8	Client	1. Het door het Ministerie van Infrastructuur en Waterstaat beschikbaar stellen van budget voor innovaties geeft circulariteit een boost	Institutioneel/Wet- en Regelgeving/Overheid
		2. Het circulaire viaduct heeft voor een merkbare toename in het aantal circulaire projecten gezorgd.	Socio-cultureel

		3. Publieke opdrachtgevers moeten zelf meer gaan onderzoeken met nieuwe bouwmethodes en deze testen in proeftuinen, om zodanig materiaalinnovaties sneller te kunnen valideren en opschalen	Technologisch/Informatie
		4. Een gezamenlijk platform voor het opslaan van de informatie van bouwwerken ontwikkelen (i.e. Madaster)	Technologisch/Informatie
		5. Het ontwikkelen van gezamenlijke visies voor alle materiaalketens zorgt ervoor dat organisaties iets hebben waarop ze zich kunnen committeren (Betonakkoord, Asfaltimpuls zijn er al. Die voor staal en hout zijn in ontwikkeling)	Organisatorisch/Management
9	Client	1. De top binnen gemeente [9] moet circulariteit meer gaan dragen, zodat de rest van de organisatie vanzelf wel manieren vindt om circulairder te worden	Organisatorisch/Management
		2. Binnen gemeente [9] is een duurzaamheidspotje beschikbaar gesteld	Organisatorisch/Management
		3. De circulaire ambitie op alle lagen binnen de gemeente [9] laten doorstromen (dus van het scheiden van afval, zuinig omgaan met koffiekopjes, energie neutrale voertuigen tot het uitvoeren van projecten), zodat circulariteit in het DNA komt te zitten en de transitie in een versnelling belandt.	Organisatorisch/Management
		4. Het afstemmen van vraag- en aanbod van materialen aan de markt overlaten	Technologisch/Informatie
		5.	
10	Recycling company/ Wholesaler of building materials	1. Meer dwingende eisen/regelgeving m.b.t. circulair gebruik van materialen gaat voor een versnelling zorgen	Institutioneel/Wet- en Regelgeving/Overheid
		2. Publieke opdrachtgevers moeten vaker de rol van launching customers vervullen om zodanig bij te dragen aan het op de markt krijgen van innovaties/projecten met nieuwe werkwijzen	Organisatorisch/Management
		3. Organisaties moeten zelf actief markten creëren voor materialen om leveranciers en afnemers bij elkaar te krijgen [10] doet dit zo)	Economisch/Financieel/Markt
		4. Initiatieven zoals het Betonakkoord/Asfaltimpuls geven de markt een boost en maken deze meer stabiel doordat publieke opdrachtgevers nu de percentages zoals overeengekomen in deze akkoorden opneemt/uitvraagt in hun contracten	Institutioneel/Wet- en Regelgeving/Overheid
		5. Publieke opdrachtgevers moeten de markt meer ruimte geven om nieuwe ontwikkelingen toe te passen	Institutioneel/Wet- en Regelgeving/Overheid
11	Engineering & Consulting firm	1. *no ranking of results by respondent	
		2.	
		3.	
		4.	
		5.	
12	Client	1. Verandering van bovenaf doorvoeren. Top-down benadering gaat de transitie naar CE in GWW op gang krijgen. Dus door andere wet- en regelgeving.	Institutioneel/Wet- en Regelgeving/Overheid
		2. Als opdrachtgevers een circulair beton of asfalt willen zullen ze genoegen moeten nemen met de garantietermijnen die daarvoor worden aangeboden.	Organisatorisch/Management
		3. Bestuurlijke moed tonen door circulaire innovatieprojecten uit te voeren	Organisatorisch/Management
		4.	
		5.	
13	Engineering & Consulting firm	1. Veel bouwwerken in de GWW zijn na 30 tot 50 jaar functioneel verouderd, terwijl de technische levensduur van GWW bouwwerken tussen de 50 tot 100 jaar ligt, hetgeen volgens respondent het belang onderstreept voor het ontwerpen met aanpasbaarheid, demontabiliteit en circulariteit.	Technologisch/Informatie
		2. Het ontwikkelen van een shearing layers/lagen-model voor in de GWW (o.b.v. die van Stuart Brandt) Volgens respondent heeft een dergelijk model voor GWW in elk geval minder lager dan B&U *Noot: Het ontwikkelen van een model à la Brand (stimulus 2) een manier om anders na te denken over levensduren (stimulus 1). Die zijn dus sterk verbonden. Stimulus (2) is een manier om (1) inzichtelijk te maken.	Technologisch/Informatie
		3. Aanbestedingen op de markt zetten waarin zowel aanleg als onderhoud (voor een langere periode) in 1 contract vallen (hier zit een prikkel in om op de lange termijn kwaliteit te leveren)	Organisatorisch/Management
		4. Het standaardiseren van afstanden tussen landhoofden en verbindingspunten voor (beweegbare) bruggen bevorderd de mogelijkheid tot hoogwaardig hergebruik	Technologisch/Informatie
		5.	
14	Demolition contractor / recycling company	1. Opdrachtgevers zouden sloopbedrijven eerder moeten betrekken om te kijken welke materialen zich in een te slopen werk bevinden en welke materialen hiervan hoogwaardig hergebruikt kunnen worden	Organisatorisch/Management
		2. Het feit dat bepaalde opdrachtgevers circulariteit belangrijk zorgt ervoor dat Beelen meer ruimte (en vooral ook: extra tijd) krijgt om te experimenteren (opdrachtgever werkt/denkt mee en biedt zelfs locaties aan voor tijdelijke opslag materialen)	Organisatorisch/Management

		3. In aanbestedingen minimum-percentages opnemen m.b.t. hergebruik materialen	Institutioneel/Wet- en Regelgeving/Overheid
		4. Het invoeren van de MPG (Milieuprestaties Gebouwen) heeft er toe geleid gebouwen steeds energiezuiniger gebouwd zijn. Een vergelijkbare eenduidige norm voor de milieu-impact van materialen zou ook in de GWW toegepast moeten/kunnen worden	Institutioneel/Wet- en Regelgeving/Overheid
		5. Aannemers zullen circulair moeten gaan uitvragen (en dit ook specifiek maken). Gezien de 'u vraagt, wij draaien' cultuur binnen de aannemerij in de GWW is dit de enige manier om naar een CE te gaan	Organisatorisch/Management
15	Engineering & Consulting firm	1.	
		2.	
		3.	
		4.	
		5.	

Appendix E – Calculation of relative frequencies CE barriers and drivers

This appendix is an elaboration of section 5.1 and describes the basis for the comparison of the CE barrier- and driver-categories as identified in respectively the literature review and the interviews. This has been done to determine the applicability of the literature-based framework on Dutch infrastructure projects. The applicability has been determined by calculating the relative frequency with which the different CE barrier- or driver-categories appeared in the literature review and compare these with the relative frequency with which CE barrier- or driver-categories have been mentioned during the interviews. The calculations are done as follows:

The calculations for CE barrier categories are done as follows:

- Relative frequency CE barrier categories in literature review = number of unique articles in which CE barrier category has been mentioned in the literature (Figure 5) / number of articles in which CE barriers were studied (n=25)
- Relative frequency CE barrier categories in interviews = number of interviews in which CE barrier category was identified (bottom row of Table 45) / number of interviews (n=15)

The relative frequency with which the different CE barrier-categories appeared in the literature review versus during the interviews are listed in Table 43.

Table 43 – Relative frequencies with which CE barriers were mentioned in literature review vs. interviews. Source: own work

Rank	Barrier category	Mentioned in % of articles lit. review	Mentioned in % of interviews*	Percentage increase literature review vs. interviews
1	Institutional/Regulatory/Governmental	72%	93% [↑2]	+29%
2	Organisational/Managerial	52%	87% [↑2]	+67%
3	Economic/Financial/Market	84%	73% [↓1]	-13%
4	Technological/Information	88%	67% [↓3]	-24%
5	CE definition/framework	8%	53% [↑3]	+563%
6	Performance indicators	4%	33% [↑3]	+725%
7	Sociocultural	44%	20% [↓2]	-55%
8	Supply chain	24%	20% [↓2]	-17%
9	Environmental	12%	0% [↓2]	-100%

** Please note that the position with which CE barrier category has risen/lowered as opposed to the rank in literature-based framework is shown in brackets*

It can be concluded that the majority of barrier categories as identified in the literature have also been mentioned during the interviews. The only exception is for barriers in the category Environmental, which were not mentioned in the interviews. While the rest of the barrier categories were mentioned in the interviews, the relative frequency of appearance differed. The largest increases can be observed for the categories Performance indicators, CE definition/framework and Organisational/Managerial, which were identified significantly more often during the interviews than in the literature. Barrier category Sociocultural, on the other hand, were identified significantly less frequently during the interviews than in the literature review.

The calculations for CE driver categories are done as follows:

- Relative frequency CE driver categories in literature review = Number of unique articles in which CE driver category has been mentioned in the literature (Figure 6) / Number of articles in which CE drivers were studied (n=9)
- Relative frequency CE driver categories in interviews = Number of interviews in which CE driver category was identified (bottom row of Table 46) / Number of interviews (n=15)

The relative frequency with which the different CE driver-categories appeared in the literature review versus during the interviews are listed in Table 44.

Table 44 – Relative frequencies with which CE drivers were mentioned in literature review vs. interviews. Source: own work

Rank	Driver category	Mentioned in % of articles lit. review	Mentioned in % of interviews *	Percentage increase literature review vs. interviews
1	Institutional/Regulatory/Governmental	56%	87% [↑1]	+55%
2	Organisational/Managerial	33%	60% [↑3]	+82%
3	Economic/Financial/Market	89%	40% [↓2]	-55%
4	Technological/Information	56%	27% [↓2]	-52%
5**	Supply chain	33%	20% [-]	-39%
5**	Performance indicators	0%	20% [↑4]	N/A
7	Sociocultural	33%	13% [↓2]	-61%
8	Environmental	44%	0% [↓4]	-100%

** Please note that the position with which CE barrier category has risen/lowered as opposed to the rank in literature-based framework is shown in brackets*

*** Drivers categories Supply chain and Performance indicators share the 5th place*

For the driver categories can be concluded that the majority of driver categories as identified in the literature were also identified during the interviews. While the relative frequency with which the CE driver categories appeared in the literature and the interviews differ, most of the driver categories from the literature review were also identified during the interviews. An exception again applies to the category Environmental, for which no drivers were mentioned during the interviews. Another exception applies to category Performance indicators, which was not identified in the literature as a driver category but was in fact mentioned during three interviews.

Overviews of number of barriers and drivers per category

In this part of the appendix the overviews of the number of barriers and drivers per category that were mentioned during the interviews is presented. These numbers have been used for the calculation of the relative frequency with which barriers or drivers in certain categories were mentioned during the interviews. This enabled comparing the interview findings with that of the literature review.

Table 45 – Number of mentioned barriers per category during interviews. Source: own work

Interview ID	Stakeholder type	Technological/Information	Economic/Financial/Market	Institut./Regul./Government.	Organisational/Managerial	Sociocultural	Supply chain	Environmental	CE definition/framework	Performance indicators	# of barriers identified in interview
1	Contractor	0	3	2	5	0	2	0	0	1	13
2	Contractor	3	1	4	4	1	0	0	0	0	13
3	Client	5	1	3	3	0	0	0	1	3	16
4	Client	1	0	1	0	0	0	0	0	0	2
5	Client	0	0	1	2	0	0	0	0	0	3
6	Supplier of building materials	2	2	0	4	0	0	0	0	0	8
7	Contractor	1	1	2	3	1	0	0	1	1	10
8	Client	4	0	2	3	0	0	0	0	0	9
9	Client	0	1	0	5	0	0	0	1	0	7
10	Recycling company/ Wholesaler of building materials	1	1	1	7	0	0	0	1	0	11
11	Engineering & Consulting firm	0	1	0	7	0	0	0	0	0	8
12	Client	2	0	1	3	0	0	0	4	2	12
13	Engineering & Consulting firm	1	2	0	4	1	0	0	2	0	10
14	Demolition contractor/ recycling company	1	3	0	0	0	0	0	1	0	5
15	Engineering & Consulting firm	1	2	1	2	0	0	0	1	1	8
	# of barriers per category:	**22**	**18**	**18**	**52**	**3**	**2**	**0**	**12**	**8**	**135**
	# of interviews in which barrier category was mentioned	**11**	**11**	**10**	**13**	**12**	**1**	**0**	**8**	**5**	

Table 46 – Number of mentioned drivers per category during interviews. Source: own work

Interview ID	Stakeholder type	Technological/Information	Economic/Financial/Market	Institut./Regul./Government.	Organisational/Managerial	Sociocultural	Supply chain	Environmental	CE definition/framework	Performance indicators	# of drivers identified in interview
1	Contractor	1	0	4	2	0	0	0	0	0	7
2	Contractor	0	0	3	0	0	0	0	0	0	3
3	Client	0	1	2	0	0	0	0	0	0	3
4	Client	1	1	1	1	0	0	0	0	0	4
5	Client	2	0	0	3	0	0	0	0	0	5
6	Supplier of building materials	0	0	3	0	1	0	0	0	0	4
7	Contractor	0	1	1	0	0	0	0	0	0	2
8	Client	4	0	3	3	1	0	0	0	0	11
9	Client	1	0	0	3	0	0	0	0	0	4
10	Recycling company/ Wholesaler of building materials	0	1	3	1	0	0	0	0	0	5
11	Engineering & Consulting firm	1	0	2	1	0	0	0	0	1	5
12	Client	0	0	1	2	0	0	0	0	0	3
13	Engineering & Consulting firm	3	0	0	1	0	0	0	0	0	4
14	Demolition contractor/ recycling company	0	0	3	3	0	0	0	0	0	6
15	Engineering & Consulting firm	1	0	1	2	0	1	0	0	1	6
	# of drivers per category:	**14**	**4**	**27**	**22**	**2**	**1**	**0**	**0**	**2**	**72**
	# of interviews in which driver category was mentioned:	**8**	**11**	**12**	**11**	**2**	**1**	**0**	**0**	**2**	