Identifying Key Barriers and Potential Strategies for Implementing Circular Infrastructure Assets: A Client-Contractor Perspective at Schiphol Airport

Master thesis
Complex System Engineering & Management
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Identifying Key Barriers and Potential Strategies for Implementing Circular Infrastructure Assets: A Client-Contractor Perspective at Schiphol Airport

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Preface

The report in front of you is my final work to complete the Master's degree in Complex System Engineering and Management from the Delft University of Technology. During the past eight months, I have conducted scientific research on barriers and strategies for circular infrastructure assets. This thesis would not have been a success without the help of several people, whom I would like to thank in advance.

First and foremost, I'd like to thank my supervisors for their guidance over the last few months. I want to thank Jan Anne for always being available for questions and unexpected meetings. This made the journey of writing my thesis more pleasant as I could always contact Jan Anne whenever I got stuck. These meetings with Jan Anne ensured that I was able to continue the process in good spirits. In addition, I want to thank Jaco for his sharp look on my work during the meetings. Jaco's expertise in the subject of the circular economy has led me in the right directions for my thesis regarding this topic. Furthermore, I would like to thank all people involved of Bam Infra and Schiphol Airport, particularly those at the perceel 3 department of Bam Infra Schiphol. Additionally, I would like to thank everyone I interviewed for their time and knowledge to make this thesis become a success.

In addition, I would like to thank my parents, Jan and Rita, as well as my sister, Sophie, for their unwavering support and interest in my journey. Last but not least, a special thanks to Moreen, who has been there for me throughout the entire process of overcoming all barriers that I had to face the last few months of writing my thesis report.

I hope you will enjoy reading my thesis.

Kind regards,

Bart van den Tooren

Summary

The past decades have been marked by numerous agreements and goals to increase the wellbeing of this planet. Many of these agreements and goals are supported by the concept of the Circular Economy (CE). In line with the climate neutrality targets of the European Union, the Dutch economy is aiming to be fully circular by the end of 2050, and thus become a waste-free economy. An interim target, proposed by the Dutch government, states that the usage of primary material will have to be reduced by half at the end of 2030, compared to 2014. Despite all these national and international goals, the circular economy has not yet been implemented to a considerable extent in the Dutch economy. The construction sector in the Netherlands is still accountable for 50% of all raw material consumption. For this reason, the focus lies largely on this sector as this is the most waste producing sector in comparison to other industries. The construction sector can be divided in three parts: the residential building sector, the utility building sector, and the infrastructure sector. The latter mentioned is responsible for half the waste produced by the entire Dutch construction sector. The question that arises, is why the circular economy is still not penetrated within this sector and how this such penetration can be accelerated.

Despite the significance and central role of the CE theme, the literature tends to stay behind practice in the field of examining barriers and potential strategies for circular infrastructure assets. Although a large number of studies in the CE literature focus on circular buildings (including residential buildings, commercial buildings, and other types of building property), the topic of the CE within the infrastructure domain seems neglected. To clear this gap, four goals are composed for this study: gain insight on the barriers and strategies that are available in the existing literature for the CE in the European construction sector, identify what barriers and strategies are present for obtaining circular infrastructure assets on the landside of Schiphol Airport according to practitioners in this field, compare the empirical results achieved within this thesis with the insights obtained through the literature exploration and analyze to what extent these barriers and strategies can be generalized to the broader infrastructure sector. The following research question is set out to achieve these four goals:

"What are the key barriers and potential strategies for the implementation of circular infrastructure assets at Schiphol Airport?"

To answer this research question, a theoretical framework was composed in which all literature that focuses on CE barriers and strategies for the construction sector was systematically analyzed. A single in-depth case study was conducted to acquire empirical evidence and to get insights into the key barriers and potential strategies for circular infrastructure assets. As a result, the findings of this case study can be compared to the established theoretical framework. The case study focused on the infrastructure assets on the landside at Schiphol Airport that is constructed and managed by Bam Infra. To acquire a comprehensive overview of what barriers and strategies exist in this sector, practitioners and experts in the field were consulted. By conducting semi-structured interviews within these two companies, information on where practitioners in the field of infrastructure assets face challenges were gathered, and strategies for CE adoption were proposed. The

grounded theory method and content analysis were used to code the transcripts from these semi-structured interviews.

During the semi-structured interviews, in total 24 barriers and 17 strategies were identified. These barriers and strategies were created by combining terms and codes from the interview transcripts and are divided into six categories: economic, organizational, sociological, regulatory, technical, and environmental. The table below lists these barriers and strategies.

Category	Barrier	Category	Strategy
Economical	Missing financial incentive	Economical	Financial management
	Market issues		Market innovations
	Additional costs		
Organizational	Lacking key players	Organizational	Risk improvements
	Low CE willingness		Client contractor
	Increase in time		Contractual improvements
	Low transparency		Stimulate CE operations
	Planning issues		Enhance planning
Sociological	Low CE awareness	Sociological	Create awareness
	Undesirable human behavior		Enhance communication
	Wrong CE perceptions		Stimulate trust
	Communication issues		
Regulatory	Outdated certification	Regulatory	Update requirements
	Regulations		
	Strict guidelines		
	Lack of incentives		Stimulate government control
Technical	Technology related barriers	Technical	Innovative measurements
	Long-lifespan		Disassembling improvements
	Technical quality and safety		Monitoring and inspections
	Lacking project design		Circular project design
	Disassembling issues		Innovative materialization
Environmental	Transport	Environmental	N/A
	Storage issues		
	Pollution		

The results of the study show that there are numerous barriers and strategies existing for the implementation of circular infrastructure assets at Schiphol Airport. However, some of these barriers and strategies were mentioned more often than others. The barrier that was most cited by the interviewees, is the barrier of strict guidelines imposed by Schiphol Airport. Even though the circular approach is often feasible, these guidelines (e.g. aesthetic and quality requirements) frequently hinder these circular applications. Another barrier that was often cited and increases the difficulty to implement circular methods for infrastructure assets, is the barrier of outdated certification requirements. Due to these outdated certification requirements, circular materials that are technically applicable, are frequently not suitable for the current certification standard. For overcoming these barriers and improving circular infrastructure assets, multiple strategies resulted from this thesis as well. The strategy that is mostly mentioned by the interviewees to be efficient, is the strategy of communicational improvements. According to the interviewees, the existing information gap between the stakeholders involved in the infrastructure asset construction and maintenance processes will be bridged by applying these

communicational improvements. Another strategy that is often mentioned, is the reconsideration of the process of assigning materials to infrastructure assets. Experts frequently argue that limiting the number of materials available and setting a limit on these materials forces the designer to think more creatively regarding circular approaches.

Based on all findings, it can be concluded that many barriers need to be overcome and multiple potential strategies can be deployed within the field of circular infrastructure assets. The commonly mentioned barriers share a strong interconnection regarding their outdated and conservative nature. They are characterized by outdated institutional characteristics (stringent guidelines and certification requirements) as well as conservative behavior. Furthermore, limitations related to the CE approach's unreadiness (low virgin material pricing and a lack of financial incentives) prevent circular infrastructure assets from becoming profitable and, as a result, from being widely applied. According to experts, circular infrastructure assets are technically viable, but abovementioned constraints prevent CE from thriving for infrastructure assets. Finally, the nature of the strategies imposed by the participants of the interviews differ.

Most of these barriers and strategies were not yet identified in other studies, whereas the combination of these barriers and strategies was not yet mentioned. Therefore, this master thesis contributes to the CE research field. The results of this study can be useful/applicable for both scholars and practitioners in this sector, as it adds to existing information by examining the CE barriers and strategies in the infrastructure sector. Furthermore, the resulting CE barriers and strategies from this thesis partly overlap CE barriers and strategies that were earlier identified in literature for the broader construction sector. Due to the novelty of CE, some of the identified barriers and strategies in this thesis can be applied to the broader construction sector, or even to a certain level to all industries where circular issues are present. Concluding, not all findings in this study were entirely new, leading to the assumption that overlapping characteristics of the infrastructure sector and the broader construction sector translate to correlated barriers and strategies.

Throughout this thesis, multiple limitations were obtained and translated into recommendations. These limitations primarily followed from the methods used within this thesis as they could have influenced the results. This thesis provides recommendations for future academic research on how these results can either be tested, compared or extended. In addition, recommendations for this specific case and for the infrastructure sector in general are set out as well.

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Definition of terms

Circular Economy	An economic system where the concept of 'end-of-life' is replaced with recycling, reducing, and recovering materials within the distribution, production and consumption processes (Kirchherr et al., 2017).
Sustainability	Sustainable development is development that meets the needs of the present generation without compromising those of future generations. This concerns economic, social, and environmental needs (Kates et al., 2005).
Schiphol Airport	Schiphol Airport is the largest Dutch airport and an important airport in Europe. The airport is owned by the Royal Schiphol Group
Bam Infra	BAM Infra Nederland B.V., a company which is part of the Royal Bam Group, and which provides advice and designs for urban infrastructure, large-scale line infrastructures such as roads, railways and waterways, and ports and coastal hydraulic engineering.
Construction sector	Construction is the economic sector or industry concerned with the production of residential buildings, utility buildings and infrastructure (Nelissen et al., 2018; Wientjes et al., 2017).
Infrastructure asset	Physical assets of the entity or another entity that contribute to meeting the public's need for access to major economic and social facilities and services, e.g. roads, drainage, footpaths and cycle ways (Department for Victorian Communities, 2004).

List of abbreviations

BB	Building Barrier
BCI	Building Circularity Index
BIM	Building Information Modeling
BS	Building Strategy
CB	Construction Barrier
CDW	Construction Demolition Waste
CS	Construction Strategy
DfD	Design for Deconstruction
ECI	Environmental Cost Indicator
EU	European Union
GPP	Green Public Procurement
GHG	Greenhouse Gas
IAL	Infrastructure Asset Lifecycle
LC	Lean Construction
MCI	Material Circularity Indicator
SPM	Supplier Performance Measurements
SSI	Semi-Structured Interview
SWMP	Site Waste Management Plans
RC	Recycled Concrete
TC	Total Cost of Ownership

1. Introduction

1.1 Background

In recent years, the circular economy (sometimes abbreviated as: CE) has become the holy grail as a tool to some of the world largest sustainability challenges. The root cause of these sustainability challenges is tackled by the concept of CE where, in its optimal form, waste does not exist, and materials are kept in use. This, in contrast to the linear economy and economy with feedback loops as seen in figure 1. At various geographic magnitudes, attention is given to this theme. On global level, the Paris Agreement on climate and the 2030 Sustainable Development Goals are of high level on sustainability matters. 196 countries signed the Paris Agreement which resulted in the first global consensus on the need to intervene in the destructive climate change (Woolven, 2021).

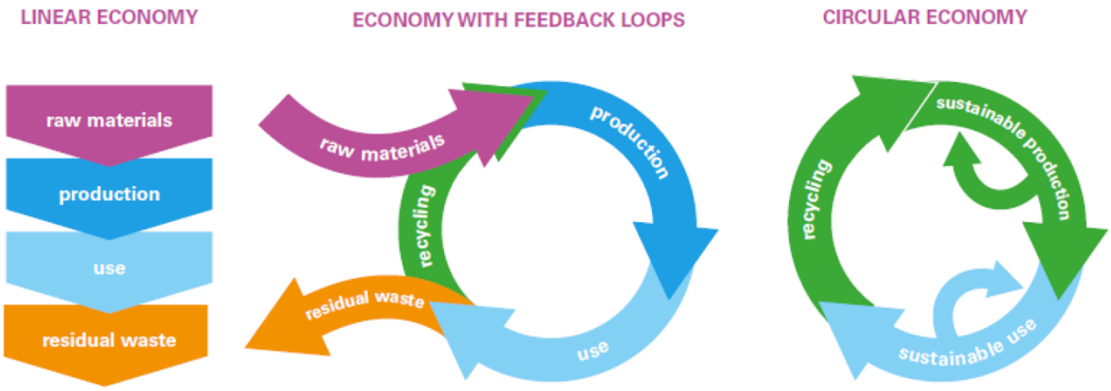

Figure 1: Different types of economies (Tweede Kamer der Staten-Generaal, 2013)

In addition, Europe has its own list of goals and agreements as well. The European Commission introduced a Green Deal in which Europe must reduce CO2 emissions by 55 percent by 2030 compared to 1990 and become fully circular by 2050. Europe will then become the first climate-neutral continent and will therefore no longer contribute to global warming through the emission of greenhouse gasses (GHG). To achieve and speed up this objective, the European Commission has issued a new plan for the circular economy in March 2020, the "New Circular Economy Action Plan". This action plan can be seen as one of the main building blocks for the earlier mentioned European Green Deal (European Commission, 2020).

In line with these international goals, several commitments have been made by the Dutch government. The Dutch economy aims to be fully circular by the end of 2050, and thus become a waste-free economy. An interim target, proposed by the Dutch government as well, states that the usage of primary material will have to be reduced by half at the end of 2030, compared to 2014. Within this transition agenda, a distinction between 5 priority chains is made: biomass and food, plastics, manufacturing industry, construction (building & infrastructure) and consumer goods.

1.2 Circular economy in the construction sector

Since all industries will have to meet the goals described in the previous section, and integrate CE in their processes, the Dutch construction sector attempts to do so as well. In general, in the reports on CE, the Dutch construction industry is divided into three parts: the residential building sector, utility building sector, and the infrastructure sector, as presented in figure 1 (Nelissen et al., 2018; Wientjes et al., 2017). The Transition Agenda for a 'Circular Building Economy (CBE)' was issued in 2018 as a follow-up to the 'Raw Materials Agreement' from 2017 and the government-wide program 'Circular Netherlands in 2050'. The ambition to make the entire built environment circular before 2050: an economy in which sustainable renewable raw materials are used as much as possible, products and raw materials are reused and in which waste does not exist.

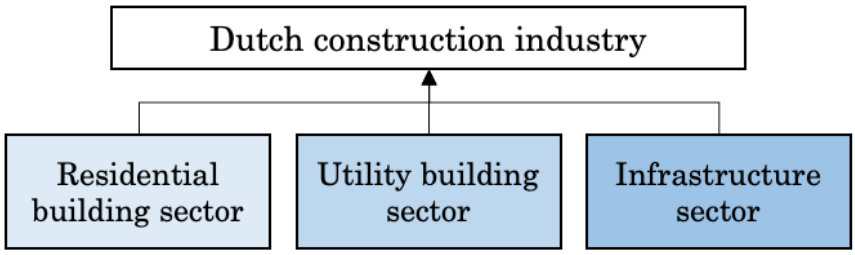

Figure 2: the classification of the Dutch construction industry (Nelissen et al., 2018; Wientjes et al., 2017)

The asset management process of Rijkswaterstaat also faces this challenge. Rijkswaterstaat has a more ambitious vision of the future, as they aim to work fully circular by the end of 2030 for their asset management processes. In addition to Rijkswaterstaat, the Minister and State Secretary of I&W has presented a strategy to achieve a climate neutral and circular national infrastructure by the end 2030. To contribute to this change on local level, Amsterdam Airport Schiphol has signed an agreement with, among others, Rijkswaterstaat, the province of North Holland and various municipalities to stimulate the CE in the province of North Holland. With the declarations of intent, the organizations agreed during the Collaboration Day to accelerate the reduction of the use of primary raw materials. Schiphol Airport will make a major contribution since it has the ambition to become the most sustainable airport in the world and to become waste-free by the end of 2030. Schiphol is doing this under the name "Zer0 Waste 2030". Zero waste means that all raw materials, components, and products used by the Royal Schiphol Group will be reused or recycled to the highest degree possible according to the waste hierarchy (Pronk, 2019). In addition, and in line with the governmental ambitions, Schiphol Airport aims to become fully circular by 2050.

1.3 Problem description

Despite all these visions and agreements mentioned in the previous sections, the concept of circular economy has not yet been implemented in the Dutch construction sector to a high degree. The construction sector is still the most waste producing sector within the Dutch industries as seen in table 1.

Top 5 waste producing industries	Waste production*
Construction	23,5
Metal	10,2
Nutrition	10,1
Textile, wood, and paper industry	3

Table 1: Waste generated per industry in the Netherlands, 2016 (CBS, 2019) ***(% of all production (products and waste))***

The worldwide construction sector in general, is far from a wasteless economy as 45% to 65% of waste materials are dumped in landfills (Ahmad et al., 2021) and consumes roughly 3 billion tons of raw materials every year (Guerra et al., 2021). These numbers are not different for the Dutch construction sector as it is accountable for 50% of raw material consumption, 40% of the total energy consumption and 30% of the total water consumption in the Netherlands (Rijksoverheid, 2019). Furthermore, a large part of all waste in the Netherlands (approximately 40%) relates to the construction and demolition waste and the sector is responsible for approximately 35% of CO2-emissions (Rijksoverheid, 2019). Despite these rather shocking numbers, nearly 38% of the materials used in the construction industry were recycled (CBS, 2019). So, the construction sector is producing the most waste, but also accounts for more than half of the use of all recycled materials. Although these high recycling percentages are often present within this sector, this does not reflect to its degree of circularity. The largest part of the Dutch construction and demolition waste (CDW) is namely downcycled (Zhang et al., 2020), which refers to the process in which reclaimed material is used in an application of less value than the original application (Allwood, 2014). This low-value application of recycled materials is for a large part embedded in the infrastructure sector (Nelissen et al., 2018). This is not in line with the concept of CE where materials should circulate at their highest value.

> *"An economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling, and recovering materials in production, distribution, and consumption processes."* (Kirchherr et al., 2017, p. 229)

The transition towards a circular economy is thus about the closing of cycles and using raw materials as efficient as possible. To comply with this statement for the infrastructure sector, the cycle regarding materials used and released for infrastructural assets must be closed. The outgoing "disposal" arrow, as seen in figure 1, should therefore become as small as possible or, even better, disappear completely. Then, circularity for infrastructure assets is reached.

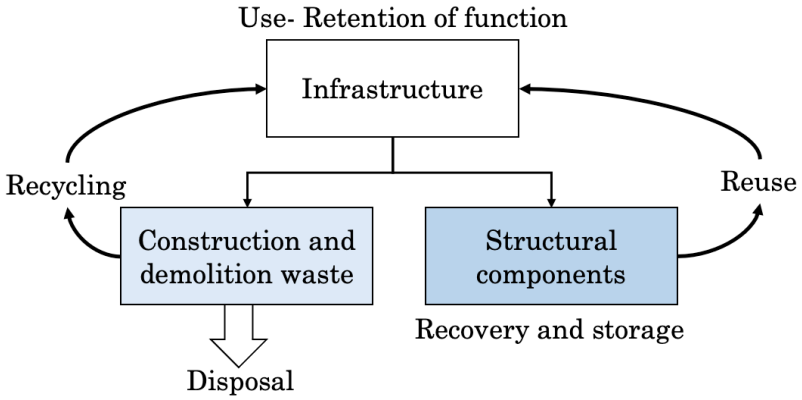

Figure 3: Recycling and reuse of infrastructure assets (Iacovidou & Purnell, 2016)

To summarize, the goals and visions to implement CE in the construction sector, and in specific, for infrastructure assets are extensively discussed in various reports and roadmaps. However, looking at the current state and extent to which circularity has penetrated this sector, these goals and visions have not yet led to sufficient progress. The question that arises is why these infrastructure assets are not fully circular in practice yet and how this can be fixed. Much academic research focusses on circular construction and the barriers and strategies involved, however, this is too broad and does not focus on the infrastructure assets, or the infrastructure sector in general. More research is needed on the matter of circularity within the infrastructural industry field.

1.4 Scope of this thesis

The infrastructure sector, as seen in the previous sections, is not implementing CE to its full potential. The present research does not explain why this is the case or what might be done to resolve the problem. To close this knowledge gap, an investigation into a case involving this topic is required. Identifying the CE barriers and strategies for this specific case should, in theory, close the gap in the larger sector. Therefore, the investigated case within this thesis, focusses on identifying barriers and strategies for increasing circularity in infrastructure assets within the Dutch construction sector. In specific, key barriers and strategies for the circular implementation within infrastructure assets on the landside of Schiphol Airport. This will be an interesting case as it provides the necessary information to clear the knowledge gap. Hence, only the infrastructure assets that are located on the landside infrastructure of Schiphol Airport will be investigated. On this landside territory of Schiphol Airport, Bam Infra executed all activities necessary to construct or maintain these assets. Therefore, this thesis will be performed at Bam Infra in collaboration with Schiphol Airport. Both the visions on this issue of Bam Infra and Schiphol Airport will form the empirical knowledge necessary for this study.

1.5 Objectives and research question

The overall aim of this thesis is to increase the level of knowledge on circularity barriers and strategies for the infrastructure sector in the Netherlands through a single in-depth case study, for infrastructure assets within Schiphol Airport. The following objectives are set out for this these:

- Gain insight on the barriers and strategies that are available in the existing literature for the circular economy in the European construction sector
- Identify what barriers and strategies are present for obtaining circular infrastructure assets on the landside of Schiphol Airport according to practitioners in this field
- Compare the empirical results achieved within this thesis with the insights obtained through the literature exploration
- Analyze to what extent these barriers and strategies can be generalized to the broader infrastructure sector

The main research question is: *"What are the key barriers and potential strategies for the implementation of circular infrastructure assets at Schiphol Airport?"* The main research question is divided in five sub-questions, these sub-questions are;

1. *"What are the most important barriers and strategies for the circular economy within the existing literature for the construction sector and how can they be categorized?*"
2. *What are the barriers according to the practitioners at Bam infra and Schiphol Airport for enhancing CE within infrastructure assets at Schiphol Airport?*
3. *"What strategies are available to implement CE to a larger degree infrastructure at the landside of Schiphol Airport according to Bam infra and Schiphol Airport experts?*
4. *"In what way do the outcomes differ or correlate to the CE barriers and strategies in in the construction literature?"*
5. *"Can the outcomes of this study be generalized to the broader infrastructural sector?*

1.6 Relevance of this study

1.6.1 Scientific relevance

In order to establish the CE concept, a system level transition is necessary (Coenen et al., 2020). However, a transition as such needs countless small steps, involving a lot of incremental innovations (Geels, 2002). This research will be one of the "many" incremental innovations that contributes to the system change needed for CE to thrive. By adopting a more in-depth company and business study on this CE subject, CE will become more applicable to the wider audience. This research will therefore have a significant contribution to the academic knowledge on this subject. It will be built on the literature available within this research domain to extend the knowledge and add scientific relevance. Besides, as stated by Coenen et al., 2020, there is a shortcoming of research on the circularity of infrastructural assets. Today's literature has not put enough emphasis on the infrastructure sector and its associated assets on a more holistic manner. This research attempts to replenish this shortcoming of knowledge by obtaining information

from experts in this research field through semi-structured interviews. With the results of this study, a wider understanding of this subject will be achieved and can in this way contribute to contemporary science. In addition, the lack of firm level studies on the circular theme (Werning et al.,2019; Munaro et al., 2021) justifies the in-depth single case study on barriers and strategies for this specific theme. Furthermore, the absence of holistic research within this field (Werning et al.,2019; Munaro et al., 2021; Charef et al., 2021) validates the fact that the entire infrastructure asset lifecycle is taken in consideration. Besides, inherent attention is given to the practitioners and professionals operating in this sector (Casanovas-Rubio & Ramos, 2017; Heravi et al., 2017), which is why these practitioners will be involved in this thesis. Finally, to identify the actions that can stimulate the implementation of CE, strategies are identified in this thesis.

1.6.2 Social relevance

The social relevance of this research is achieved through the possible circularity improvements of the infrastructural sector with the outcomes of this research. Private and public parties within the infrastructure domain that are willing to increase their degree of circularity will benefit from the results of this study. In addition, this research contributes to the circularity ambitions set by the Dutch government. As mentioned above, Schiphol Airport has signed an agreement with multiple governmental bodies to stimulate the CE in the province of North Holland. Furthermore, Schiphol Airport has a large societal impact on the Dutch economy and may set an example for other companies that are willing to increase their circularity.

1.6.3 Relevance to study program

This research fits well with the Complex Systems Engineering & Management theme since there are many overarching topics and characteristics of the master's program. First, since the adaptation of the CE within the infrastructural sector deals with many stakeholders with different needs, complexity in this area will be present as was central within the master's program. In addition, the main issue of this study lies in the relative novelty of CE and especially its application in the infrastructure industry, therefore contains many uncertainties. These complex socio-technical systems were central during the study program. Furthermore, the values of both the public and private domains are covered within this thesis. Both Bam Infra and Schiphol Airport exhibit aspects that are typical for the private domain. many complexities of the public domain are dealt with as well, such as existing regulations, permits, subsidies, e.g.

1.7 Outline thesis

This thesis is divided into nine chapters. After the introduction in chapter, the methodology of this thesis will be set out in chapter 2. In chapter 3, the case that is being investigated will be explained in further detail. To comprehend the current state of knowledge on barriers and strategies for the implementation of CE in the European construction sector, literature exploration will be set out in chapter 4. In chapter 5, the results and analysis of the semi-structured interviews is displayed. The discussion of these results will be discussed in chapter 6 and in chapter 7, the conclusions and recommendations are set out.

2. Methodology

This research will adopt an exploratory, interpretive approach mainly since there is a lack of theory within the research domain. An attempt to discover something new and interesting by delving deeper into the research topic is central (Swedberg, 2020). The overall objective of this study is to further understand how the CE can be wider developed within the infrastructural sector by focusing on a specific case within the infrastructure field. In this manner, opportunities for improvements in this broader area can possibly be identified. The research strategies and methods will be explained through the order of Johannesson & Perjons (2014) as seen below.

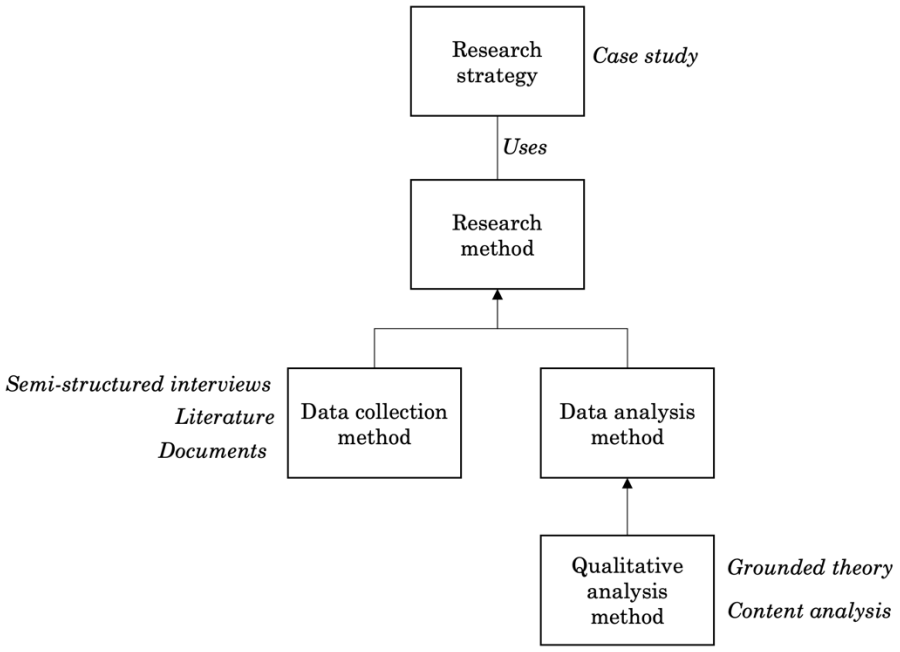

Figure 4: Research strategies and research methods (Johannesson & Perjons, 2014)

2.1 Research strategy

2.1.1 In-depth single case study

A lack of information exists on what the key barriers and potential strategies are for the implementation of CE within infrastructure assets. Concrete and contextual knowledge about this specific topic is missing in the academic literature. Therefore, rich in-depth insights and descriptions of where CE barriers are located and what strategies are available for this sector are necessary. A case study has the ability to portrait the detailed picture of a certain instance that is necessary for this situation (Johannesson & Perjons, 2014). A case study is thus chosen to retrieve the missing information and to describe, compare, evaluate, or understand the different aspects of the problem.

So, the infrastructure sector in general is lacking their degree of circularity, and the reasons why and how to overcome these barriers are uncertain. A case was chosen from which information could be extracted to identify this existing gap between knowledge and practice. By studying barriers and strategies for implementing circularity in the infrastructure assets that are present on the landside Airport on Schiphol, the necessary

information can be obtained. The rationale for this case study is the representativeness of the case (Yin, 2009) and the link to the broader issue. The case study will represent a typical project of infrastructural construction involving a client and main contractor, especially for the infrastructure construction located at airports. According to Kamminga (2009), clients and contractors have the most impact on infrastructure projects. As this research aims to obtain better understanding in what the CE barriers and strategies are for infrastructure assets, the client and contractor of these infrastructure projects will therefore be focused on. The client in this case, Schiphol Airport, owns the infrastructure assets and outsources its construction and maintenance to the main contractor, Bam Infra. The availability of infrastructure assets on Schiphol Airport and the available expertise at Bam Infra ensures this to be a suitable case for the intended purpose.

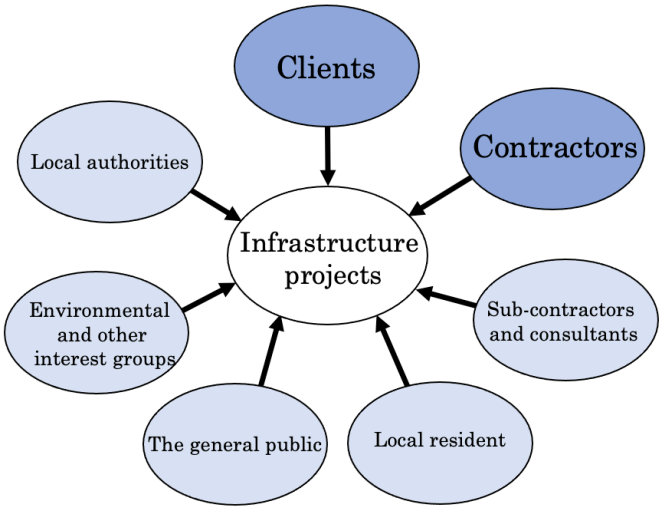

Figure 5: Actor influence on the construction of infrastructure (Kamminga, 2009).

2.2 Data gathering methods

In a case study, evidence and data can be gathered through different sources as documents, interviews, and direct observations (Yin, 2009). For this case study, semi-structured interviews will be used as main data gathering method, which will have assigned section 3.3. For the exploration part of this thesis, documents and literature will be analyzed, which will be explained in this section.

2.2.1 Literature review

A literature review summarizes and assesses a body of work on a particular subject (Knopf, 2006). Another purpose for writing a literature review is that it can provide a framework for relating new findings to previous findings (Randolph, 2009). Without establishing the state of the previous research, it is impossible to establish how the new research advances the previous research. In the case of this thesis, the current state of literature on barriers and strategies for adopting CE within the construction sector will form a comprehensive list that will be used as the theoretical framework of this thesis. This theoretical framework will be tested against the empirical results achieved by this thesis. In addition, the literature review is used to gain methodological insights, identify recommendations for further research, and seeking support for grounded theory.

2.2.2 Documents

Another way to obtain information and data when performing a case study approach is through document inspection. Documents are a great way to explore the case that is being studied. In this case, organizational records and personal communications are used to comprehend a better view of the case that is the subject of the study. Organizational records include company memos and annual reports while personal communication documents exist of emails and other messages (Johannesson & Perjons, 2014). In this thesis, company documents were available at the construction company Bam Infra. These documents were available online and on-site. The information from these documents helped to guide the interviews (Bowen, 2009) and to have a good understanding of the "course of events" for the analyzed case. So, primarily, documents are used for obtaining information on the case study and the agreements on circularity decisions between Bam Infra and Schiphol Airport.

2.3 Semi-structured interviews

When performing a case study, information on the case that is being investigated is needed. One way of retrieving this information, is through performing semi-structured interviews which will provide in-depth information on the experience and expertise of the participants in the case (Evans & Lewis, 2017). Semi-structured interviews are therefore well suited to obtain expert's view on a specific subject (Gill et al., 2008) and highlight common emerging ideas (Creswell & Poth, 2016a). The view of experts at Bam Infra and Schiphol Airport will be used to test the outcomes of the literature exploration on barriers and strategies for the construction sector with the empirical data obtained through thses semi-structured interviews.

2.3.1 Interview population

In order to help the investigator in a case study, respondents for interviews are selected based on what they might know that can help in in gathering the pieces of a puzzle (Aberbach & Rockman, 2002). Semi-structured interviews are useful when collecting opinions and experiences (Longhurst, 2003). In this case, internal experts, and professionals of Bam Infra and Schiphol Airport provided empirical data necessary for this thesis. This is essential since this research attempts to gain information in a more holistically way and involve professionals and practitioners on how the CE can be best adopted.

2.3.2 Interview scheduling

To schedule these interviews, use was made of connections within the construction company where this thesis took place, Bam Infra, and the associated client, Schiphol Airport. Besides, experts in this research field were reached too as well, in order to obtain their opinion on this matter. The snowball method was used to expand the population with additional stakeholders operating within Bam Infra or Schiphol Airport who were not within the direct connections of the researcher. In appendix E, the overview of the interview scheduling process is displayed.

2.3.3 Interview preparation

One of the most important and crucial parts of the preparation for semi-structured interviews is the creation of effective research question for the interview (Turner, 2010). From literature (McNamara, 2019), several key points were derived which should be considered when creating these questions; (1) the questions must have an open-end, (2) there must be neutrality in the questions, (3) only one question should be asked at the time, (4) the wording should be clear in the questions, (5) and lastly, "why"-question should be asked only when strictly necessary. In creating and conducting these semi-structured interviews, extra attention will be paid to these key points. Follow-up questions can also be used in the sense of verbal and non-verbal probing techniques (Kallio et al., 2016). By expressing the interviewee's point or showing interest in the expertise of the interviewed person, verbal probing can be used (Whiting, 2008). Nonverbal probing can be deployed by remaining silent and by letting the interviewee think out loud (Whiting, 2008). Both the verbal as well as the non-verbal probes were used in obtaining objective opinions from the interviewees. In Appendix E, the interview questions are set out. In addition, a Data Management Plan (DMP) was set up which contains the data is stored and manage the data during the project, and what happens to the data after the project.

2.4 Data analysis methods

Qualitative data describes the phenomenon instead of measuring the data as quantitative data does. The qualitative data that needs to be analyzed for this thesis are the semi-structured interviews. A data analysis method is needed to analyze the semi-structured interviews. A mix of grounded theory and content analysis is used to analyze the transcripts obtained from the semi-structured interviews.

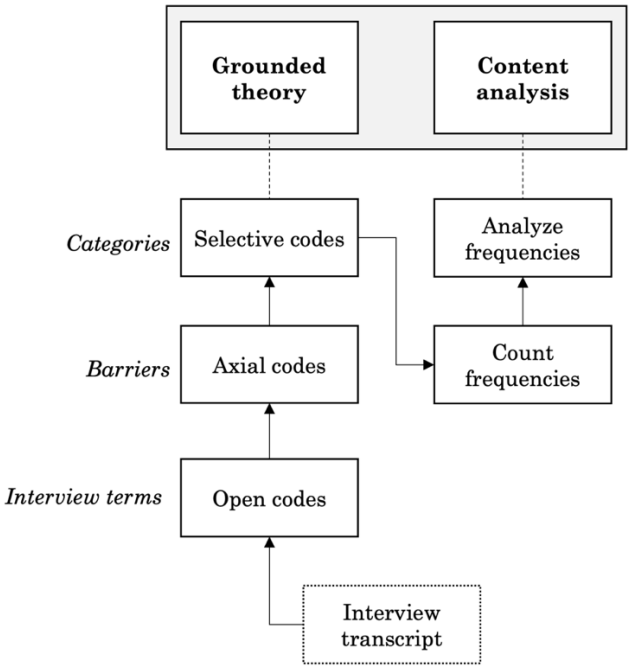

Figure 6: Mixed data analysis method approach

2.4.1 Grounded theory

The semi-structured interviews are performed to obtain empirical information on what barriers and strategies are present according to practitioners in the infrastructure field. It is therefore necessary to subtract these barriers and strategies from the transcript texts obtained during these interviews. Therefore, after all the interviews are transcribed, coding must be performed to analyze these pieces of text. To do so, grounded theory was deployed to quantify and classify the empirical data obtained through the interviews. Grounded theory is a scientific research method for the development of theories through the systematic collection and analysis of qualitative data. According to Johannesson & Perjons (2014), coding through grounded theory exists of three steps: open coding, axial coding, and selective coding. By open coding, the empirical data is observed by marking important lines or words and link them to a code. In the next step, axial coding, the most important codes are put in categories. In the case of this thesis, these categories are the barriers and strategies. Then, in the final step, selective coding is used to further categorize the outcomes of axial coding in themes. Categories obtained in the previous coding stage, axial coding, will be selected and organized to obtain a higher level of abstraction. In the case of this study, these are the categories of both barriers and strategies obtained in the literature search. The software ATLAS.ti is used to code the interviews and to further analyze these codes.

2.4.2 Content analyses

In addition to subtracting all these barriers and strategies form the interview transcripts, statements on the occurrence of these barriers and strategies are desirable as well. This will indicate to what extent these barriers and strategies are present during their daily operations on circular infrastructure assets. To obtain these occurrences, frequencies of the barriers and strategies must be analyzed. This can be performed with content analysis. So, in addition to the grounded theory method, content analysis was also included in the latter part of the data analysis method. The idea of content analysis is to divide pieces of texts into categories, and then calculate the frequencies of the occurrence of these pieces of texts (Johannesson & Perjons, 2014). The transcripts were categorized using the grounded theory method, and the frequencies were determined according to the content analysis. According to Denscombe (2010), content analysis exists of six steps. In this thesis, the last two steps will be used; count the frequency of the units for each category and analyze the texts in terms of frequency. the content analysis is performed in this thesis to be able to make statements about the extent to which barriers and strategies are mentioned. Where grounded theory has been used to form barriers and strategies, this case involves making statements to what extent the interviewees mentioned these barriers and strategies.

3. Case description

As explained in the previous chapter, this study will make use of an in-depth single case study. This case study will focus on the barriers and strategies for circular infrastructure assets on the landside of Schiphol Airport. In the case of Schiphol, the airside part of the airport entails all roads, (civil) engineering structures, parking areas and associated infrastructure on the public part of Schiphol Airport. The landside section is highlighted in yellow in the figure below.

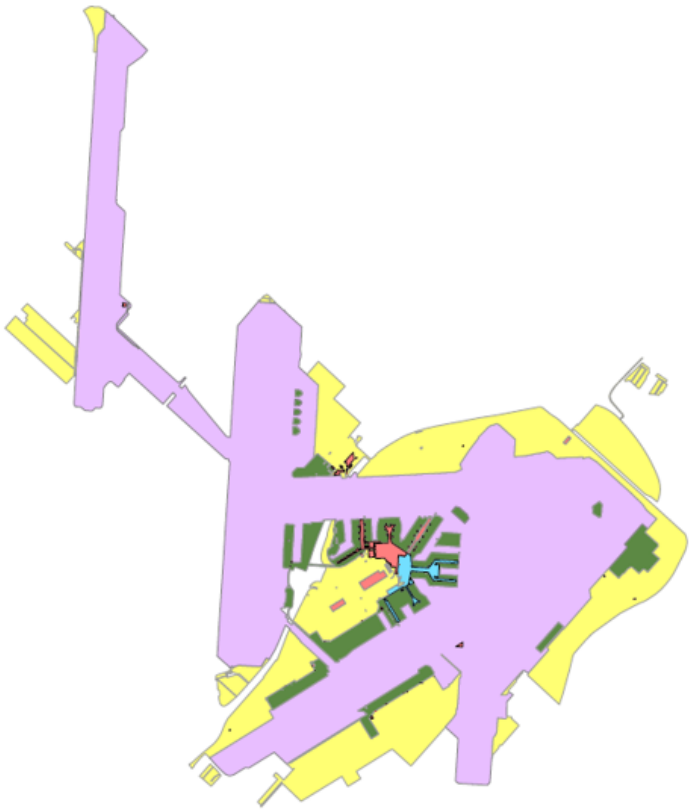

Figure 7: Schematic representation of Schiphol Airport

3.1 Future vision Bam Infra and Schiphol Airport

Schiphol Airport and Bam Infra have essentially the same sustainability ambitions in terms of reducing emissions, waste and increasing circularity. The objective of Schiphol Airport in the field of sustainability are optimal asset return, excellent organisation, innovation, and digitization. Since this thesis focuses on CE improvements of the infrastructure assets, this part of the ambition will be explored. The circular visions of Bam Infra and Schiphol Airport are displayed below.

Royal Schiphol Group	Royal Bam Group
Schiphol Airport has two goals regarding CE: Zero-waste airport by 2030 and Circular airport by 2050 (Schiphol Group, 2022). Schiphol wants to achieve these goals by circular design principles, reuse and upcycling and closed loops (Schiphol Group, 2022).	In addition to the requirements in the agreement, Bam is committed to this objective by reusing 100% of our demolition waste and 83% of construction waste. This is based on the fictitious scope as indicated in the registration form. By the end of 2025, Bam wants to be a circular construction company.

3.2 Circular economy at Schiphol Airport & Bam Infra

The abovementioned future visions of Bam Infra and Schiphol Airport can be achieved by implementing circular improvements in the entire processes of infrastructure assets at Schiphol Airport performed by Bam Infra. Schiphol has the ambition to become a Zer0 Waste Airport by the end of 2030 and fully circular by the end of 2050. Three strategic measures have been identified by Schiphol Airport to reach these goals and visions:

- (a) Circular design and realization of all new construction and/or renovation of assets and (b) circular procurement of products and services
- Maximize the return on resources by "circulating" these resources as long as possible in the usage phase within infrastructure assets
- Achieving maximum economic residual value from residual flows that are released from all processes and activities through reuse and/or recycling

These objectives cannot be achieved without Bam Infra adhering to them. Bam Infra is in the contractor that builds and manages the infrastructure assets that are present on the landside of Schiphol Airport. To meet the visions and the strategic measures given by Schiphol Airport, Bam Infra set out the following activities: circular design and implementation, circular procurement, and processing residual flows. Several examples of projects where CE-principles are given in Appendix J.

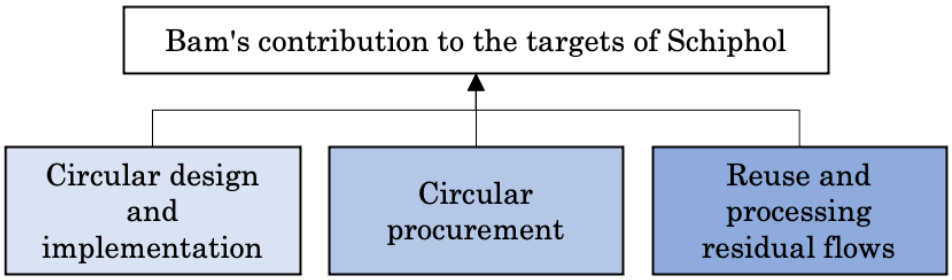

Figure 8: Actions of Bam Infra to contribute to the CE targets of Schiphol Airport

3.2.1 Circular design and implementation

The approach of Bam Infra to their use of materials is based on the "Trias materialis". The material triad focuses on reducing the use of finite materials as can be seen in the figure below. The trias materialis provides a guideline for the right choice of material and can be set out in three steps (van der Palen & Luijten, 2019):

1. Developing material efficient products and production processes by limiting the material requirement and using finite materials as efficiently as possible
2. Closing the material chain through reuse of materials and components
3. Searching for alternatives to scarce materials and raw materials

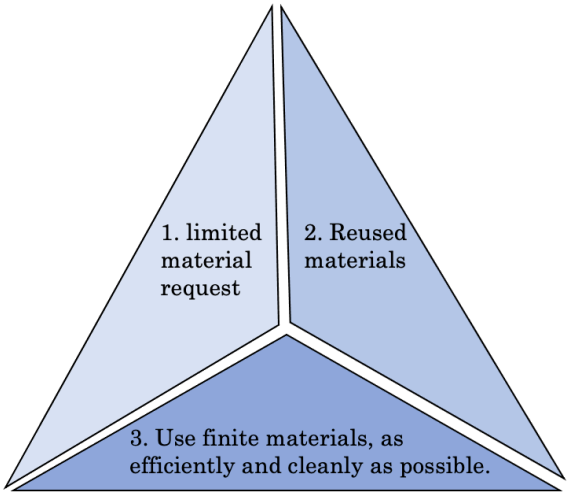

Figure 9: Trias materialis

3.2.2 Circular procurement

Sustainability is subject to continuous developments. That is why Bam Infra cooperates with partners who support the field of CE. Each key supplier will submit a plan in which it is discussed which measures are taken in the field of sustainability. Suppliers are assessed for sustainability via performance measurements. In addition, requirements are imposed on our partners:

- A key supplier must use materials and resources only if these materials are not harmful to the environment unless there is no alternative available. In the latter mentioned, it must be stated why there is no alternative for the use of these harmful substance and what the objective is for phasing out these harmful substances.
- Products supplied to Bam Infra by the key supplier contain the highest possible percentage of recycled material, where possible 100%.

3.2.3 Reuse and processing residual flows

Separating residual flows into different segments contributes to Schiphol's Zer0 Waste ambition by making the segments suitable for reuse or recycling. Within Bam Infra and Schiphol Airport, a distinction is made between two residual flows:

- Infra residual flows
    - Management, maintenance, and modifications
    - Construction of infrastructure
- Operational residual flows

Infra residual flows arise from activities related to the construction, renovation and/or maintenance of the infrastructure assets. The separation percentage of at least 95% is aimed at for this residual stream. The "construction of infrastructure" residual flow consists of all leftover-waste resulting from infrastructure asset construction and demolition waste which is released during the demolition of existing infrastructure assets. This concerns bulk materials as milling material, (concrete) rubble and soil. Operational residual flows are all the other residual flows that are not related to construction-related activities such as office waste. The aim for recycling operational waste is 80%. Bam and Schiphol are neither waste processing companies. For this reason, they will not be able to treat and recycle the residual materials. Nevertheless, they are responsible for proper waste processing.

3.3 Agreements among Schiphol Airport & Bam Infra

Agreements among both the contractor and client are important for CE to thrive. Therefore, it is necessary to analyze what agreements between within these two companies, and how they relate to CE of infrastructure assets at the landside of Schiphol Airport.

3.3.1 Long-term contract

In the case of Bam Infra and Schiphol Airport, as is not unusual with larger infrastructure sites, a long-term contract is concluded between the client and main contractor. This requires both parties to tailor these contracts as they have their own dynamics. Long-term contracts need additional measures compared to single transactions (Kamminga, 2009). A number of these measures are; regular evaluation, inclusion of procedures for renegotiation, ethical rules in the construction sector (Kamminga, 2009). For this reason, a good relationship is necessary for smooth cooperation and continuation of business. In the case of Bam Infra and Schiphol Airport, one-directional guidelines are set up by Schiphol Airport for Bam. These guidelines are discussed and reconsidered in a pre-discussed time frame. In these long-term contracts, several agreements are made on the circularity of infrastructure assets on the territory of Schiphol Airport, and how Bam Infra must adhere to this.

3.3.2 Best-value Procurement

Best Value Procurement (BVP) is the approach in which the aim it to obtain the most value for the best price. In Best Value cooperation, the contractor takes the lead, so that his expertise can be used optimally (BAM Infra Nederland, 2020). In the case of Bam Infra and Schiphol Airport, this BVP is present. The contractor takes on the role of expert in all projects, which offers many opportunities for circularity improvements. Especially since Bam Infra is given the freedom to come up with a design itself. Schiphol only comes up a strict guideline that Bam must meet without many specific requirements.

Targets for BVP (Rijkswaterstaat, 2015) :

- Achieve the most value for the best price.
- Optimal use of the expertise of both parties.
- Thinking from the common interest (win-win).
- Reducing risks through clear planning.
- Simplify decision-making and reduce transactions.

This BVP will have benefits for both the main contractor and the client. Bam Infra will have more opportunities to enhance their operations regarding circularity improvements and Schiphol Airport will retrieve more quality, without it being necessary to check every step of the contractor. Since the management and maintenance will be placed under responsibility of Bam Infra, they will be responsible for the infrastructure assets located in the landside of Schiphol Airport. These BVP contracts are getting more implemented over time in the entire construction industry, as Rijkswaterstaat is willing to do so as well.

3.3.3 Guidelines Schiphol

Schiphol has set up guidelines and requirements that all main contractors operating at the territory of Schiphol Airport must adhere to. Bam Infra must consider these guidelines during all operation on infrastructure assets of Schiphol Airport. These guidelines mainly consist of specifications and certification requirements.

3.4 Collaboration process between Schiphol Airport & Bam Infra

As the main contractor for the infrastructure on the landside of Schiphol Airport, Bam Infra and Schiphol Airport have had a strategic partnership since April 2019. This collaboration consists of several agreement for the management, maintenance, and new construction of these assets. So, to summarize, Schiphol asks for the “what” and Bam fills in the “how”. The standard collaboration process for construction is set out by Kamminga (2009). In this overview, the different processes are set out and where the client and contractor collaborate within these processes. According to Kamminga (2009), the client and contractor will only not collaborate during the planning phase but begin their collaboration when tendering. This standard collaboration process, however, is different for the situation of Bam Infra and Schiphol Airport.

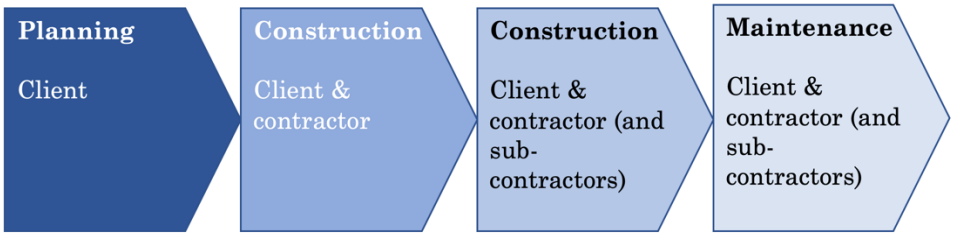

Figure 10: The main collaboration processes between client and contractor that take place during the construction process (Kamminga, 2009).

The tender stage as described above in figure 9, which happens during regular construction processes, is not included in the case of Bam Infra and Schiphol Airport. A tender is a procedure in which a client invites companies to submit a quotation for the performance a certain service or for the delivery of a product. Construction companies register with a quotation for the work or service. The collaboration process as is the case for Bam Infra and Schiphol Airport, is reflected in figure 10. In addition, both the client and contractor are involved in the planning and construction stage. The maintenance of infrastructure assets is managed by Bam Infra, which is the result of the BVP.

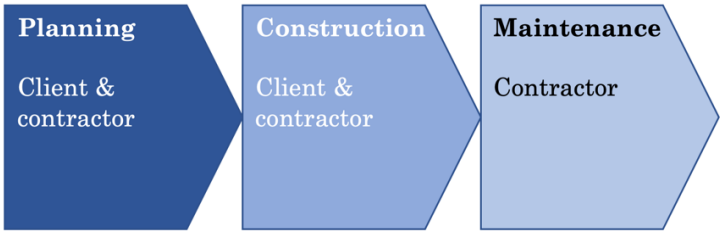

Figure 11: Collaboration process between Bam Infra and Schiphol Airport

3.5 Infrastructure asset lifecycle and residual stream

For obtaining barriers and strategies for enhancing circularity within the infrastructure asset lifecycle, it is important to set out what infrastructure assets are included in the case of Schiphol Airport, how the infrastructure asset lifecycle looks at Schiphol and what materials are used for these infrastructure assets.

3.5.1 Infrastructure assets on the landside of Schiphol Airport

Within this case study, the infrastructure assets will exist of all roads, bridges, viaducts, parking areas and other associated infrastructure on the landside of Schiphol Airport. This includes one million square meters of asphalt pavement, 13 Civil engineering constructions, more than 4,500 signs and 30,000 m2 of marking, 230 hectares of planting and approximately 8,000 gullies and wells.

3.5.2 Infrastructure asset lifecycle

To adhere to the approach taken in this thesis and therefore obtain a holistic approach, the entire infrastructure asset lifecycle must be overviewed. It is important to notice that circular barriers or strategies within the construction domain are not solely located in one part of the infrastructure asset lifecycle. However, studies often tend to focus on one part of the many phases of construction (Kivilä et al., 2017; Silvius & de Graaf, 2019). Within the academic field, the lifecycle of infrastructure assets is set out differently. In the

handbook on sustainable development of infrastructure assets provided by the United Nations, the lifecycle of a physical asset consists of four phases: planning, acquisition, use and disposal (United Nations, 2021). However, Giglio et al. (2018) describes the lifecycle of infrastructure assets in a more detailed manner as can be seen in figure 14 below.

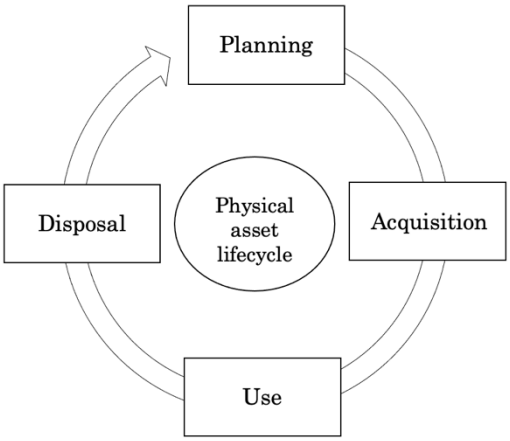

Figure 13: Physical asset lifecycle

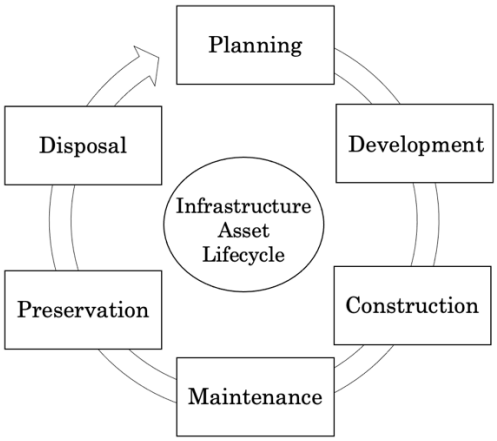

Figure 12: Infrastructure asset lifecycle

Despite this divergent life cycles, it is important to note that within this thesis, barriers and strategies for the entire infrastructure asset lifecycle will be explored. Most practitioners and professionals operating at the landside of Schiphol Airport, are involved in the entire asset lifecycle, and therefore will be analyzed as a whole.

3.5.3 Current material stream of Bam Infra at Schiphol Airport

When analyzing the raw material residual streams of infrastructure assets during the activities carried out by Bam Infra at Schiphol Airport, a material stream overview can be made as seen in Appendix I. For the period 2021-01 to 2022-01, the released materials from the highest to lowest amounts are seen in Appendix I as well. Most of these materials are being recycled by third party recycling companies. The problem here, however, is that Bam Infra as well as Schiphol Airport lose their influence and insights on the materials that are being recycled. As stated in the first chapter, circularity is more than recycling. Ideally, the material stream should not be a linear stream as is the case now, but a circular loop in which none of the materials leaving the infrastructure assets are lost in the environment. The way in which this loop can be achieved is one of the pressing challenges that Bam Infra and Schiphol Airport face. Hopefully this challenge will result in more concrete actions through the results of this study. The far most residual streams are: crushed aggregate “menggranulaat”, asphalt residues “frees schollen” and concrete chunks “BSS”. This thesis focusses on the barriers and strategy for obtaining CE in the infrastructure assets at Schiphol.

3.6 Summary case study

The overall objective of this thesis is to better understand what the barriers and strategies are present for closing the loop of infrastructure assets resulting in a (at least more) circular application of the infrastructure assets. These infrastructure assets are present at the landside of Schiphol Airport where Bam Infra carries out the construction and maintenance of these assets. Obtaining these insights on barriers and strategies is thus perfectly suitable at this location with these two main actors. Bam and Schiphol both have coordinated circular ambitions. These ambitions are linked to actions to ensure that these ambitions are achieved. Bam Infra set out the following activities: circular design and implementation, circular procurement, and processing residual flows. These different visions, ambitions, contracts, and agreements are set out in this chapter which have to be taken in consideration during this study.

4. Literature exploration on CE barriers and strategies

In this chapter, an extensive overview will be given of the existing literature about CE barriers and strategies within the construction domain. Before delving deeper into the barriers and strategies that arise in the research field of this thesis, the literature search methodology will be explained, in section 4.1. Then, in section 4.2, an overview of the categorization of CE barriers and CE strategies will be obtained and what categorization will be used in this thesis. In section 4.3, the barriers for the CE implementation for the building sector and the construction sector in general will be set out. Thereafter, in section 4.4, the strategies that are available within the existing literature for both the building sector and construction sector in general will be obtained. Lastly a summary of the literature exploration will be displayed in section 4.5.

4.1 Search plan

In gaining information on the subject of CE within the infrastructural sector, a review of the current literature was conducted. This way, key findings and relationships between these findings can be identified. The literature review is mainly based on scientific journal articles that are written in English. First, an analysis of the research topic was performed through the identification of key words as 'Circular AND Infrastructure', 'Infrastructure AND Assets', 'Circular AND Construction', 'Sustainable AND Construction', 'Circular AND Economy', 'Circular AND Infrastructure AND Assets', 'Circular AND Assets', 'Circular AND Barriers', 'Sustainable AND Barriers', 'Client AND Contractor', 'Infrastructure AND Projects". These search terms were used to obtain an overview of where the today's research is. Most of the searches were conducted in Scopus, Web of Science, Science Direct and Google Scholar. To obtain more literature on this subject, use has been made of the "Snowball method" and the "citation search method". With these methods, related articles to the already found literature can be obtained.

Thereafter to obtain literature on the articles that focus on the barriers for construction like industries, the search was used: (TITLE-ABS-KEY (circular AND barrier)) AND ((construction)). For strategy identification the search terms were as followed: (TITLE-ABS-KEY (circular AND strategy)) AND ((construction)). The focus of these search terms was finding articles that identify CE barriers or/ and strategies. As this thesis focusses on the construction of infrastructure on Schiphol Airport, several boundary conditions are set out to which articles to involve in this exploration.

4.1.1 Literature on construction sector

This thesis focusses on the infrastructure sector which as a specific subsector of the construction sector in general. The construction sector namely exists of industrial construction, building construction and infrastructure construction (Chitkara, 1998). Since literature on CE barriers and strategies on the construction of infrastructure is limited, literature on the entire infrastructure will be included in this literature exploration. All literature that focusses on non-construction subjects will be excluded from the identification of barriers and strategies.

4.1.2 Literature on barriers and strategies for CE

The identification of barriers and strategies for circular improvements of infrastructure assets is central in this study. The shortcoming of these barriers and strategies in the existing literature for this specific sector leaded to this investigation. Therefore, literature that centers barriers or strategies for the implementation of CE is included in the literature exploration. Literature that focusses on barriers or strategies separately are included in this search as well.

4.1.3 Literature on EU construction

As this thesis focusses on barrier and strategy identification for the case of Schiphol Airport, ideally literature that focusses on the Dutch construction sector should be used to create an overview of barriers and strategies. However, since there is a shortcoming of Dutch literature within this field, it will be expanded to literature that focus on the European construction sector. Due to the many characteristics difference in the European construction sector and the non-EU construction sector, no use will be made of literature that does not put the scope on the European construction sector.

The first reason for the exclusion of non-European research is the mentality of the EU to change from a linear waste management system in the construction sector to a circular one (Zhang et al., 2022). These EU-ambitions have a significant impact on the different barriers and strategies that may apply to the case of this thesis. In addition, the management of construction in the EU, regarding regulations, laws, policies, and technologies are specific and play an important role towards a circular construction sector (Zhang et al., 2022). This is mainly since the construction sector is largely influenced by the contextual environment of a country or region (Chan & Tse, 2003). Institutional support is an important factor for CE (Ranta et al., 2018), which in the case if the Netherlands is traced back to the EU.

To summarize:

1. The publications must have the construction industry or a more specific branch of this subject as their main focus.
2. Barriers and/ or strategies regarding the implementation of CE must be central.
3. The scope of the study must be in one or more European countries.

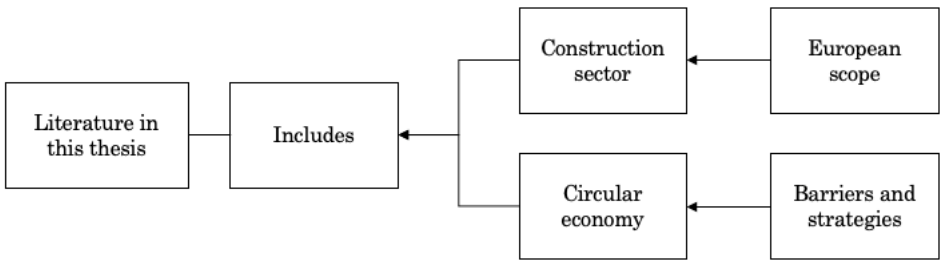

Figure 14: Included literature in thesis

4.2 Categorization of circular economy barriers & strategies

Given the wide number of barriers and strategies that are available within the existing literature, this thesis sought to classify them into several categories. The different categories that are present within the existing literature will be set out in this section. This way, a well-considered decision can be made what categorization is most suited to apply in this thesis. Section 5.2 will be divided into two parts:

- The categorization that is used in papers that identify barriers and/ or strategies for the European construction sector
- the categorization that is used for the entire available literature on CE barriers and strategies

The first part will obtain all categories that are used in papers that focusses on circularity barriers and strategies within the European construction domain. In the second part, categories will be extracted from papers that focus on CE barriers and/ or categories in general. So, for the second part, both the restriction to pus emphasis on the construction sector and on European countries are removed. The reason being, is that identifying categories for barriers and/ or strategies within the existing literature will not have any geographical or sector specific restrictions. Therefore, the generic characteristic of categories will make the restrictions discussed in the search plan redundant for section 5.2.2.

4.2.1 Categories used for the European construction sector

The categorization used by the papers where the barriers and strategies for the theoretical framework are abstracted from will be described in this chapter. In total, 12 different disciplines for the categorization in the found literature for the CE barriers and strategies within the European construction domain.

In a Scandinavian study by Sigrid Nordby (2019), a distinction is made between technical, organizational, market and policy barriers and drivers for the Norwegian building sector. The main goal of this study was to analyze in what way building materials can be reused on a large scale in Norwegian building industries. The separation of four categories is used by Huuhka & Hakanen (2015) as well in another Scandinavian study. Huuhka & Hakanen (2015) distinguished, technical, economical, sociological, and ecological barriers for the reuse of steel and concrete of load bearing structures for buildings in Finland. Adams et al. (2017) added one more category to his study and thus made a distinction between five categories. In the current awareness, challenges, and enablers for the CE, technical, economical, policy, organizational and business issues and opportunities were addressed. This industrywide study focusses on the built environment with its challenging constituting elements. In the Danish building industry, Selman & Gade (2020) separated six categories as well, technical, economical, sociological, policy, collaboration, and digitalization issues were addressed. This study investigates the potential of using CE in building design, and waste reducing circular strategies. Morel et al. (2021) studied how earthen architecture in western Europe could enhance the transition to CE. A differentiation between six categories was obtained, technical, economical, sociological, political, organizational. This distinguish was made since Morel et al. (2021) stated that

too much research focused only on the technical aspects of CE while other aspects were as important according to recent findings.

In table 2 below, all mentioned categories in the analyzed papers for the barrier and strategy identification within the European construction sector are set out. In the coming chapters, the content of these papers, which these categories have been extracted from, will be explained in more detail.

Category	Used by authors	#
Technical	Selman & Gade (2020); Sigrid Nordby (2019); Morel et al. (2021); Adams et al. (2017); Huuhka & Hakanen (2015)	5
Economical	Selman & Gade (2020); Morel et al. (2021); Adams et al. (2017); Huuhka & Hakanen (2015)	4
Sociological	Selman & Gade (2020); Morel et al. (2021); Huuhka & Hakanen (2015)	3
Policy	Selman & Gade (2020); Adams et al. (2017); Sigrid Nordby (2019)	3
Organizational	Morel et al. (2021); Adams et al. (2017); Sigrid Nordby (2019)	3
Environmental	Morel et al. (2021); Sigrid Nordby (2019)	2
Political	Morel et al. (2021)	1
Collaboration	Selman & Gade (2020)	1
Digitalization	Selman & Gade (2020)	1
Business	Adams et al. (2017)	1
Market	Sigrid Nordby (2019)	1
Ecological	Huuhka & Hakanen (2015)	1

Table 2: Categorization by European construction papers

4.2.2 Categories used for general CE barriers and strategies

In studies that do not focus on European construction but identify barriers and strategies for other industries are set out in this chapter. In these studies, on the CE in general, more categories are set out. The categories that are distinguished will be discussed without going too much into the content of these studies as that is not the main aim of this section. The largest studies on this matter will be analyzed below.

One of the largest European studies on barriers for the CE in general is performed by Kirchherr et al. (2018). In this large-N-study for the implementation of CE within Europe, a distinction is made between four barriers categories: cultural, regulatory, market and technological. These four barrier categories are recognized by other studies but are often named differently. However, the nature of these four-barrier categorization does not vary much between the different studies categorizing barriers. Another worldwide study, where a four-categorization is used, is by De Jesus & Mendonça (2018) on the drivers and barriers for the CE, that uses the categorization technical, economic, institutional, and social. In addition, De Jesus & Mendonça (2018) makes a separation between in soft and hard barriers and drivers were technical and economic barriers can be seen as the hard barriers and the social and institutional as the soft barriers. This soft approach is used in the study by Rakhshan et al. (2020) with only organizational and political as main categories. Grafström & Aasma (2021) uses the four-scale categorization as well to study how the CE can be implemented. Grafström & Aasma (2021) chooses to distinguish economical, technical, regulatory, and social categories.

Other studies use a more extensive classification of categories where six and seven categories are distinguished. This classification of six categories is done by Ritzén & Sandström (2017) where a distinction is made between financial, structural, operational, attitudinal, and technological categories. In this study, barriers for moving towards CE through multiple case studies by performing semi-structured interviews led to this categorization. Araujo Galvão et al. (2018) distinguishes seven barrier categories: technological, policy and regulatory, financial/ economic, managerial, performance indicators, customer and social. These categories were the outcome of bibliometric research as a methodological approach. Cruz Rios et al. (2021) also uses seven categories for their categorization: economic, educational, cultural, technical, environmental, regulatory, technological. These categories were used to obtain barriers and enablers for circular buildings in the US. In table 3 below, the categories used by the different papers is set out.

Category	Used by Authors	#
Technical	Kirchherr et al. (2018); De Jesus & Mendonça (2018); Araujo Galvão et al. (2018); Ritzén & Sandström (2017); Grafström & Aasma (2021)	5
Economical	De Jesus & Mendonça (2018); Araujo Galvão et al. (2018); Cruz Rios et al. (2021); Grafström & Aasma (2021)	4
Regulatory	Kirchherr et al. (2018); Araujo Galvão et al. (2018); Grafström & Aasma (2021)	2
Sociological	De Jesus & Mendonça (2018); Araujo Galvão et al. (2018); Grafström & Aasma (2021)	2
Financial	Ritzén & Sandström (2017)	1
Institutional	De Jesus & Mendonça (2018)	1
Market	Kirchherr et al. (2018)	1
Cultural	Kirchherr et al. (2018)	1
Policy	Araujo Galvão et al. (2018)	1
Managerial	Araujo Galvão et al. (2018)	1
KPIs	Araujo Galvão et al. (2018)	1
Customer	Araujo Galvão et al. (2018)	1
Structural	Ritzén & Sandström (2017)	1
Operational	Ritzén & Sandström (2017)	1
Organizational	Rakhshan et al. (2020)	1

Table 3: Categorization by general CE papers

4.2.3 Categories applied in this thesis

Most studies divide their barriers and strategies into four to seven categories. The most common category divisions according to the analyzed literature, are economical, organizational, sociological, technological, and regulatory as seen in table 2 and 3 in the previous section. Since several studies use synonyms for the same type of category, these categories can be combined. The combining of the categories is set out below.

- The **economical** category focusses on the economic benefits, economic incentives, and economic consequences concerning the CE implementation (Selman & Gade, 2020). It will include all financial aspects of the CE adoption including the difficulties of CE business models as well as their ill-functioning markets and obstacles (Grafström & Aasma, 2021).

- The **technological** category will address the missing or proven technologies that could hinder or accelerate the adoption of CE (Kirchherr et al., 2018). The digitization category is combined with the technical barrier as digital barriers or strategies are of a technological nature.

- **Regulatory** involves the current policies and legislations (Selman & Gade, 2020). Therefore, will this category be merged the political and institutional categories. It will in fact involve the actions and barriers created by regulations and the institutions that draw up these regulations.

- **Organizational** involves all the barriers and strategies with the subject of firms and companies Rakhshan et al. (2020). This mainly concerns decisions by management and partnerships. In addition, this includes the operational side of a company and where barriers and strategies may be present.

- The behavioral aspects and the psychological challenges are included in the **social** category (Selman & Gade, 2020). Barriers and categories associated with the social and cultural aspects will be included in this category.

- This **environmental** category examines the barriers and strategies that affect the environment and the surrounding area. Ecological terms will also be included for this reason.

The six categories that are applied in this thesis are set out below in table 4. In the table, the categories by what they are combined as well as a brief description of the category is set out. The decision this six-categorization approach was to get a more comprehensive analysis. For every one of these barrier categories, barriers and strategies will be added in the next two sections.

Category	Combined by	Explanation
Economical	Market, Financial, Business	Barriers or strategies that cope or deal with economic viability (Kirchherr et al., 2018)
Technical	Digitalization	Include all technical barriers and strategies that will be applicable in this thesis
Regulatory	Institutional, Political	Barriers and strategies related to regulations and legislation
Organizational	Managerial, Collaboration, Operational, Structural	In terms of business activities and the strategies and barriers that develop in this environment
Sociological	Cultural	Socially and culturally dependent barriers and strategies are involved in this research
Environmental	Ecological	Barriers and strategies that have impact on the environmental and ecological system

Table 4: Categorization used in this thesis

4.3 Circular economy barriers for the construction sector

The CE barriers for the European construction sector that are found in the existing literature will be set out in this chapter. Due to the shortcoming of literature that focusses on identifying barriers for circular infrastructure assets, the broader construction sector will be studied. This means that literature on industrial construction, building construction and infrastructure construction will be included in the analysis, as these three sectors define the entire construction industry (Chitkara, 1998; Nelissen et al., 2018; Wientjes et al., 2017).

Within the search to the articles that identify these barriers, it can be concluded that most research CE on barriers is performed in the building sector (including residential buildings, commercial buildings, and other types of building property). This sector is receiving much attention from academics regarding CE, which is why the number of articles that put the emphasis on the building sector is high. Not much emphasis is put on other construction sectors in addition to the building sector regarding CE barriers. This chapter will therefore make a distinction between two types of research in the identification of CE barriers:

1. Building sector literature
2. General construction sector literature

In the figure below, the distribution can be seen of the number of articles on CE barriers. This shows the emphasize on the building sector in contrast to non-building construction sector.

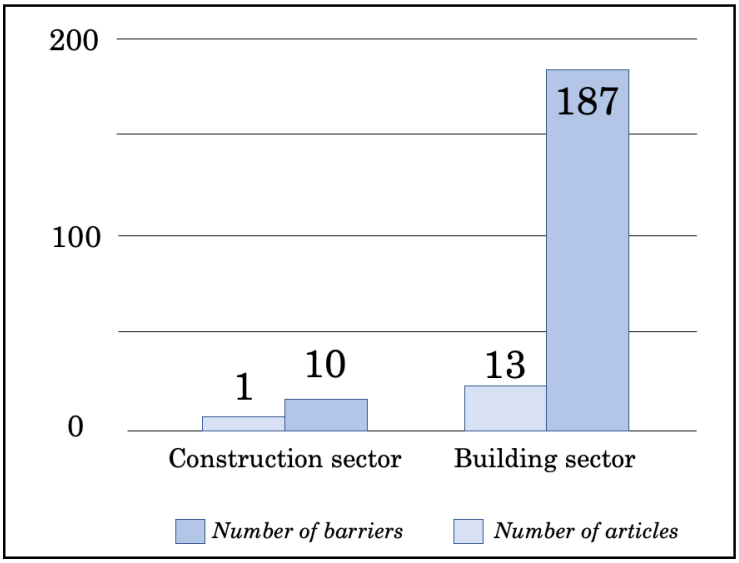

Figure 15: Distribution of barriers for the construction and building sector

To further understand how CE barriers are present within the today's literature in the construction sector, first literature that focus on the building sector will be analyzed. The literature on CE barriers within the building sector is extensive. A total of 187 CE barriers

for the building sector were identified in the existing literature. These studies focused on circularity of buildings and their building components.

Two studies on CE barriers in building design are performed by Selman et al in Denmark, where 38 barriers are identified (Selman et al., 2021; Selman & Gade, 2020). In his first study, 27 barriers by performing semi-structured interviews along with questionnaires in the building design. His second research focused on the readiness of the Danish construction sector (with the focus on buildings) by considering the current level of implementation and understanding of circular solutions. Lack of financial profitability and expertise along with 9 other barriers were the conclusion of his research. Another study in Denmark by Ottosen et al. (2021) investigated what barriers are withholding the implementation stage for the circular economy in the Danish building sector. By conducting semi-structured interviews, barriers to scale CE from niche to wider adoption were identified. For scaling the idea of CE, 8 barriers were the outcome of this study.

Giorgi et al. (2022) identified 6 CE barriers by analyzing five European countries and their policies and practices. The focus of this research was to identify what circular strategies were used and to investigate the related barriers for circular buildings. A wide range of barriers were identified. In another multi-country European study, Kanters (2020) analyzed the circular building design by performing a series of semi-structured interviews in four European countries. The two main barriers that came forward in his study were the conservative nature of the building industry and the lack of political priority.

The reuse of building materials in Norway was investigated by Sigrid Nordby (2019). Three barriers for the reuse of construction products in Norwegian building materials were identified: lack of economic driving forces, lack of information on the materials used and lacking legislation that is not adopted to secondary materials. Another study in Norway on construction material in the building in industry by Knoth et al. (2022) analyzes the challenges that professional actor involved in building projects experiences. This leads to another three barriers for the circular construction of buildings. A lack of collaboration in the value chain, a lack of pilot projects and a lack of support from authorities were key barriers that resulted from this study. In Finland, the CE barriers for sustainable buildings are investigated by Häkkinen et al. (2011). Several interviews and case studies were performed to recognize 4 CE barriers. Key barriers identified in this are the lack of understanding among clients and the lack of general knowledge about the concept. To further understand the building sector in the Nordics, Zu Castell-Rüdenhausen et al. (2021) studied how policies support CE in the Nordics. Nordic actors were interviewed across the value chain in the construction sector in Denmark, Finland, Norway, and Sweden. 7 key barriers were identified.

The obstacles for circular economy and modern architecture are studied by Jean Claude Morel et al. (2021). Through interviewing stakeholders in Europe, Morel et al. tries to explain why circular economy still a niche market within modern architecture. This resulted in a total of 60 CE barriers for the construction of buildings. Another industrywide study is performed by Adams et al. (2017) that analyze CE awareness, challenges, and enablers. By doing so, 8 barriers were identified for minimizing construction waste for

buildings. The most significant challenges were the absence of buildings for disassembly and reuse at their end of life. The design for deconstruction (DfD) and the barriers involved was further studied by Akinade et al. (2020). 26 barriers for DfD were identified. Six focus groups were conducted in the United Kingdom to come to this conclusion. Huuhka & Hakanen (2015b) identified the lack of established practices as the main barrier for reusing steel and concrete of load bearing structures for buildings. In addition, 18 other barriers emerged from surveying a panel of 11 experts in the field of construction.

4.3.1 Construction sector barriers

To further comprehend where CE barriers exist for the specific construction of infrastructure, the broader construction sector in a more general sense will be studied. If we look to the existing literature on CE barrier and strategy identification within the European construction sector in general terms, only one article arises. This article of Sarhan et al. (2013) identifies ten potential CE barriers that focusses on lean construction (LC). In specific, the management of LC in the UK. Through questionnaire survey, key barriers were identified that centers on structural and cultural barriers alone.

4.3.2 Summary barriers

By combining all the CE barriers for the European building sector and the European construction sector in general, an overview can be made of the most mentioned barriers in the existing literature. For every category, the top 5 mentioned barriers for the implementation of CE are set out in table 5 below. The entire overview of the CE barriers can be found in Appendix C for both the building sector and the construction sector in general. The reason for displaying the top 5 per category is since the mutually different interests per category cannot be accurately estimated and are each implemented differently in the literature. For this reason, it is important not to rate one category as being of higher importance than another category.

Category	No	Barrier
Economical	1	Additional costs of the circular approach
	2	Client willingness for circularity
	3	Lack of facilities for reclaimed materials
	4	Profit-seeking first mentality of stakeholders
	5	Cost of the circular approach
Organizational	6	Lack of skills and responsibilities
	7	Organizational changes needed
	8	Working methods and approaches
	9	Lack of support from top management
	10	Communication issues
Sociological	11	Cultural beliefs
	12	Lack of awareness and understanding
	13	Resistance to change
	14	Lack of trust
	15	Human influence
Regulatory	16	Regulation issues
	17	Lack of policies
	18	Insurance issues
	19	European absence
	20	Lack of incentives from authorities
Technical	21	Recovered material issues
	22	Recoverability of materials
	23	Variety of buildings
	24	Data issues
	25	Building lifespan
Environmental	26	Transport emission
	27	Space issues (site access, storage for recovered materials)
	28	Use of polluted or low recoverability materials
	29	Use of virgin resources
	30	Unclear environmental benefits

Table 5: Most mentioned CE barriers obtained from literature

4.4 Circular economy strategies for the construction sector

To obtain information on what strategies exist that can help to further implement the CE in the construction of infrastructure, literature study will be carried out to achieve an overview of strategies for the CE adoption in the European construction sector. The number of articles that identify CE barriers is significantly higher for the building sector in comparison to other construction sectors. The division is given in the diagram below.

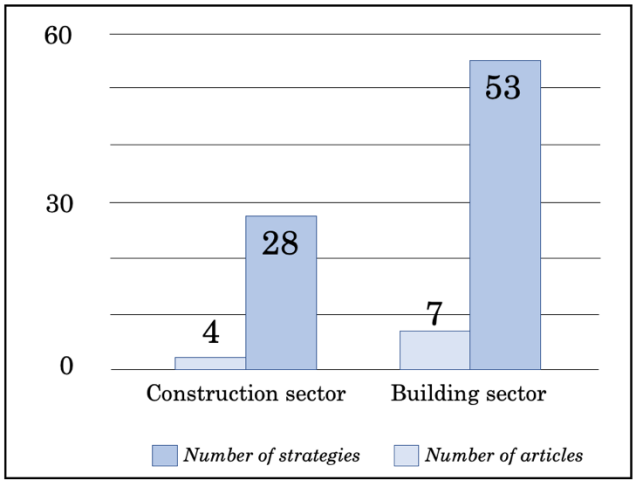

Figure 16: Distribution of strategies in the building and construction sector

4.4.1 CE strategies for the building sector

Within the literature on CE strategies for the building sector, it is remarkable that in contrast to the articles that identify barriers, the different articles have a more diverged opinion regarding the approach to CE.

By interviewing building stakeholders in 5 different European countries followed that greater international coordination is necessary in terms of practices, policy and enabling tools. 12 strategies were identified in this research by Giorgi et al. (2022). Akinade et al. (2020) identified 6 strategies for the for the current practice's improvement for Design for Deconstruction (DfD). According to Akinade et al. (2020) these strategies will bring DfD towards achieving the global sustainably agenda. Zu Castell-Rüdenhausen et al. (2021) promotes four policies as drivers in his article. The implementation of these policies through key concepts is crucial for the CE to be wider implemented in the Nordics. Anastasiades et al. (2021) focusses on standardization as main strategy to implement a more circular design for construction components reuse. 6 key strategies are set out by this article. These standardization strategies will try to improve the design for building disassembly in the end-of life stage. More success factors are set out by Knoth et al. (2022) and his study to increase the reuse of construction products in Norway. Improvement in communication and corporation between actors involved in the value chain are the main conclusions of this study. In addition, improvement in legislation is still one of the most impactful success factors according to Knoth et al. (2022). 7 other success factors are set out in this study. In analyzing where drivers are present for a more circular building sector, Kanters (2020) performed several interviews with architects and consultants that operate in the circular building design industry. The main driver that was identified by Kanters (2020) is the presence of a supportive client towards circular economy with a well-defined idea. Another study on opportunities to reuse building materials in Norway by Sigrid Nordby (2019) states that the main strategy is national targets for greenhouse gases, which will lead to higher demand for used building materials. Better management of resource flow is another driver to increase the reuse of building materials.

4.4.2 CE strategies for the general construction

For the European construction sector, three articles arise that identify strategies to implement a circular design. Migliore et al. (2020) describes in what way the negative external effects of the processing, extraction and production of construction materials can be lowered in a European study. 7 key actions are set out by Migliore et al. (2020) that allow for the reduction of environmental impacts related to waste production in the construction sector. The strategies and actions deal with organizational, political, and technical aspects and focus on how the lifespan can be expended of building materials. Górecki et al. (2019) investigates what the best and most important strategies are to convince players in the construction sector to implement a more circular design. Mainly four strategies came forward out of this study. The most pressing strategy was to vertical and horizontal implement stakeholders in the construction sector. Gálvez-Martos et al. (2018) focusses on the construction and demolition waste generated in Europe. Core principles are outlined by this paper and how new approaches in this sector are urgently necessary. The outcomes of this study are core principles and best practices for the

management of construction waste. The implementation of these principles in a systematic way will improve resource efficiency.

4.4.3 Summary strategies

When analyzing the existing literature on CE strategies for the European infrastructure, a total of 81 strategies can be obtained. 53 of these strategies are achieved from literature that focusses on CE implementation in the building sector in specific and 28 strategies came from studies that studied the construction sector in general. In Appendix D, in table the two overviews of strategies for the building and construction sector in general are displayed separately. When the CE strategies of the obtained through literature exploration of both the building and construction sector in general are merged, an overview can be made of these strategies combined. The top 5 most mentioned strategies per category are shown in table 8 below. The entire overview of the merged strategies is presented in Appendix D.

Category	No	Strategy
Economical	1	Stimulate online market for recovered products
	2	Tax shifts
	3	Service-oriented business models
	4	Networking among stakeholders
	5	Financial incentives & economic instruments
Organizational	6	Decision making of experts in the design phase
	7	Improve waste management
	8	Extended manufacturer responsibility
	9	Creativity and innovation capacity
	10	Pilot buildings and dissemination of experience
	11	Improve actor collaboration
Sociological	12	Convincing the client
	13	Promote recycling and secondary raw materials
	14	Increase knowledge awareness
	15	Addressing the acceptability and understanding
	16	Understanding of the motivations and consequences
Regulatory	17	Better management of resource flows
	18	National grading system/ targets/ roadmap
	19	Information exchange service
	20	Use of sustainability certification
	21	Appropriate policy instruments and regulations
Technical	22	Reuse of building elements
	23	Design for reversibility
	24	Use of software for design e.g., material passport
	25	Smart design for adaptability and deconstruction
	26	Innovative repair and reuse
Environmental	27	Reduce of resources consumption
	28	Perfect construction components
	29	High-performance materials
	30	Avoidance of materials landfilling

Table 8: Most mentioned CE strategies obtained from literature

4.5 Conclusion of literature exploration

In this chapter, the discovery of barriers and strategies within the existing literature on CE was central. With the literature exploration on this theme, the high attention that is given to the building sector is noticeable. Most of the existing literature on barriers and strategies for CE put focus on this sector and its corresponding building related topics (including residential buildings, commercial buildings, and other types of building property). Not much studies deviate from this concept. In addition, most of the literature that does not focus on the building sector, tend to take the broader construction sector in consideration without specific emphasize on one part of this sector. As a result, no scientific attention is given to the infrastructure sector in specific. Therefore, it can be concluded that there is need for studies on this specific theme

During this literature exploration, in total 77 barriers and 71 strategies were found. These barriers and strategies will form the theoretical framework of this thesis. Within this thesis, these barriers and strategies are classified into six categories: economical, technical, regulatory, sociological, and environmental. These six categories were chosen since these were the most common categories used within the existing literature on this topic. These barriers and strategies found in this literature exploration will be tested against the empirical results obtained through the investigation of the case. It will be discussed what barriers or strategies overlap, differ and which one are new and therefore extent the knowledge in the literature. This will be done in the chapter 6 “discussion”.

5. Results and analysis of the interviews

In this chapter, the results of the semi-structured interviews will be presented. First the interview population will be set out in section 5.1. Then, in section 5.2, the coding process of the transcripts obtained from the semi-structured interviews will be described. The overview of all barriers and strategies resulted from the interviews will be given in section 5.3. In section 5.4 and. 5.5, the barriers and strategies will be individually discussed. The relation between these barriers and strategies is displayed in section 5.6.

5.1 Respondent's profile

The interview population is divided into two groups: client employees and main-contractor employees. They all operate within the field of infrastructure assets and can in this way be seen as a homogenous group. According to Creswell & Poth (2016b) and his study on the average amount of semi-structured interviews per research, 8-17 is the most common range of semi-structured interviews for qualitative studies. Therefore, this study aimed to fall within this range on the amount of semi-structured interviews performed. To get the best possible insights of where certain core CE barriers and strategies exist for infrastructure assets, various tasks that are performed within the processes of these infrastructure assets will be considered. The focus on each of the individual interviewees will be on what the most pressing CE barriers and strategies are according to them. The semi-structured interviews focused on the entire infrastructure asset lifecycle. Depending on the responses and outcomes of the interviewees, some parts will be elaborated more than others. Most of the interviewees are fulfilling multiple tasks within the entire infrastructure asset lifecycle. This will give a clear holistic view on this lifecycle and where critical points exists.

Participant number	Name in thesis	Job Title	Company
1	[1]	Project organizer	Bam Infra
2	[2]	Asset engineer	Bam Infra
3	[3]	Project lead	Bam Infra
4	[4]	Senior procurement	Bam Infra
5	[5]	Project lead	Bam Infra
6	[6]	Sustainability manager	Bam Infra
7	[7]	Senior airport developer	Schiphol Airport
8	[8]	Project organizer	Bam Infra
9	[9]	Project manager	Schiphol Airport
10	[10]	Asset Manager	Schiphol Airport

Table 6: Interview respondents

To increase the validity of the interviews performed, every interview was recorded, and transcription word-by-word as is recommended by Fellows & Liu (2021). Due to the COVID-19 measures that where present during this thesis, most of these interviews were performed online. The duration of these interviews varied from half an hour to more than one hour.

5.2 Coding process

After all interviews were conducted and the transcripts were obtained, the coding of these two types of qualitative analysis methods were used to analyze these transcripts: grounded theory and content analysis. The grounded theory method consisted of three main steps and a preparation stage. The preparation stage consisted of cutting the interview transcript into smaller "interview terms". These "interview terms" were subjects or themes describing the main concern of a barrier or strategy. In total, 230 interview terms were obtained. Through the open coding method, these interview terms are merged into open codes that subject a more comprehensive description. In total 227 open codes were identified of which 127 of these codes were dedicated to barrier identification and 100 to the identification of strategies. These codes were then further combined to axial codes which are equated to the barriers and strategies. The way in which these barriers and strategies are created through the grounded theory method is given as an example in figure 16. The overview of all barriers and strategies with the corresponding codes are displayed in the next section 7.3. The entire way in which barriers and strategies are composed through coding is seen in Appendices G and H.

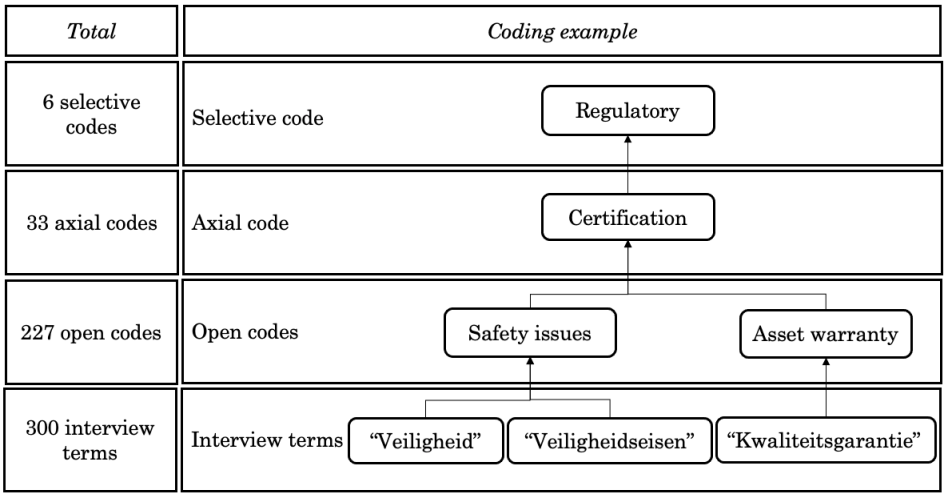

Figure 17: Grounded theory coding process and distribution of codes

Then to obtain information on the frequency that the different barrier and strategies are mentioned by the interviewees, content analysis on the outcomes of the grounded theory data analysis method was performed. In specific, the last two steps of the content analysis as provided by Denscombe (2010); count the frequency of the units for each category and analyze the frequency of terms. The frequencies of the barriers and strategies are calculated by the sum of the times interviewees mentioned the interview term connected to the barrier. Then, these frequencies can be seen as an indication of how much these barriers and strategies play a role in the activities of the practitioners. Due to the fact that this data is obtained through a qualitative data method, quantification of this data is not desirable. However, light statements on the number of times that interviewees mentioned the barriers and/ or strategies is acceptable, as this are factual statements of the empirical outcomes.

5.3 Overview of barriers and strategies

In the two figures below (figure 17 and figure 18), the distribution of mentioned categories by the interviewees is displayed. Interviewees mentioned barriers in the regulatory category most frequently and the environmental barriers less frequently. In the terms of strategies, the organizational category was most mentioned by the interviewees and the environmental category, as was the case for barriers as well, less frequently. In table 7 and 8, the barriers and strategies are displayed after the coding of the transcripts obtained from the semi-structured interviews. 24 barriers and 21 strategies for obtaining circularity within infrastructure assets were obtained through these interviews.

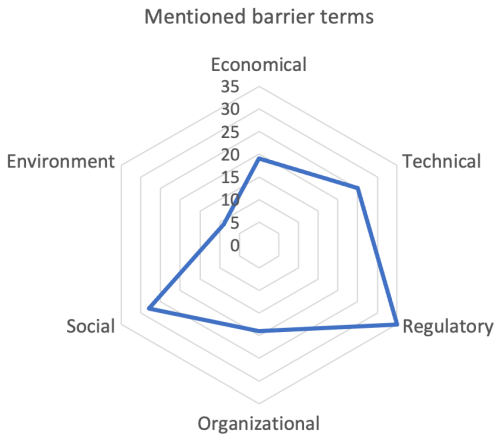

Figure 18: Radar chart of the mentioned barrier terms

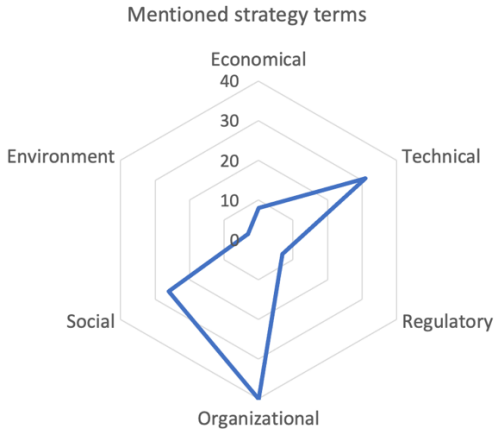

Figure 19: Radar chart of the mentioned strategy terms

The possible reasons for the varying distribution of these barriers and strategies within the categories will be discussed in both the reflection on the methodology, section 6.4, and the reflection on the results, section 6.5.

5.3.1 Overview barriers

According to the outcomes of the semi-structured interviews, the overview of the 24 barriers as seen in table 7 could be made. Outdated certification, strict guidelines and undesirable human behavior were the three most mentioned barriers by the participants of the interviews. In overall, the regulatory barriers were the most discussed category while obtaining the semi-structured interviews. All the barriers in the table below will be explained in section 5.4.

Category	Barrier	Explanation
Economical	Missing financial incentive	Barriers considering the absence of incentives for the CE approach
	Market issues	Issues regarding shortcoming of the current market
	Additional costs	Costs that come in addition with the CE approach
Organizational	Lacking key players	Third party characteristics that hinder the CE implementation
	Low CE willingness	The willingness of people involved in the process for implementing CE
	Increase in time	Barriers regarding time issues of the CE approach
	Transparency	The lacking transparency between stakeholders causing lacking CE
	Planning issues	Planning causes CE approaches for projects to be cancelled
Social	CE awareness	The awareness of CE is strongly depended on its adoption
	Undesirable human behavior	Undesirable human behavior causes unintentional CE barriers
	Wrong CE perceptions	Wrong CE perceptions conclude practitioners to take wrong decisions
	Communication issues	Barrier concerning the lack of communication between stakeholders
Regulatory	Outdated certification	Issues regarding certifications withhold CE to thrive
	Regulations	Strict regulations are not yet adopted to the CE approach
	Strict guidelines	Guidelines provided by Schiphol do often not match with CE
	Lack of incentives	The shortcoming of incentives from out the government
Technical	Technology related barriers	All barriers related to the insufficiency of technical procurements
	Long-lifespan	The long lifespan of infrastructure assets causes problems for CE
	Technical quality and safety	The technical quality and safety are too specific for circular materials
	Lacking project design	The design of projects can be in contrast with CE approaches
	Disassembling issues	Issues regarding the disassembling of infrastructure assets
Environmental	Transport	Increase in transportation for CE practices
	Storage issues	Barriers regarding storage difficulties when adopting CE
	Pollution	CE approach can increase pollution during its processes

Table 7: Identified barriers after interview coding

5.3.2 Overview strategies

17 strategies were achieved after the coding process in the previous section. These strategies are displayed below. The most mentioned strategies by the participants of the interviews were the use of innovative measurements, innovative materialization and communication enhancements. All the strategies will be further explained in detail in section 5.5 below.

Category	Strategy	Explanation
Economical	Financial management	Financial strategies that suppress the adverse cost aspect
	Market innovations	Innovations that can help to further develop a CE market
Organizational	Risk improvements	Strategies concerning the removal of CE risks
	Client contractor	Improvements on the contractor client relationship
	Contractual improvements	Strategies on improving contractual agreements that stimulate CE
	Stimulate CE operations	Organizational actions that can improve CE within companies
	Enhance planning	Points of attention that improve project planning concerning CE
Social	Create awareness	Approaches to enhance awareness on the concept of CE
	Enhance communication	Communication is necessary to enhance collaboration on CE
	Stimulate trust	Trust between and within companies operating in the field of assets
Regulatory	Update requirements	Adapting requirements to allow for
	Stimulate government control	Applying pressure on the need for governmental control m
Technical	Innovative measurements	Stimulating the use of circular measurements will increase CE
	Disassembling improvements	Disassembling strategies will decrease demolition of assets
	Monitoring and inspections	Lifespan extension can be attained by monitoring and inspections
	Circular project design	Strategies for adapting more circularity within the project design
	Innovative materialization	Increase better materialization will stimulate circular materials use
Environmental	N/A	N/A

Table 8: Identified strategies after interview coding

5.4 Explanation of the mentioned barriers

The barriers mentioned by the interviewees will be explained in this chapter. For every category, for each barrier, a description will be given with the participants ID's that corresponds to the interviewee(s).

5.4.1 Economical barriers

5.4.1.1 Financial incentives missing

Financial incentives are essential in the case of implementing CE within infrastructure assets according to interviewees at Bam Infra and Schiphol Airport. The biggest objective, although sometimes denied, is the profit motive of both Bam Infra and Schiphol Airport [3]. In addition, as most interviews mentioned, the infrastructure sector has very low profit margins [4][5]. Prices have been driven down for years which resulted in margins of 1%. With these low margins, it is not desirable to innovate and invest in in circular developments [4]. This tightness in the market will allow the price to keep continue dropping, which will worsen this issue. For that reason, this sector is lacking when it comes to innovative techniques in the circular field. In consequence, these low margins lead to tight project budgets [5][6][7][8][9]. These tight project budgets often create a significant barrier for the enhancement of circular infrastructure assets according to the interviewees. Not only are these tight project budgets caused by the low margins of this sector, but also due to the fact that these project budgets are calculated baes on traditional estimates. This ensures that the budget for CE within these projects are not accountable for in a sufficient manner.

5.4.1.2 Market issues

The supply and demand for materials necessary for circular infrastructural assets is not in balance [1]. Due to the large influx of new materials and opportunities to obtain new materials, little attention is paid to the secondary market. The value of secondary material and the cost of new material cannot yet compete. Today's linear raw material prices are

too low which ensures that the incentive remains too high to purchase new raw materials [3]. In addition, traditional market thinking is another obstacle that is present within this field which worsens the effect [4].

5.4.1.3 Additional costs

The additional costs of the CE approach is an important barrier for Bam Infra and Schiphol Airport to not implement CE in their projects [4][5][7]. Besides, initial (start-up) costs must be made to implement CE designs in the culture and working methods of both companies [6][9]. These investments in sustainability and circularity are high and due to the low margins of this sector, the willingness is low.

5.4.2 Technical barriers

5.4.2.1 Technologies related barriers

The technologies related barriers focus on the technical infeasibility of certain infrastructural assets for CE [1][9]. Often circular materials for infrastructure assets clash with the technical functionality [7]. As an example, various bollards at Schiphol Airport offer protection against, among other things, terrorist attacks. These posts are made of special materials as they must withstand great resistance. So far, there exist no circular alternative to these posts that offer the same quality. In addition, CE often clashes with the current management and maintenance of infrastructural assets [7].

5.4.2.2 Lifespan of infrastructure

Due to this long lifespan, many of the infrastructure assets on the landside of Schiphol Airport are constructed decades ago. At the time of construction, the concept of circularity was not yet introduced to the infrastructure sector [7]. Therefore, most infrastructure asset that are currently present at the landsides of Schiphol Airport are not constructed with the CE concept in mind. This results in assets that cannot easily be dismantled [7].

5.4.2.3 Quality and safety

The technical quality and safety are often not guaranteed by secondary materials [1][6][7][8][10]. Often, circular materials can technically not meet the safety requirements that are necessary [1], which is the case for quality requirements as well [6][7][8][10]. Since the technical quality and safety requirements of Schiphol Airport are specific and strict, it is difficult to exactly meet these requirements with circular materials.

5.4.2.4 Project design

A common mentioned barrier for the implementation of CE in infrastructure assets is the project design and its outdated design requirements and building principles [7]. Due to the outdated way of working, these design and construction principles are not innovative and have not kept up with sustainability matters. This is due to the traditional nature of construction industry in general. Still, many practitioners view each work as customization, and therefore are mostly not willing to apply circular techniques as it limits their design freedom [3]. Due to location dependence [3][10], especially in the central areas of Schiphol, some projects do need custom designs [1]. These areas have such a specific character that the requirements are higher than outside the center of Schiphol Airport. These projects are often split up in different parts, as roads and traffic routes cannot be

hindered for longer periods of time. For this reason, it is often unclear what materials are going to be available till the last moment, which hinders the CE approach.

5.4.2.5 Disassembly issues

Another technical barrier is the dismantling of existing assets [7][9]. This concerns the possibility of dismantling that is often not possible. The infrastructure assets were often constructed longer times ago due to their long lifespan. For this reason, the possibility of dismantling is sometimes limited and therefore, assets are demolished more often [7]. The second disassembly issue is the unknown materials that are present within the existing infrastructure [7]. It is hard to analyze and reuse these materials in a circular way as no plan can be made upfront.

5.4.3 Regulatory barriers

5.4.3.1 Certification

Certification is one of the most mentioned barriers by the practitioners in the infrastructure field. Outdated certification requirements are a stumbling block that many practitioners encounter [1][4][6][7][8]. Due to the traditional way of certificating, which is still applied, it is not always possible to use secondary materials that are technically feasible. In addition, requirements related to safety and fire safety are one of the most important certification requirements and therefore difficult to obtain for reused materials [1][7]. Materials that are used within infrastructure assets must have quality guarantees as well to ensure the quality to the client [6]. These quality guarantees are often not present for circular materials since most of these secondary materials have not yet been tested to a high degree.

5.4.3.2 Legislation & regulations

Despite the fact that the Dutch government is willing to help the transition to CE by adapting their legislation and regulation, these legislations and regulation still slow down or abort the CE [3][4][8][10]. According to the experts at Bam, government agencies often unjustly reject circular designs for infrastructure projects. "Bodemloket", for example, aims to map or improve the soil quality of, among other things, Schiphol Airport. However, since the governmental regulations are not yet set to take the circularity change into account to that extent, this ensures that certain techniques or secondary materials are rejected [3]. The legislation on material requirements needs to be changed. There is still a traditional view on many infrastructural assets regarding legislation which hinders the implementation progress of CE in infrastructure assets and make it more difficult to obtain permits for circular approaches.

5.4.3.3 Guidelines

Schiphol Airport's guidelines are strict, and all main contractors must adhere to them. The guidelines of Schiphol Airport are separate from government regulation and are composed by Schiphol Airport to comply with regulations on their territory. The guidelines of Schiphol Airport, according to the interviewees, create a major barrier for the CE implementation [1][3][8][9][10]. Circularity mostly does not comply with these guidelines which in many cases lead to rejections of circular designs as it does not fit within Schiphol's guidelines. Bam Infra was unable to implement the reuse of 95% recycled asphalt since

95% recycled asphalt may not officially be called “asphalt” according to the official certification requirements. Likewise, Schiphol’s’ guidelines only allow a certain amount of recycled concrete in their infrastructures despite it already being technically feasible to reuse concrete for almost 100%. Schiphol Airport does not only value the quality requirements of their infrastructure assets, but aesthetic requirements are almost as important [1][6][10]. Circular materials can often not comply with these aesthetic requirements, which is one of the main reasons for Schiphol Airport to use linear materials instead.

5.4.3.4 Lack of incentives

According to a few interviewees, the lack of incentives is an important barrier [8][9]. This mainly concerns the lack of government support in the field of circularity in the construction of infrastructure. Due to the previously mentioned low margins that are present in this sector, governmental support in the form of financial subsidies will allow higher circularity budgets. In addition, government support is often not given to circularity improvements. It seems most subsidies are granted for mobility improvements rather than circularity or sustainability enhancements [8].

5.4.4 Organizational barriers

5.4.4.1 Key players

Some interviewees blame the insufficient CE adoption on key players that are involved in the processes regarding infrastructure assets. It is stated that many suppliers still have a traditional way of thinking which narrows the possibility of circular cooperation [7]. In addition, it is difficult to verify if suppliers are developing in the field of CE [7]. It is often unclear to determine to what extent you can and should influence the CE approach of third parties. Furthermore, the existence of the principal agent problem is present as well in this case [3][4]. Not all directions from “higher ground” are carried out as instructed according to the interviewees, circular actions in the design of a project does not guarantee implementation. The monitoring and inspections on the operational side within infrastructure projects is limited. Insufficient waste registration is another important factor for CE to be inhibited [6]. The entire waste registration process is unstandardized and contains too many processes between too many parties which leads to mistakes being made. This, in turn, leads to inaccurate registration of residual materials, and therefore incomplete optimization of circular use of materials.

5.4.4.2 CE Willingness

CE willingness can be seen as another import barriers for CE implementation at Bam Infra and Schiphol Airport. CE is not the main concern for many practitioners in the infrastructural field, and therefore, not often priority is given to CE in business operations [2]. According to the interviewees this low priority led to cautious targets that do not meet today’s circularity innovations. On the other hand, this low priority can lead to targets that are too ambitious as well [4][6]. Both reduce the willingness to act accordingly to CE to lower.

5.4.4.3 Time

Another important factor why CE often does not penetrate the design, according to the interviewee, is the time barrier [6][7]. Adopting CE in infrastructure assets simply takes more time. Projects are on a tight time schedule, which will incentivize to drop the time-intensive CE approach. In addition to the time-consuming CE method, there is also a transition period that must be considered according to the interviewees [7]. This transition period is necessary to go from the linear mode to a circular mode of work.

5.4.4.4 Lack of transparency

Lack of transparency is a major bottleneck for CE [4][6]. According to interviewees on the contract side, Bam Infra, Schiphol Airport is not always transparent about their needs regarding circular infrastructure. Transparency will be a major barrier for CE to penetrate more into infrastructure assets. If Schiphol is not transparent about the objectives and targets, they want to achieve, Bam Infra will not be able to respond and adhere to this. Uncertainty then arises on the contractor side, which will result in aborting the CE approach, due to the existence of the chance that the CE plan and preparation will be rejected by Schiphol Airport. The willingness of Schiphol Airport to invest in CE must be made clear.

5.4.4.5 Planning

Strongly linked to the barrier “time” mentioned in paragraph 6.4.4.3, CE is often interrupted by planning issues [1][6][7]. The planning of a project is key, and the main priority it that the planning schedule is met. Especially when taking the "Fast moving environment" of Schiphol Airport in consideration, planning is sacred. Therefore, if CE is not properly considered in the design and planning phase, the chances of implementing the CE approach are nihil. Circular design plans take more time and will deter both the client and the contractor.

5.4.5 Social barriers

5.4.5.1 CE awareness

Lack of expertise on both the contractor and the client side is mentioned by several interviewees [3][6][7]. This lack of expertise and knowledge is mainly present within the operational field at construction level. The number of CE-experts who operate in the design and planning phases within Bam Infra and Schiphol Airport are low as well according to some interviewees. In addition, the awareness of the topic of CE is another barrier since employees who operate in this sector may not feel the need to apply circular principles as they are not aware of the negative effects of the linear economy [4][7]. This is often due to the abstractness of the CE term. The abstractness of CE is seen as an important barrier as it is not tangible or concrete to most employees [3].

5.4.5.2 Undesirable human behavior

Undesirable human behavior is another important social barrier where ignorance & negligence play an important role [3][6][7]. This barrier focusses on the human aspects and interference on why circular approaches often do not succeed. Frequently the “easy road” is chosen according to the interviewees. The conservative culture of the infrastructural sector is largely causing this [3][4][5][7]. Construction workers are not willing to put in extra time and effort in circularity tactics. This can lead to hasty decisions

which are often irreversible and therefore cause for limiting in CE option in later stages [3]. In addition, the extent to which CE is implemented in the design is often individually dependent [1][3]. No actions will be performed when the individual in lead is not open to circular actions. According to the interviewee, this is often the case.

5.4.5.3 Wrong perceptions

Often, wrong perceptions can lead to a lack of vision [4]. Having wrong perceptions on the concept of CE will create a vision that is not in line with CE progress. This will ensure that there is little confidence in the CE approach or techniques [2][3][8] and therefore risk adverse behavior will be exhibited [3][4][7]. Trust in this matter can be divided into two different forms: confidence in the CE approach in general and confidence in the way in which the approach is implement or applies.

5.4.5.4 Communication issues

Another key barrier for CE is the lack of communication between Bam Infra and Schiphol Airport [6]. Despite the long-term contract between the client and contractor, still parts of the communication are missing [2]. This creates a gap between information between Schiphol Airport and Bam Infra [6]. The client, Schiphol Airport, may not know what the possibilities of Bam Infra are regarding CE and Bam Infra might not know what Schiphol Airport is willing to offer for more circular improvements [4].

5.4.6 Environmental barriers

5.4.6.1 Transport

To ensure that all materials used by Bam Infra on Schiphol Airport are also processed and reused, the total number of transports will increase [3]. In addition, many waste processing firms are not located around the Schiphol Airport territory. So, the frequency as well as the distance of transport will increase [3]. This will result in higher emissions from transport when recycling material that Bam Infra uses for its projects on Schiphol Airport [3].

5.4.6.2 Storage issues

The storage of secondary circular material is another issue that occurs due to the limited capacity [1][7]. A large part of the retained asphalt is refused at the asphalt central and can therefore not be recycled for higher purposes. There is an oversupply of demolished or dismantled material in the available storages at Schiphol Airport [4]. Furthermore, the possibility for materials to be stored [7] is another issue, not all materials within the construction of infrastructure may be stored due to durability or safety and therefore do not have a destination [7].

5.4.6.3 Pollution

Another barrier that is often overlooked when implementing CE is the addition of pollution when recycling materials to be reused [7]. Recycling infrastructural residues releases both energy and other air-polluting substances.

5.5 Explanation of the mentioned strategies

The strategies mentioned by the interviewees will be explained in this chapter. For every category, for each strategy, a description will be given with the participants ID's that mentioned the strategy. As no environmental strategies were mentioned by the interviewees in this thesis, this category will not be included.

5.5.1 Economical strategies

5.5.1.1 Circular financial management

Better management of finances can lead to a higher adoption of CE in the infrastructure assets. This should consist of circularity investments and in coherence, the acceptance of development costs [4][5]. Furthermore, flexible project budgets will ensure circularity improvements to gradually be introduced [3]. The determination whether CE can be implemented in the design cannot always be set up front. When strict project budgets are issued, unexpected CE opportunities that may arise cannot be implemented afterwards. These non-price requests are occurring at Schiphol Airport on a small scale. Not only the price is considered, but also other performances such as circularity of infrastructural assets. If these non-price requests are issued more often by Schiphol Airport, Bam Infra will be able to boost the circularity of infrastructure assets on Schiphol Airport [4].

5.5.1.2 Market improvements

An online marketplace for secondary materials should allow for quicker materialization and better expectations on what materials are available [7]. It also ensures that the material released from the projects can be sold more quickly and are stored less longer periods. There are two types of online marketplaces that should be enhanced in the environment of Bam Infra and Schiphol Airport: the local marketplace on Schiphol Airport and a nationwide marketplace. For Schiphol Airport, an online environment where all released materials from infrastructure assets on Schiphol Airport will allow for quicker exchange of materials on the territory of Schiphol Airport. These released materials, however, are not certified as no they are not processed outside of Schiphol Airport. The enhancement of the nationwide marketplace will contribute to larger scale of materials, and most often, these materials are certified but less quickly available [7]. In addition, the increasing and expected scarcity on the market [7] creates opportunities to increase CE in the future. The large material quantities necessary for infrastructure assets will create high profits when secondary material prices increase. Furthermore, this competition on the market [4] for sustainable and circular contractors is rising which will stimulate companies to compete in this market [5].

5.5.2 Technical strategies

5.5.2.1 Innovative measurements

Broadening the research by preliminary investigation [1] as asphalt research [7] will allow for better chances of circular approaches to be adopted. With preliminary investigations, it can be discussed between the client and contractor how circularity issues are dealt with [1][7]. These extensive calculations provide more clarity and will generate more acceptance at both Schiphol Airport and Bam Infra [3]. In addition, other metrics should be implemented in infrastructure projects of Bam Infra at Schiphol Airport that can

increase the measurability of circularity. One of these metrics that must be broader used is the Building Circularity Index (BCI) [7]. The ECI that Bam Infra uses is too generic since it focusses on sustainability general, and therefore, circularity is not directly stimulated. Measures could also include pilot project [7], which could generate more coherence. A sufficient way of executing pilot projects is to use less exhausted infrastructure assets. This way, new circular techniques can be applied without having a major impact if it fails. System engineering can then be further used to provide better estimates of these pilot projects [10].

5.5.2.2 Disassembling improvements

The first point to improve dismantling is to construct a dismantling plan instead of a demolition plan [7]. This will stimulate modular working methods and increase the degree of circular infrastructure assets [3]. If disassembly of an asset is not possible, it is important that the qualities of the asset are separated during the demolition phase [3]. The separation of qualities is often overlooked.

5.5.2.3 Monitoring and inspections

Another strategy that can help CE adopt further in infrastructure assets at Schiphol is monitoring and inspections. Monitoring and inspections are crucial as it allows to intervene earlier in the process of which can extent the lifespan of infrastructure assets [1]. The next step is digital monitoring, which can result in an online insight into the remaining lifespan of infrastructural assets [1]. This way, timely actions to enhance the lifespan or to coordinate releasing materials from this asset can improve circular economy principles.

5.5.2.4 Project design

Innovative project designs and new building principles are important to enhance creativity for designers [7]. Designs of infrastructure assets should be adjusted to released materials of disassembled infrastructure assets. Instead of being able to design freely, the available materials determine the design [7].

5.5.2.5 Materialization innovations

Innovating the materialization of infrastructure projects will help to adopt CE within infrastructure assets. Timely materialization will lead to gaining better overviews of possibilities and avoid hasty decisions [7]. To ensure that less material is used, and more material is reused, prescribing less material is a good strategy [6][10]. By prescribing less materials, the designer is stimulated to obtain a more sustainable way of material use in the design. To ensure that designers use secondary material, an online overview of all this material will be required [1]. Standardization will in addition allow for more materials to be reused since the possibilities of these materials to be reused increases [7][4].

5.5.3 Regulatory strategies

5.5.3.1 Update requirements

By changing and innovating quality requirements, the reuse of materials can increase [3][7][9]. The requirements that issue by governmental bodies outdated and should implement circularity consideration in these requirements. As well Bam Infra as Schiphol

Airport should reach to policy makers to initiate progress and create awareness for this issue.

5.5.3.2 Stimulate government control

Government control seems necessary for CE to be adopted in infrastructure assets [4]. As the stimulus for using circular material is not yet present, most project designers will reach for linear use of materials. Same as the previous strategy, Bam Infra and Schiphol Airport have minimalistic influence on governmental control, however, can stimulate awareness for this issue.

5.5.4 Organizational strategies

5.5.4.1 Risk improvements

An important factor for organizations within the construction of infrastructure to not implement CE is the risk it entails. Therefore, managing risk will increase the degree of CE implementation. Not only managing risk but increasing the risk acceptance for CE topics during the risk analysis will allow for more freedom regarding circular approaches [3][3][8]. In addition, the innovation manager of Schiphol stated that circular approaches that do not fit within the current risk analysis will be partially accommodated by Schiphol Airport [6]. This will relieve the pressure on those responsible for the circular design. Buying off warranty is thus a great way to stimulate CE for infrastructure projects especially since the number of materials in this sector are large and thus risky [7].

5.5.4.2 Client contractor improvements

Client contractor improvements will be important since both the client and the contractor are responsible for the adaption of CE on Schiphol Airport. An increase in partnership during the projects executed on Schiphol Airport will allow for better corporation [2] [8] [4]. The sharing of insights and information ensures that the knowledge is evenly distributed among both parties, which will lead to better understanding [3]. By suggesting improvements and early involvement of both parties in the entire process [3], innovations from both sides will be expressed [2]. This will speed up the transition and can lead to broader involvement of both parties [3]. In addition, Bam Infra will have to convince Schiphol Airport as they are expert within this field [3] [4]. This way, the vision of Schiphol Airport can be changed in a positive way and can have a great effect on CE implementation for infrastructure assets at Schiphol Airport [4].

5.5.4.3 Contractual improvements

Innovative contracts can further implement CE within infrastructure assets on the landside of Schiphol Airport and will ensure the bond between contractor and customer to increase [3]. Bam Infra and Schiphol Airport are applying several innovative contract properties where the potential for joint CE objectives increases. A Best Value Procurement (BVP) is present, which means that the expertise is positioned at the contractor [8]. Appointing the contractor as an expert has positive consequences for circular improvements in the design [1][4][8]. Bam Infra is expected to attain state-of-the-art knowledge on the techniques available for circular improvements. These circular improvement plans should be discussed during the contractual agreements upfront [4]. Ideally, further implementing joint responsibility between Schiphol Airport and Bam Infra

should be implemented in these contracts [7]. In addition to contractual performances between Bam Infra and Schiphol Airport, is the need to improve the contractual agreements with suppliers and other third parties [7]. Strict contractual requirements should be issued to these third parties in line with the visions of Schiphol Airport and Bam Infra.

5.5.4.4 Stimulate CE operations

Several CE operations that can enhance the adoption should be further integrated in the organizations of Schiphol and Bam. The main stimulation for Schiphol Airport and Bam Infra is to expand their CE experts [5]. This will have to be accompanied with the expansion of circularity meetings [9]. Additionally, by incorporating larger number of CE experts, innovative thinking will be stimulated in the entire organization [5]. According to the interviewees, incorporating CE experts to a larger degree will postponement of maintenance and refusing of new construction [3][7].

5.5.4.5 Enhance planning

Good preparation and good planning are key for circular concepts to be implemented in the project design [7]. Pre-prioritizing these circular plans ensures that no unexpected situations arise. In addition, circular plans need to be adopted in advance as they are not able to be determined afterward due to planning issues [9]. According to the interviewees, incorporating extra "CE time" for non-CE-experts will enhance attention to this matter by practitioners in this field [6]. This ensures non-CE-experts to put more time and effort in activities concerning the CE theme without it affecting their main tasks.

5.5.5 Social strategies

5.5.5.1 Create awareness

Creating awareness is an important social strategy for adopting CE to a large extent. If motivation and willingness are present within business operations, the degree of circularity will increase [7]. This can partially be achieved by demonstrating circular techniques and introducing initiatives as the concept of CE will then become more tangible [4][8]. Addressing the benefit and impact of this approach on sustainability problems will have a possible effect as well [3].

5.5.5.2 Stimulate trust

A good bond of trust between Schiphol Airport and Bam Infra must be present for CE to succeed on the landside of Schiphol Airport [8]. Transparency and openness between these two firms are important factors for this trust to improve [6]. Then, circular innovations and advice proposed by Bam Infra to Schiphol Airport will more likely be implemented [4][6]. Additionally, Bam Infra will more likely propose these circular innovations to Schiphol Airport as well.

5.5.5.3 Enhancing communication

Enhancing communication is often mentioned by the interviewees as a strategy to enhance the CE approach [2][3][6][7]. The lack of communication between Schiphol Airport and Bam Infra is creating an information gap. Bam Infra has limited information on the willingness for circular concepts of Schiphol Airports and Schiphol Airport lacks

information on the capabilities regarding these circular concepts of Bam Infra. By enhancing commutation by increasing the dialogue between client and contractor, this information gap will be narrowed [2][3][7][8]. In addition to increasing the dialogue, Bam Infra must actively convince Schiphol Airport to increase circularity within their infrastructure assets [3][4][9].

5.6 Relation between barriers and strategies visualized

During the semi-structured interviews, some participants were able to reveal relations between barriers and strategies. These relationships are discussed in this section and are presented visually in figure 20. However, most barriers and strategies were reported in isolation during the semi-structured interviews. Therefore, not all barriers and strategies can be given connections.

The first relation is the effect that the materialization, in specific, the prescribing of less materials has on the project design [6][10]. Interviewees stated that project designers often choose the path of least resistance and therefore differ from the circular approach. By prescribing less materials, the project designers are forced to include circularity or at least less materials in their design.

The second relationship are the disassembly improvements that can cure disassembling issues. The enhancement and further adoption of disassembling plans can decrease the disassembling issues [7]. This disassembly plan must be made upfront so no planning related issues can rise.

Thirdly, contractual improvements, requirements of suppliers, can obviate the lacking key players [7]. The sharpening of contracts appointed to third party suppliers will have a direct effect on key players to adjust on circularity needs. This will have an additional indirect effect on the entire market in which the key players are located to enhance competition.

In addition, by sharing insights and convincing the client, the CE willingness of the client can increase [3][4][9]. Often, the client does not possess the same knowledge on circular infrastructure assets as the contractor operating in these infrastructure assets. Therefore, the positive effects and the technical feasibility of the CE approach is not known at the client side. By actively convincing the client, with CE information, the client willingness for the CE approach will most likely rise.

Finally, creating awareness will obviously increase the awareness on this topic. Through introducing initiatives [8][9][0] and motivating [4][7], wrong perceptions and the lack of awareness on CE will decrease. Most infrastructure asset operators do not have sufficient knowledge on the CE concept, which causes them to have wrong perceptions on the CE approach. By clearing out these wrong perceptions and by increasing the awareness of what effects CE may bring, the social barriers for increasing circular infrastructure assets may be cleared.

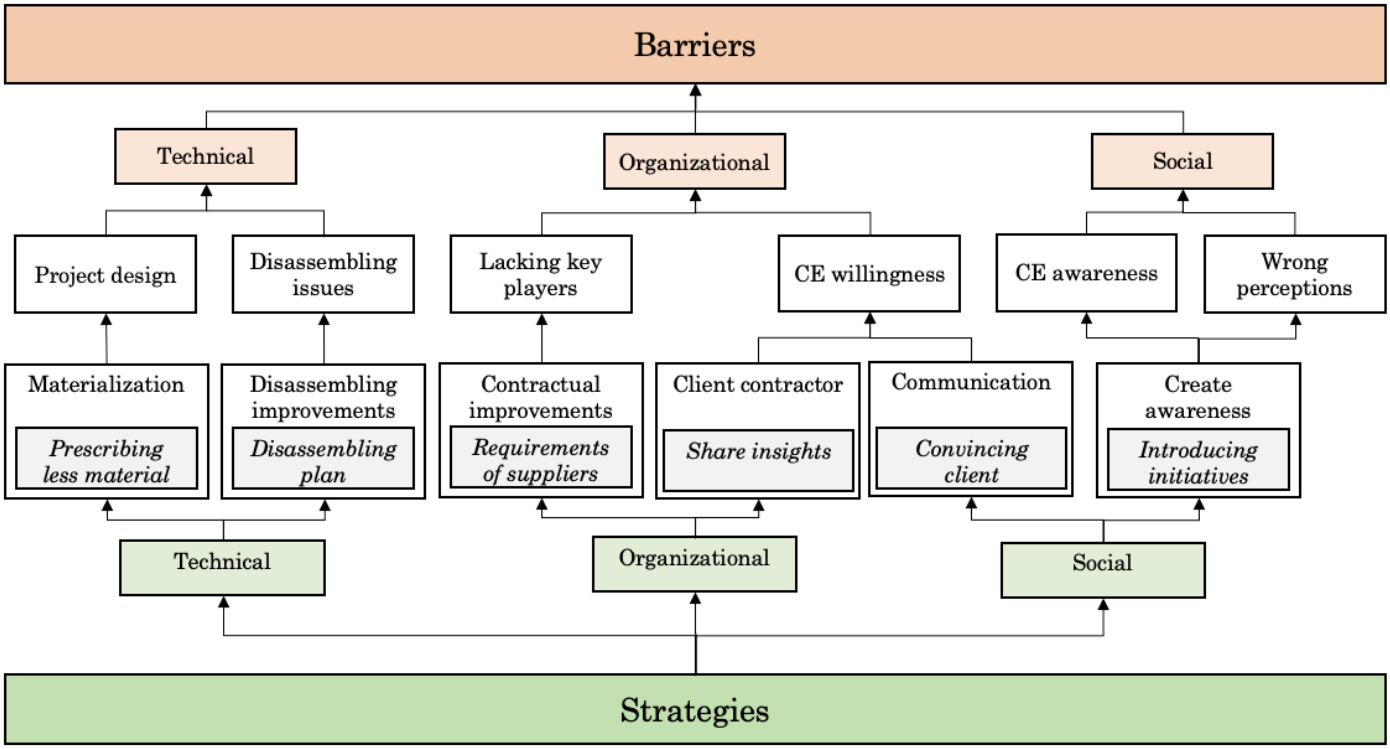

Figure 20: Visualization of the relations between barriers and strategies

6. Discussion

In this chapter, the discussion of this thesis will be set out. In section 7.1 and 7.2, the barriers and strategies obtained through the semi-structured interviews within this case study will be compared to the barriers and strategies extracted from the existing literature. So, the empirical results of this thesis are compared to the contemporary literature. Thereafter, in section 7.3 and 7.4, the reflection on the methodology and results is given. In 7.5, the scientific contribution of this thesis will be elaborated on and lastly, the limitations of this study will be given in section 7.5.

6.1 Barrier comparison to literature

In this section, the barriers that are attained from the interviews during this case study are compared to the barriers obtained through the literature review in chapter 5. The barriers are relatively evenly distributed among the categories in the existing literature, except for the regulatory and environmental categories. The result of this thesis, however, show that practitioners in the field of the infrastructural sector mostly mention regulatory and social barriers as the hindrance of the CE implementation. These differences between the literature exploration and the results from the semi-structured interviews will be explained below per category.

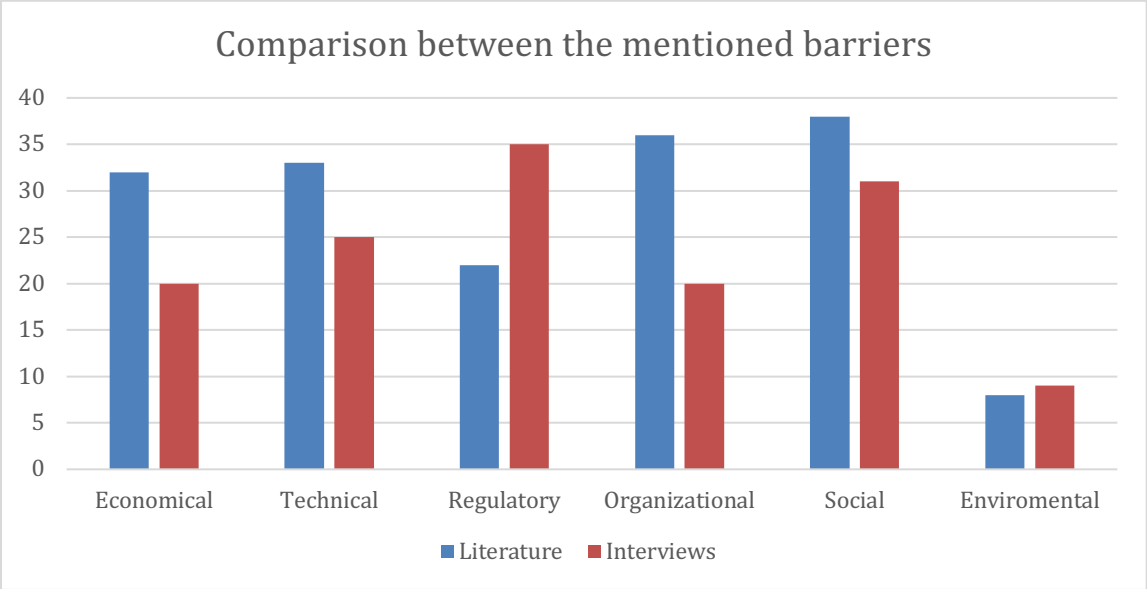

Figure 21: Comparison between the mentioned barriers

6.1.1 Economic barriers

The lack of financial incentives, imbalance in the market and the additional costs are reflected in the literature as well as in the results of the interviews. The major difference between the literature and the outcomes of the semi structured interviews, is the existence of low margins that the infrastructure sector deals with according to the interviewees of this thesis. For that reason, the circular approach on infrastructural assets has made little progress in recent decades. What was not mentioned by the interviewees, but what is reflected in the literature, is the too expensive labor in Europe, which means that too little manpower is put on CE.

6.1.2 Technical barriers

Regarding the technical barriers, the existing literature partly corresponds to the results of the interviews. What stood out in relation to the technical barriers found in the literature, was the specificity of projects that was seen as a barrier by the interviewees. Designers of infrastructure assets see their work as custom and project specific. This creates the need to obtain customized materials and thus hinders the circular design. This barrier was not found during the literature exploration. In addition, according to the interviewees, circular infrastructure assets clash with management and maintenance of these assets and its technical quality, which was not found in the existing literature neither. However, part of the technical barriers obtained during the literature study overlap with the barriers resulted from this thesis. The reason being, is the similarity of the lifespan of both infrastructure assets, and other construction assets, such as buildings. The design life of both buildings and infrastructures are comparable and ranges from 50 to more than 100 years (Guerra et al., 2021). For this reason, part of the discussion regarding the lifespan of infrastructural assets can be compared to longer lifecycle constructions or buildings.

6.1.3 Regulatory barriers

One of the most common mentioned categories by the participants of the interviews were the regulatory barriers. Most of the interviewees stated that the lack of certification and the presence of strict guidelines are withholding the implementation of circular infrastructure assets. However, these two most mentioned barriers were not found during the literature exploration and therefore can be seen as specific to this case of improving the circularity of infrastructure assets. In addition, the existing literature and the interviewees are very much in line with the lack of regulations regarding circular improvements. It can therefore be stated that the lack of regulations adapted to CE is an issue that arises more often in this research field.

6.1.4 Organizational barriers

The barriers on organizational level mentioned by the interviewees differentiated to a large extent compared to the barriers obtained during the literature exploration. Lacking key players, time, and planning were mentioned by the interviewees but was not stated in literature. In a broader sense, there is consensus that there are "new approach issues" for the circular economy. The complexity of the supply chains is mentioned in the literature as an important barrier for the CE but is not cited by the interviewees.

6.1.5 Social barriers

Regarding the social barriers, the two outcomes are relatively in line with each other. Mainly the awareness of the concept, understanding of the concept and the traditional attitude with its associated issues corresponds between literature and the empirical results of this study. However, the undesirable human behavior and communication issues were commonly mentioned by interviewees but are not stated in the existing literature on this concept. In addition, the trust barriers explained in literature differentiated from the trust barriers by the interviewees. Were literature focusses on the lack of trust regarding

circular materials, did the interviewees mentioned the lacking trust in the approval of their circular designs.

6.1.6 Environmental barriers

In the case of the environment category, both the barriers extracted from the literature and the barriers mentioned by the interviewee are very similar. Emissions from transport were particularly common in contemporary literature, but the interviewee mostly emphasized the fact that there is little storage for secondary material.

6.1.7 Summary strategy comparison

In a broad sense, the division of barrier categories among the results of the semi-structured interviews and the barriers extracted from literature do not very much. However, social barriers were most stated in the literature regarding CE in the construction sector and regulatory barriers came forward most mentioned for this case study. Certification issues, tight project budgets and high technical quality requirements came forward often during the interviews. Where budget related barriers were often present within the literature, certification issues and high technical quality requirements were not.

6.2 Strategies comparison to literature

The strategies for the CE implantation are not as evenly distributed in comparison to the barriers within the existing literature and the results from the interviews. Regulatory strategies are most mentioned in the literature as where organizational, social, and technical strategies are the most cited strategies by the interviewees. Innovative measurements and creating awareness were most mentioned by the practitioners to further enhance CE implementation within the infrastructure assets. Better management and traceability of resource flows and the reuse of building elements.

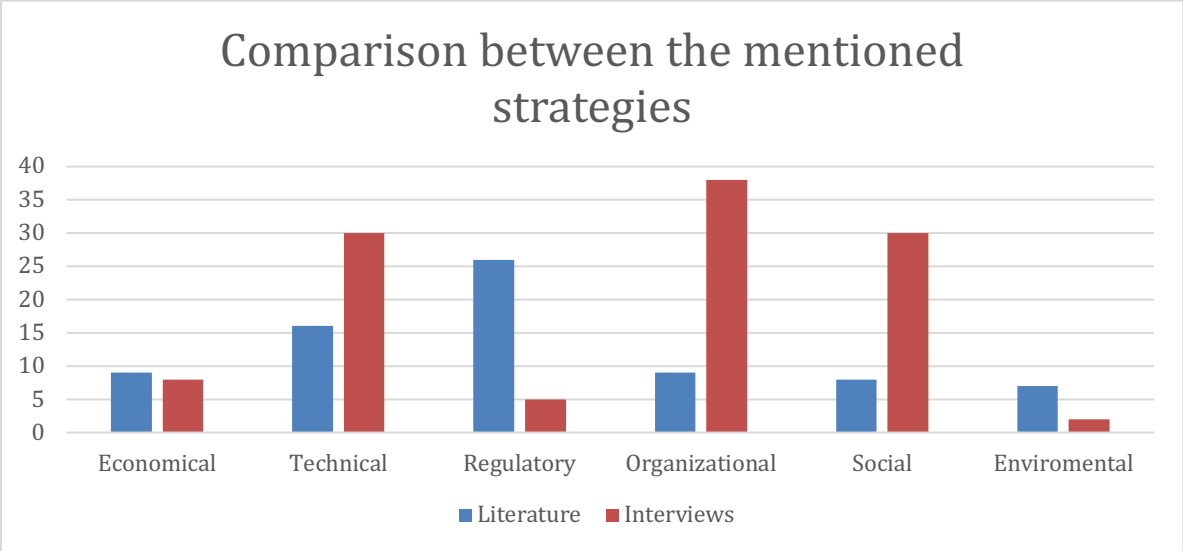

Figure 22: Comparison between the mentioned strategies

6.2.1 Economic strategies

Market innovations, as the stimulation of an online market for recovered materials, were mentioned by both the academics in literature and the interviewees. However, financial management strategies are not quite elaborated within the existing literature. These financial management strategies, as implementing flexible budgets through non-price request were mentioned by interviewees as sufficient strategies to enhance circular infrastructure assets.

6.2.2 Technical strategies

The number of strategies mentioned by the interviewees are more extensive than those obtained in the literature. The most common mentioned strategy during the interviews, was the further implementation of innovative measurements, such as preliminary investigation. This strategy was not pointed out by literature to a large extent. In addition, materialization improvements, time materialization e.g., were not extracted during the literature exploration but were mentioned second most by practitioners during the interviews in this case study. Some strategies, as deconstruction and disassembly improvements were both stated by the interviews, as well as the literature.

6.2.3 Regulatory strategies

Regulatory measures were not extensively mentioned by the interviewees in contrary to the literature observations. Both mention the need for governmental control and regulations. The most mentioned regulatory strategy by the interviewees is the need for updated requirements regarding the quality of reused materials. The improvement of the use of sustainability certifications is stated by literature as an important strategy. So, both agree to the need for innovative certifications and requirements, however the interviewees emphasize that circular materials meet infrastructural asset needs, but not the requirements.

6.2.4 Organizational strategies

The client contractor relationship and contractor improvements were central to the results of the interviews. What stood out in relation to the literature was that the client contractor relation was not even mentioned, although most mentioned by the interviewees in the case study of this thesis. In addition, enhancing the planning of CE operations seemed another important measure which was mentioned by the interviewees but did not came forward in the literature exploration. Both agree that earlier involving experts in the process will help stimulate CE.

6.2.5 Social strategies

Convincing the client, promoting, and increasing knowledge on CE are the most mentioned strategies in the literature on CE construction within the social category. Creating awareness is most mentioned by the interviewees as well, which overlaps with the found strategies in the literature. However, stimulating trust and enhancing communication not found in the existing literature but are mentioned by the interviewees.

6.2.6 Environmental strategies

The literature mainly focused on enhancing or avoiding construction components and materials. In addition, the avoidance of landfilling was raised. The interviewees within this thesis mentioned the reduction of materials as well. They stated that prescribing less materials can help CE grow further. This more specific action was not found in the literature, but the overarching goal was mentioned instead.

6.2.7 Summary strategy comparison

The division of strategy categories resulted from the interviews differentiated from the obtained strategies through the literature exploration. Strategies within the organizational field were most mentioned by the participants of the interviews whereas regulatory strategies were most cited within the existing literature. Increase communication with the client, enhance an online overview of circular materials and nominating the contractor as expert were most mentioned by the interviewees but were found during the literature exploration. Convincing the client arose as an important strategy within literature and overlaps with the communication improvements stated by the participants of the interviews from this case study. The establishment of an online overview of circular materials was often mentioned by interviewees but was not specifically mentioned in the current literature. Academics emphasized an online marketplace to enhance the exchange of circular materials. Whereas the interviewees mentioned the online overview as a tool for designers of infrastructure assets

6.3 Generalization of results to broader infrastructure sector

In this section, it will be discussed to what extent the results of this study can be generalized to the broader infrastructure sector.

6.3.1 Degree of specificity of the barriers or strategies

The semi-structured interviews resulted in barriers and strategies that have a different degree of specificity. The guidelines of Schiphol Airport, for example, are of a high degree of specificity since these guidelines are linked to this case study. The awareness of CE, on the other hand, can be seen as a more general barrier and therefore will be more likely applicable to the broader sector.

6.3.2 Client contractor relationship

This thesis zooms in on the client and the main contractor of the landside infrastructure assets of Schiphol Airport. According to Kamminga (2009), these two stakeholders have the most impact and influence on the infrastructure projects. However, other stakeholders do have impact and/ or influence on infrastructure assets as well, are barely considered in this thesis. In addition, Schiphol Airport and Bam Infra are two large players in the field for respectively client and contractor. Therefore, the results of this thesis will mainly be of use for likewise clients and contractors.

6.3.3 Long-term contract

Bam Infra and Schiphol Airport are linked by a long-term contract. As many interviewees mentioned, this long-term contract is very decisive for the cooperation. There is often a less competitive relationship and less competition on price. In addition, Bam has a best value contract, which means, that the contractor is set up as an expert in this case. This gives freedom of movement to think in terms of circular innovations. If this long-term contract is not present, this open relationship will probably not exist. With short-term projects, as the interviewee called "market projects", this open relationship will probably not exist. For this reason, not all results of this thesis can be generalized in this matter. The BVP that is present within this case study ensures that the contractor has a high degree of freedom in the way they it organizes the infrastructure assets.

6.3.4 National and local legislation

According to the interviewees, legislation is an important factor for CE to break through. To argue the generalization, it is important to make a distinction between local and national regulation. This thesis focusses on infrastructure assets that is located at the territory of Schiphol Airport and therefore must deal with different types of legislation at municipality, province, and water board level. Infrastructural assets outside the area of Schiphol Airport will therefore most likely not be able to use the results in terms of local legislation. However, legislation at national level will apply to all infrastructure assets located in the Netherlands. This also applies to the regulations at EU level, although these were not mentioned by the interviewees.

6.3.5 Schiphol Guidelines

The fast-paced environment in which Schiphol Airports is located results in many custom guidelines for contractors and other stakeholders that operate at projects or territory of Schiphol Airport. These guidelines are present on Schiphol's territory only. As this study focusses on the landside of Schiphol and not on the airside, guidelines are less strict but are still present.

6.4 Reflection on methodology

During this thesis, multiple methods were used to gather and analyze information to obtain results for this study. The reflection on these methods will be discussed in this section. An in-depth-single case study was performed in this thesis to investigate the issue addressed. This method is suited well in attempting to find where barriers and strategies exist for improving the circularity of infrastructure assets. Therefore, barriers and strategies are obtained that exist solely within the investigated case. This results in the fact that the data collected cannot necessarily be generalized to the wider construction sector. As a result, data collected through case studies may not always be relevant or particularly useful. In addition, this thesis sought to identify barriers and strategies by analyzing one case where the data was collected by one researcher. As a result, the chance of bias in the data collection is substantial and, therefore, to a greater extent, unavoidable. The main data gathering method for this case study was the semi-structured interview method. These interviews were performed to obtain the necessary information and views of the practitioners that operate within the field of infrastructure assets. Interviewees

were selected from both Bam Infra and Schiphol Airport that have sufficient knowledge of infrastructure assets and the CE theme. Although these two stakeholders are quite relevant considering infrastructure projects, other stakeholders play a role as well. The results of this study, therefore, only show the view of these stakeholders on the barriers and strategies investigated for this thesis. The participants frequently mention regulatory barriers as the hindrance to the implementation of circular infrastructure assets. Since the participants are active within the operational field within at Bam Infra or Schiphol Airport, they have no expertise in the regulatory field. This explains why very few regulatory strategies were mentioned by the same participants. Therefore, it can be stated that reflecting on this way of choosing participants, the relevant regulatory actors are also relevant to be interviewed. Not only will this lead to more insight in the regulatory barriers but it will increase the number of strategies for overcoming these regulatory barriers. When applying the interviewing method, interviewees of the two companies, Bam Infra and Schiphol Airport, are not evenly distributed. Although the roles of the participants of Schiphol Airport are set out accordingly to obtain a good vision of the barriers and strategies existing in this case, a more evenly distribution of the participants between the two companies will lead to better results. Lastly, the grounded theory and content analysis were used to analyze the data, which were well suited for the analysis of the interview transcripts. It gives a clear overview of what barriers and strategies were mentioned, and in addition, the frequency of the mentioned barriers and strategies could be obtained with these data gathering methods.

6.5 Reflection on results

The results of this study clearly show what barriers and strategies are present within the investigated case. In addition, the comparison of these results with the existing literature on barriers and strategies for the CE in the broader construction sector clarifies what is considered different, similar, or new for circular infrastructure assets in specific. Since this thesis solely focuses on the circularity barriers and strategies for infrastructure assets, several of these barriers and strategies are the result of the novelty of the CE concept in general. Thus, they are not specific to the application of infrastructure assets but rather on CE and the change needed to achieve CE in general. For this reason, it can be stated that some barriers and strategies are too generic and solely focus on this concept. In the problem statement, it was indicated that the barriers and strategies from studies on other sectors are too broad. This issue is thus partly present in the results of this study as well. The participants of the interviews mentioned the regulatory category most often for barriers that hinder the adoption of CE within infrastructure assets. It would therefore have been desirable to have a sufficient number of strategies suggested by the interviewees within this regulatory category. Since this is not the case, the results come short on this matter.

6.6 Scientific contribution

This study started with a problem statement addressing the lack of knowledge on barriers and strategies for the circular infrastructure assets. The main goal of this research was to clear the gap between the absence of literature on barriers and strategies for the

implementation of CE in infrastructure assets. This thesis aims to deliver the knowledge and information to clear or at least reduce this gap. By implementing a single in-depth case study on the landside of Schiphol Airport, barriers and strategies for the circular approach were obtained. In terms of these results, several novelties were obtained that differ from the knowledge in existing literature. Most of the results obtained during this thesis, in comparison with the existing literature on barriers and strategies, either differ, correlate, or are completely new. The view of the practitioners in the infrastructure field during the interviews allowed for new insights that will be useful for other scientific research in the field of circularity within the infrastructure sector, especially infrastructure assets. This novelty mainly lies within the client-contractor issues that are often mentioned and the difficulties that each of these stakeholders experience individually. However, since the infrastructure sector is a specific sector within the broader construction sector in general, some part of the results obtained in this study correlate with the barriers and strategies present within the existing literature. Therefore, it can be stated that on these correlating parts, the infrastructure sector does have the same characteristics as the broader construction sector in general. This correlation is especially applicable within the economic, social, and regulation field for the circular approach.

Furthermore, the literature exploration aimed to obtain an all-encompassing overview of all barriers and strategies existing in the European construction sector. Therefore, this theoretical framework can be used for further studies that aim to acquire information on barriers and strategies for CE that are present in the European construction sector. The results of this literature exploration can thus be useful/applicable for both scholars and practitioners in the sector, as it adds to existing information by examining the barriers and strategies to CE for the entire construction sector.

6.7 Limitations

Several limitations were found to be applicable within the research of this thesis:

- As stated earlier, barriers within the regulatory category were most mentioned by the interviewees to be hindering the CE implementation for infrastructure assets. However, the participants of the interviews were no experts in the regulatory field. Therefore, only a small number of regulatory strategies were mentioned by these interviewees. One of the limitations of this study is the absence of participants within the regulatory field.

- Data obtained to perform this research was gathered through semi-structured interviews. In general, conducting interviews can be subject to bias from the interviewees. This research is based on opinion of individuals operating in this field. Therefore, these empirical results should be validated by other experts within this field of expertise. Due to limited available resources, this could not be done and therefore forms a limitation of this thesis.

- The past years, the general views and need for implementation of CE has changed rapidly. Interviewees stated that the awareness and the need for this concept is gaining momentum in this sector. Still insufficient attention is given to the legislation and regulations towards CE. However, this rising attention could lead to an acceleration of the introduction of legislation and regulations in the near future which take away the barriers for the development of CE. Some barriers resulting from this study on this subject will then no longer be valid as they become outdated.

- As this thesis focusses on an in-depth single case study, results can be too specific. Therefore, some barriers and strategies may not be able to be applied to other cases. The reason that not all results of this thesis can be generalized is a limitation of this study.

- Due to the qualitative nature of this study and the low N-number of participants, no statements could be made on the importance of the barriers and strategies. In total 44 barriers and strategies were obtained through this study. Therefore, ranking these barriers and strategies by performing quantitative research is desirable as not all 44 barriers can be given attention evenly.

7. Conclusion & recommendation

The overall goal of this study was to obtain the existing barriers and strategies for the CE implementation within the infrastructure assets by using a specific case on infrastructure construction. In this specific case, barriers and strategies for circular infrastructure assets is researched. The following research question stood central during this research:

"What are the key barriers and potential strategies for the implementation of circular infrastructure assets at Schiphol Airport?

7.1 Main insights

The CE concept is a booming theme, and the attention on this subject is increasing every year. However, the increasing attention on this theme has not yet been translated into practice within the infrastructure sector to a sufficient degree. While much literature has been published on the topic of CE, no analysis on the identification of barriers and strategies for circular infrastructure assets was conducted prior to this study. To provide a theoretical framework for this thesis, all literature focusing on CE barriers and strategies for the construction sector is systematically analyzed. This theoretical framework consisted primarily of barriers and strategies that were attained from studies on circular buildings (including residential buildings, commercial buildings, and other types of building property), as this theme was most common in the current CE literature. To extend the knowledge of CE, and gain insights into the key barriers and potential strategies for circular infrastructure assets, an in-depth single case study was performed at Schiphol Airport. The view of practitioners and experts within this field was obtained to get a clear overview on the barriers and strategies present in this unexamined sector. According to these practitioners and experts, numerous key barriers and potential strategies within the economic, organizational, sociological, regulatory, technical, and environmental categories are present. The analysis of the interviews resulted in the identification of 24 barriers and 17 strategies for increasing the circularity of infrastructure assets at Schiphol Airport. It was noted that some of the identified barriers and strategies were mentioned more often during the interviews than others. The outdated and conservative nature is strongly interconnected between the most mentioned barriers. They share aspects of outdated institutional factors (strict guidelines & certification requirements) and conservative behavior. Furthermore, the CE approach's unreadiness (low virgin prices and a lack of financial incentives) is frequently the reason why this approach is not yet profitable and, as a result, is not widely used. Although the circular approach is technically feasible, these restrictions withhold the CE from thriving for infrastructure assets. That said, multiple strategies for the enhancement of circular infrastructure assets are identified as well. Commonly stated by the professionals and experts in the field was the enhancement of communication. According to the participants of the interviews, the existence of an information gap between the stakeholders involved in the processes for infrastructure asset construction and maintenance needs to be cleared. In addition, the method of allocating materials to infrastructure assets must be reconsidered. Experts commonly address that by supplying a limited variety of materials and imposing a limit on these materials; the designer is forced into circular thinking.

Meanwhile, this thesis partly confirmed previous authors' analysis of what CE barriers and strategies are for the broader construction sector. The reason is that some barriers and or strategies are applicable to the CE concept in general. For instance, the lacking CE awareness, which forms a great barrier to the implementation of circular infrastructure assets, is present in all industries in which circular novelty plays a part. Thus, it can be stated that, in line with other industries within the construction domain, the infrastructure sector is not yet able to become fully circular due to the existence of numerous barriers. However, by exposing the existence of these barriers, as this study aimed for, these barriers will be given more attention individually, which in turn will lead to a better understanding of how to tackle this issue. Furthermore, the strategies resulting from this thesis will allow for a better, clearer understanding of overcoming these barriers.

7.2 Recommendations

The recommendations are divided into three parts, recommendation for future academic research, this specific case and for the entire infrastructure sector.

7.2.1 Recommendations for future academic research

During this research multiple future research recommendations arose. Most future research recommendations resulted from the limitations of this study. The following recommendations for future research are recommended:

- Since one of the limitations of this study is the absence of experts within the regulatory field, future research on this topic should include these experts. By obtaining the view of these legal experts, clarity and a more in-depth analysis on the regulatory category can be obtained. Future research should focus on legal institutions and organisations which have influence on these regulatory barriers and thus may came up with strategies.

- Due to the qualitative nature of this research and the limited number of respondents, no statements could be made on the importance or rank of the barriers and strategies. By performing more quantitative analysis on these barriers and strategies through larger surveys e.g., other insights can be obtained. Then, a center of gravity analysis can be made on which barriers are most important.

- This thesis focusses on the two most important stakeholders within the infrastructure asset lifecycle: the client and the contractor. By further extending the stakeholders cooperating in the construction of infrastructure of Schiphol a wider understanding will exist of where barriers and strategies are present.

- Gathering information through interviews can be subject to bias as stated in the limitations of this study. Therefore, validation of the results of this study by other experts in the field is desirable. Future research should validate the results of this study and add barriers and strategies where applicable.

- Additionally, the collaboration process between the client and contractor was laid down in long-term contracts and best-value procurements. According to the results of this thesis, these types of contractual arrangements are not beneficial to CE. No information is available to what extent CE barriers and strategies exist when these types of contractual agreements are not present. A case study where short-term contracting models are present needs to be carried out to see what barriers and strategies are present in such case which may differ from the outcome of this study.

- As this thesis focusses on a single in-depth case study, the results tend to be specific to this case. To comprehend a wider understanding on where barriers and strategies exist for implementing CE within infrastructure assets, research needs to be done on other or multiple cases. Especially since some of the outcomes of this study are case specific. The specific guidelines of Schiphol Airport are often mentioned as a barrier for CE implementation. As this barrier is case specific for the landside of Schiphol Airport, it should be investigated whether guidelines of other stakeholders in general form a barrier for CE within the infrastructure sector. Guidelines are commonly issued by clients within the infrastructure sector, which may cause hindrance for applying a CE approach.

7.2.2 Recommendations for this specific case

The result of this thesis shows that the communication between client and contractor regarding CE is not always expressed to a sufficient degree. Communication should be improved between Bam Infra and Schiphol Airport. Since the objectives of both parties point in the same direction concerning CE, enhancing communication should be sufficient to increase the degree of circular infrastructure assets. In addition, Bam Infra should address the issued guidelines of Schiphol Airport regarding reused materials for infrastructural assets. A committee composed of CE experts from both Bam Infra and Schiphol Airport will ensure that there is consensus and clarity about how CE may be applied to the infrastructure assets at the landside of Schiphol Airport. Furthermore, it will be essential to define what is meant by recycling. Larger parts of the re-use of infrastructure asset materials are downcycled rather than recycled whereby this downcycling is still seen as sufficient. A better overview will need to be obtained of not only what is recycled, but what happens to the material afterward as well. In other words, what is the destination of the material to be re-used? This way, a better estimate can be made of the current situation regarding the circularity of the infrastructural assets located at Schiphol Airport. Lastly, as stated in the case description, several actions and agreements are specified by Bam Infra to meet the CE ambitions and visions of Schiphol Airport. This also involves agreements with key players and third parties involved in the processes of infrastructure assets at Schiphol Airport. However, according to the results of this thesis, key players and other third parties do not always meet the ambitions of Schiphol Airport. Interviewees point out the traditional way of working of some key players. Therefore, it should be analyzed how these key players can be replaced or given stricter requirements. In addition, all actions that Bam Infra is currently performing, need to be checked to see to what extent they are still in line with current CE developments.

7.2.3 Recommendations for the entire infrastructure sector

Most importantly, regulation and legislation should be better fitted to the CE approach in the entire infrastructure sector as this is often mentioned by the interviewees. Discussions on this specific topic should be introduced between CE-experts and counselors and the relevant governmental bodies. The government stated that it is willing to change legislation and regulations to help the transition toward a circular economy. They should examine where possible amendments to legislation and regulations are needed. This is exactly where the experts within the field of the infrastructure sector are needed to explain where and why the amendments to legislation and regulations are needed to enhance CE implementation within this sector. In addition, the price of raw materials is too low which causes the linear inflow of new materials to continue. Mining and using raw materials are still cheaper than high-quality recycling and reusing other materials. The main reason is the high taxation of labor in the Netherlands compared to the use of raw materials. A tax-shift in this field should be considered to lower this issue. This topic must be brought to the attention of higher governmental bodies and institutions.

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APPENDICES

APPENDIX A: KEY LITERATURE ON BARRIERS FOR THE CONSTRUCTION SECTOR

Literature on barriers for the building sector is displayed in the table below.

Author	Focus	# Identified barriers	Geographical orientation
Selman et al. (2020)	Building design	27	Denmark
Giorgi et al. (2022)	Building sector	6	EU
Kanters (2020)	Building sector	6	Denmark, UK, Belgium & NL
Sigrid Nordby (2019)	Building materials	3	Norway
Jean Claude Morel et al. (2021)	Building materials	60	EU
Adams et al. (2017)	Building industry	8	United Kingdom
Akinade et al. (2020)	Building deconstruction	26	United Kingdom
Häkkinen et al. (2011)	Sustainable buildings	4	Finland
Selman et al. (2021)	Sustainable and circular buildings	11	Denmark
Zu Castell-Rüdenhausen et al. (2021)	Building components	7	Denmark, Finland, Norway, and Sweden
Knoth et al. (2022)	Reuse of building parts	3	Norway
Huuhka & Hakanen (2015b)	Building components	18	Finland
Ottosen et al. (2021)	Building and construction sector	8	Denmark

Table 9: Key literature on CE barriers for the building sector

Literature on barriers for the construction sector in general that are used during the literature exploration are displayed in the table below.

Author	Focus	# Identified barriers	Geographical orientation
Sarhan et al. (2013)	Lean construction	10	United Kingdom

Table 10: Key literature on CE barriers for the construction sector in general

APPENDIX B: KEY LITERATURE ON STRATEGIES FOR THE CONSTRUCTION SECTOR

Literature that focusses on strategies for the circular economy in the building sector are displayed in the table below.

Author	Focus	# Identified strategies	Geographical orientation
Giorgi et al. (2022)	Building sector	12	Europe
Akinade et al. (2020)	Building deconstruction	6	UK
Zu Castell-Rüdenhausen et al. (2021)	Building components	5	Denmark, Finland, Norway, and Sweden
Anastasiades et al. (2021)	Construction components of buildings	6	Europe
Knoth et al. (2022)	Reuse of building parts	7	Norway
Kanters (2020)	Circular building design	3	Europe
Sigrid Nordby (2019)	Building materials	14	Europe

Table 11: Key literature on CE strategies for the building sector

Literature on strategies for the circular economy in the general construction sector are displayed in the table below.

Author	Focus	# Identified strategies	Geographical orientation
Superti et al. (2021)	Recycled concrete	6	Switzerland
Górecki et al. (2019)	Construction sector	4	Europe
Gálvez-Martos et al. (2018)	Construction and demolition waste	11	Europe
Migliore et al. (2020)	Construction and demolition waste	7	Europe

Table 12: Key literature on CE strategies for the construction sector

APPENDIX C: CE BARRIERS WITHIN EXISTING LITERATURE

CE barriers for the building industry

All the CE barriers for the building sector that were obtained from the existing literature are shown in the table below. This table represents the part of the theoretical framework for CE barriers within the building industry.

Category	Barrier	#Mentioned
Economical	Lack of balanced supply/demand	7
	Additional cost	6
	Client willingness to pay for the CE	2
	Lack of structured market	2
	Profit-seeking first	2
	Cost of the approach	2
	Lack of facilities for reclaimed materials	2
	Cost of landfill	1
	Market issues	1
	Market are not prepared before the start of a project	1
	Competition among the stakeholders	1
	Expensive labor in EU	1
Technical	Issues regarding recovered materials	5
	Issues regarding material recoverability	4
	Lack of pilot projects	3
	Materials knowledge and reliability	3
	Variety of buildings	3
	Building lifespan issues	2
	Construction methods adaptation	2
	Data issues	2
	In-use phase adaptation	1
	Lack of technologies	1
	Location of materials recovery facilities	2
	Programming and design phases adaptation	1
	Data security issues	1
	Low performance guarantees for recovered materials	1
	Components not designed for deconstruction	1
Regulatory	Lack of regulation	7
	Lack of policies-regulation	4
	Insurance issues	3
	Application of regulations	2
	Policies weaknesses	2
	Lack of incentives	1
	Policies absurdity and complexity	1
	Stakeholder liability	1
	The absence of European coordination	1
Organizational	Lack of skills	5
	Lack of responsibilities	4
	Organizational changes needed	4
	New approach issues	4
	Working methods and approaches	3
	Project type	1
	Communication issues	2
	Competence improvement needed	1
	Current approach dependency	3
	Lack of management support	2

	Lack of traceability	1
	Urban planning	1
	Complex supply chains	1
	Fragmented supply chain	1
Sociological	Consumer culture	5
	Lack of awareness and understanding	4
	Lack of trust	4
	Cultural beliefs	4
	Resistance to change	3
	Lack of concern	3
	Evolving mores, mentalities	3
	False beliefs	2
	Human influence for material selection and working methods	1
	Lack of communication/ common language	1
	Lack of trust	2
	Wrong investment expectations	2
	Insufficient collaboration	1
	Vague definition of CE	1
Environmental	Transports' emissions	3
	Space issues	2
	Use of polluted or low recoverability materials	2
	Use of virgin resources	1

Table 13: CE barriers for the building industry

CE barriers for the construction industry

All the CE barriers for the construction sector in general that were obtained from the existing literature are shown in the table below. These barriers shown below will represent the part of the theoretical framework for CE barriers within the construction industry.

Barrier category	Barriers	#Mentioned
Economical	Fragmentation and subcontracting	(Sarhan & Fox, 2013)
	Financial issues	(Sarhan & Fox, 2013)
	Procurement and contracts	(Sarhan & Fox, 2013)
	Time and commercial pressure	(Sarhan & Fox, 2013)
Technological	Lack of the use of process-based PMs	(Sarhan & Fox, 2013)
Regulatory	NA*	-
Social	Culture & human attitudinal issues	(Sarhan & Fox, 2013)
	Lack of adequate lean awareness and understanding	(Sarhan & Fox, 2013)
Organizational	Educational issues	(Sarhan & Fox, 2013)
	Lack of top management commitment	(Sarhan & Fox, 2013)
	Design/Construction dichotomy	(Sarhan & Fox, 2013)
Environmental	NA*	-

Table 14: CE barriers for the construction industry

APPENDIX D: CE STRATEGIES WITHIN EXISTING LITERATURE

CE strategies for the building sector

All strategies obtained in the in the existing literature for the building sector are displayed below. These strategies will represent the part of the framework of the CE strategies obtained for the building sector.

Category	Strategy	Authors
Economical	Tax shift	Kanters (2020); Sigrid Nordby (2019)
	Online market for recovered products	Akinade et al. (2020); Knoth et al. (2022); Sigrid Nordby (2019)
	Service-oriented business models	Giorgi et al. (2022), Knoth
	Financial incentives	Knoth et al. (2022)
	Funding schemes	Knoth et al. (2022)
	Green deals among stakeholders for circular discussion	Giorgi et al. (2022)
	Networking among operators for circular business	Giorgi et al. (2022)
	Reuse eliminates all costs related to waste disposal	Zu Castell-Rüdenhausen et al. (2021)
Technical	Reuse of building elements	Giorgi et al. (2022); Zu Castell-Rüdenhausen et al. (2021)
	Design for reversibility	Giorgi et al. (2022)
	Use of BIM software for design	Giorgi et al. (2022)
	Use of material passport	Giorgi et al. (2022)
	Innovative reuse	Knoth et al. (2022)
Regulatory	Better management and traceability of resource flows	Akinade et al. (2020); Giorgi et al. (2022), Zu Castell-Rüdenhausen et al. (2021); Sigrid Nordby (2019)
	National grading system/ targets/ roadmap	Akinade et al. (2020); Sigrid Nordby (2019)
	Information exchange service	Akinade et al. (2020), Zu Castell-Rüdenhausen et al. (2021)
	Appropriate legislation	Akinade et al. (2020); Sigrid Nordby (2019), Goreck
	Use of pre-demolition audit	Giorgi et al. (2022)
	Use of sustainability certification	Giorgi et al. (2022); Górecki et al. (2019)
	Morphological standardization	Anastasiades et al. (2021)
	Investigate building components (interconnectivity)	Anastasiades et al. (2021)
	Standard procedure for the reuse of building components	Anastasiades et al. (2021)
	Standardized series of non-destructive tests	Anastasiades et al. (2021)
	Include the CE in GPP	Anastasiades et al. (2021)
	Standard implement GPP	Anastasiades et al. (2021)
	Establish a national competence center	Sigrid Nordby (2019)
	Requirements for submission of waste plan	Sigrid Nordby (2019)
	Change property rights of buildings	Kanters (2020)
	Better waste management for construction projects	Sigrid Nordby (2019)
Organizational	Early involve reuse experts in the value chain	Akinade et al. (2020); Knoth et al. (2022)
	Extended manufacturer responsibility	Sigrid Nordby (2019)
	Share of material reuse after demolitions	Sigrid Nordby (2019)
	Creativity and innovation capacity	Knoth et al. (2022)
	Pilot buildings and dissemination of experience	Sigrid Nordby (2019)
Social	Convincing the client	Kanters (2020)
	Promote recycling and secondary raw materials	Kanters (2020)
	Increase knowledge of material content	Kanters (2020)
Environmental	Avoidance of resources consumption	Giorgi et al. (2022)
	Avoidance of materials landfilling	Giorgi et al. (2022)
	Perfect construction components	Anastasiades et al. (2021)
	High-performance materials	Akinade et al. (2020)

Table 15: CE strategies for the building industry

CE strategies for the construction sector

In the table below, all strategies for the construction sector in general are displayed that are obtained within the literature exploration. These strategies will represent the part of the theoretical framework for the CE strategies obtained within the literature on the construction sector in general.

Category	Strategy	Author(s)
Economical	Economic Instruments	Gálvez-Martos et al. (2018)
Technical	Smart design for disassembly and deconstruction	Migliore et al. (2020)
	Reuse of materials	Gálvez-Martos et al. (2018)
	Building de-construction	Gálvez-Martos et al. (2018)
	Material Use Efficiency	Gálvez-Martos et al. (2018)
	Designing out waste	Gálvez-Martos et al. (2018)
	Smart design for adaptability	Migliore et al. (2020)
	Design for maintainability,	Migliore et al. (2020)
	Design for repair	Migliore et al. (2020)
	Use building products obtained from pre-consumer by-products	Migliore et al. (2020)
Regulatory	Financial support of the European Union	Górecki et al. (2019)
	Stimulate vertical integration	Górecki et al. (2019)
	Horizontal involving industries and sectors.	Górecki et al. (2019)
	Quality assurance schemes	Gálvez-Martos et al. (2018)
	Legal regulations, policies, requirements & certificates	Górecki et al. (2019)
Organizational	Support decision making in the design phase	Migliore et al. (2020)
	Site Waste Management Plans (SWMP)	Gálvez-Martos et al. (2018)
	Site waste management and prevention	Gálvez-Martos et al. (2018)
	CDW management plans	Gálvez-Martos et al. (2018)
	Improve actor collaboration	Superti et al. (2021)
Social	Stimulate awareness on environmental impact of RC	Superti et al. (2021)
	The fact of having seen RC at least once	Superti et al. (2021)
	The number of architects and clients recommending RC to the actor	Superti et al. (2021)
	Waste sorting and processing addressing the acceptability of recycled aggregates	Gálvez-Martos et al. (2018)
	Understanding of the motivations and consequences	Gálvez-Martos et al. (2018)
Environmental	The building is non-residential, and if the awarding authority targets a construction label (e.g., Minergie)	Superti
	Improvement of the durability of the products	Migliore et al. (2020)
	Application of practices of planned maintenance	Migliore et al. (2020)
	Use building products containing secondary raw materials	Migliore et al. (2020)
	Use low content of materials building products	Migliore et al. (2020)

Table 16: CE strategies for the construction industry

APPENDIX E: INTERVIEW PROTOCOL AND QUESTIONS

Semi-structured interviews were used with 10 experts in the field of infrastructure construction and circularity. Before the start of every interview, consent for the use and recording of the interview has been requested from the person interviewed.

Interview scheduling

For the interview method, the scheduling of these interviews is an important part. The scheduling of these interview is overviewed in the figure below.

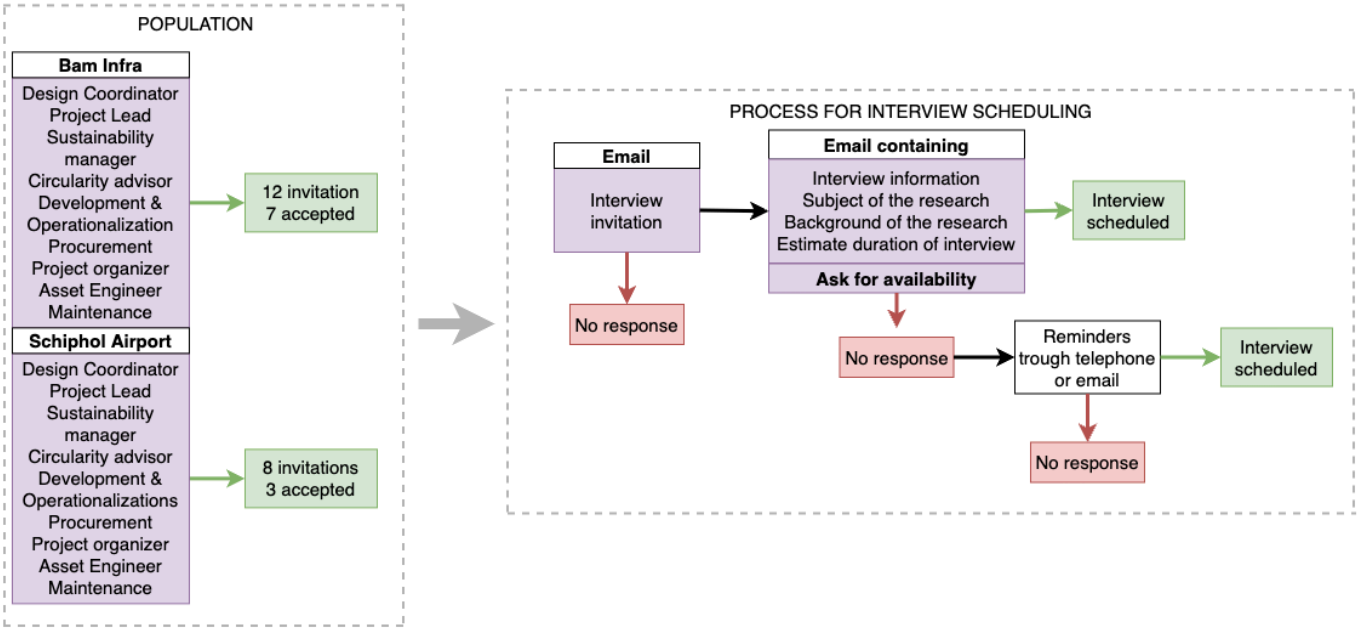

Figure 23: Interview population and interview scheduling

Introduction

First, the researcher asks if the interviewee agrees if he is willing to corporate with this study and approves to be recorded. Then, the researcher described the goal of the interview and the topic of the thesis. The main goal this research is to increase the CE at Schiphol Airport by the construction company Bam Infra. By obtaining multiple interviews at Bam Infra as well as Schiphol Airport, an overview of barriers and strategies for the CE can be obtained. This interview, thus, is to obtain more information on the barriers and strategies that are present in the construction of infrastructure.

Interview questions

The interview question for the semi-structured interviews is displayed below. Not every interview is set up according to the sequence below. Due to the "semi-structured" structure, some questions may have been asked at different times and some questions may have focused more on certain topics than in other interviews.

	Question	Follow-up probes
First stage	What is your role within Bam Infra/ Schiphol Airport?	In which phase of the infrastructure asset lifecycle do you operate? What is the task that you mainly perform within Bam Infra/ Schiphol Airport? In what way does your decisions have impact on circularity? What kind of circularity decisions do you take? Are people generally aware of what circularity entails?
Second stage	What do you think are barriers to the circular economy at Bam Infra/ Schiphol Airport regarding the infrastructure assets?	Why does it start less quickly? What prevents you or others from becoming more circular? How do you notice this in reality? Do you have other comments on the barriers for circularity regarding infrastructure assets?
Third stage	What do you think are strategies to the circular economy at Bam Infra/ Schiphol Airport regarding the infrastructure assets?	Which strategies or techniques do you apply to increase circularity? Do you feel that sufficient sustainable strategies are applied within the infrastructure sector? Do you think more attention should be paid to circularity strategies within the infrastructure sector? How do you notice this in reality? Do you have other comments on the strategies for circularity regarding infrastructure assets?
Fourth stage	Do you have anything to add regarding circularity of infrastructure assets on the landside of Schiphol Airport?	Are the decisions that are made final, or can they be withdrawn?

Table 17: Overview of interview questions

APPENDIX F: INTERVIEW CODING

The coding of the transcripts obtained from the interviews exists of two steps.

1. **Grounded theory**

The first step of the coding process was the transcribing of every interview. Every interview was transcribed by hand in word. After the transcription was completed, the transcription documents were uploaded to the software ATALS.ti, provided by the TU Delft. Then, **for the second step**, the transcripts are quickly read to make short notes. These notes are the interview terms where the open codes will exist of. **The third step** is conceiving open codes. These open codes are important lines, words, or aspects that the interviewees stated during their interviews. They attempt to establish an all-encompassing term of the interview terms obtained from the transcripts. For **the fourth step**, these open codes are grouped in axial codes, which in the case of this thesis will form the barriers and strategies. Finally for **the fifth step**, these axial codes will be merged to within selective codes which will function as the categories. The use is made of all barrier categories and barriers that are found in the literature. If there is need to add more barriers, this will be noted.

2. **Content analysis**

After the transcripts are coded according to the grounded theory method, the last two steps of Denscombe (2010) are used to obtain the frequency that every barrier and category is mentioned by the interview. This is done by counting the occurrence of interview terms for each barrier and category. **First**, all the frequencies of the open codes, axial codes and selective codes were obtained. Then, **secondly**, the different frequencies are compared to see in what extent different barriers and strategies are mentioned by the practitioners in the field of the infrastructural sector at Bam Infra on Schiphol Airport.

APPENDIX G: BARRIERS CODING OVERVIEW

In this appendix, the coding overview of all barriers is given. The selective codes are equal to the categories and the axial codes exists of the barriers. The interview term are assigned to an open code which in turn will lead to the composition of a barrier.

Selective code "Economical"

Selective codes	Axial codes	Open codes	Interview terms	Occurrence	
				Open code	Axial code
Economical	Financial issues	Profit seeking first	"Winst maken" [3], "Financiële winst" [3]	2	9
		Project budget	"Betalingsbereidheid" [7], "Budget" [6] [9], "Budget afhankelijk" [8], "Project plafond" [8], "Traditionele begrotingen" [5]	6	
		Low margins	"Laag rendement" [5], "Te lage marges" [4]	2	
	Lacking market	Supply and demand	"Vraag en aanbod" [1]	1	5
		Market issues	"Traditioneel marktdenken" [4], "Krapte in de markt" [4]	2	
		Virgin material prices	"Goedkope grondstoffen" [3], Grondstofprijzen" [3]	2	
	Additional costs	Sustainability costs	"Duurzaamheidskosten" [4], "Hoge kosten" [4] [5] [7]	4	6
		Initial costs	"Initiële kosten" [6], "Opstartkosten" [9]	2	
				Total	20

Table 18: Selective code "Economical" barriers

Selective code "Technical"

Selective code	Axial code	Open codes	Interview terms	Occurrence	
				Open code	Axial code
Technical	Technologies related barriers	Technical infeasible	"Technisch niet haalbaar" [1] [9]	2	3
		Technical Functionality	"Botst met functionaliteit' [7]	1	
		Maintenance	"Botst met beheer en onderhoud" [7]	1	
	Lifespan	Design life of infrastructural assets	"Levensduur" [7], "Oudere assets" [7]	2	3
	Quality and safety	Safety	"Niet veilig genoeg" [1]	1	7
		Quality	"Kwaliteit bovenaan" [8], "Kwaliteitsniveau eisen" [7], "Gemiddeld kwaliteitsniveau" [7], "Kwaliteitsgarantie" [6], "Kwaliteitskeurmerken" [8], "Lage materiaalkwaliteit" [10]	6	
	Traditional project design	Project specificity	"Maatwerk" [3], "Project afhankelijk" [3], "Project specifiek" [7], "Locatieafhankelijk" [1], "Onduidelijke scope" [9], "Milieu Schiphol" [9], "Project in meerdere stappen" [10]	7	9
		Outdated design requirements	"Achterhaalde ontwerpprincipes" [7], "Traditionele ontwerp eisen" [7]	2	
		Outdated building principles	"Achterhaalde bouwprincipes" [7]	1	
		Logistics flows	"Logistieke stromen" [10]	1	
	Disassembly issues	Dismantling Possibility	"Ontmanteling mogelijkheid" [7], "Ontmantelingsproblemen" [9]	2	3
		Unknown material	"Onbekend materiaal" [7]	1	
				Total	25

Table 19: Selective code "Technical" barriers

Selective code “Regulatory”

Selective code	Axial code	Open codes	Interview terms	Occurrence	
				Open code	Axial code
Regulatory	Certification issues	Certification	“Achterhaalde certificeringseisen [4]”, “Certificeringseisen [4][8]”, “Beeld & kwaliteit eisen [1][6]”, “Certificering [4][7]”, “Veiligheidseisen [7]”, “Betoneisen [4]”	9	14
		Asset warranty	“Kwaliteitsgarantie [6][4]”	2	
		Safety issues	“Veiligheid [1]”, “Veiligheidseisen [7]”	2	
		Fire safety requirements	“Brandveiligheidseisen [7]”	1	
	Regulations	Legislation	“Regelgeving [8]”, “Wetgeving [4]”, “Bodemloket [3]”, “Asfaltmolen [3]”	4	5
		Permits	“Vergunningen” [10]	1	
	Guidelines	Guideline Schiphol	“Contract eisen [1]”, “Leidend plan [1]”, “Standaard programma van eisen [8]”, “Te hoge eisen [3]”, “Richtlijnen” [9], “Certificering Schiphol” [9], “Total Cost of Ownership” [10]	7	15
		Guideline Stakeholders	“Discipline eisen” [9], “Certificering Stakeholders” [9]	2	
		Image and quality requirements	“Beeld en kwaliteitseisen” [1] [6] [10], “Esthetische eisen” [1] [10]	5	
		Technical lifespan guidelines	“Total Cost of Ownership” [10], “Technische levensduur eisen” [10]	2	
	Lack of incentives	Wrong government support	“Verkeerd subsidie doel [8] [9]”	2	2
				Total	36

Table 20: Selective code "Regulatory" barriers

Selective code “Organizational”

Selective code	Axial code	Open codes	Interview terms	Occurrence	
				Open code	Axial code
Organizational	Key players	Principal agent problem	“Uitvoerders andere visie” [4], “Niet uitvoeren” [3], “Hiërarchisch probleem” [4], “Bovenste lagen willen [4]”	4	7
		Suppliers	“Lastig verifiëren” [7], “Traditionele leveranciers” [7]	2	
		Inefficient waste registration	“Inefficiënte afvalregistratie” [6]	1	
	CE willingness	Priority	“Voorzichtige doelstellingen” [2]	1	3
		Vision Schiphol	“Visie opdrachtgever” [4]	1	
		Unrealistic ambition	“Onrealistisch ambitie” [6]	1	
	Time	Time	“Duurt langer” [7], “Extra tijd” [6], “Tijdsdruk” [6], Tijdrovend” [7],	4	5
		Transition difficulties	“Transitieperiode” [7]	1	
	Transparency	Transparency Schiphol	“Opdrachtgever niet transparant” [4], “Openheid” [6]	2	2
	Planning	Planning	“Planning” [6] [7], “Planning leidend” [1]	3	3
				Total	20

Table 21: Selective code "Organizational" barriers

Selective code “Social”

Selective code	Axial code	Open codes	Interview terms	Occurrence	
				Open code	Axial code
Social	CE awareness	Lack of expertise	“Onkunde aannemer [6]”, “Onkunde opdrachtgever [7]”, “Uitvoerders zonder CE-expertise [3]”, “Weinig CE-experts [3]”	4	7
		Awareness	“Geen kennis [7] ”, “Weinig besef” [4]	2	
		Abstractness of CE term	“Abstractheid van circulariteit [3]”	1	
	Undesirable human behavior	Hasty decisions	“Overhaaste keuzes [3]”	1	13
		Ignorance & negligence	“Onwetendheid [6] [7]”, “Onkunde [7]”. “Moeite [3]”, “Makkelijke weg ” [6]	5	
		Individual dependent	“Persoonsafhankelijk [1] [3]”	2	
		Conservative attitude	“Traditionele werkwijze” [7], “Altijd zo geweest” [4], “Terughoudendheid [3]”, “Traditionele houding [3] [5]”	5	
	Wrong perceptions	Lack of vision	“Verkeerde visie [4]”	1	7
		Risk averse	“Risicomijdend [4]”, “Voorzichtigheid [3]”, “Geen garantie op succes [7]”	3	
		Trust	“Vertrouwen [2] [3]”, “Vertrouwensband [8]”	3	
	Communication issues	Lack of communication	“Communicatiekloof opdrachtgever- aannemer [2][4][6]”	3	3
				Total	30

Table 22: Selective code "Social" barriers

Selective code “Environmental”

Selective code	Axial code	Open codes	Interview terms	Occurrence	
				Open code	Axial code
Environmental	Transport	Transport	“Meer uitstoot” [3], “Meer transport” [3]	2	2
	Storage	Storage issues	“Beperkte opslag” [1], “Opslagcapaciteit” [7], “Overvloed materiaal” [4]	3	5
		Storage possibilities	“Opslagmogelijkheid materiaal” [7]	1	
		Material destination	“Bestemming van materiaal” [7]	1	
	Pollution	Pollution	“Giftige dampen (recyclen)” [7], “Vrijkomende energie (recyclen)” [7]	2	2
				Total	9

Table 23: Selective code "Environmental" barriers

APPENDIX H: STRATEGY CODING OVERVIEW

The coding overview per selective code is given in this appendix for all strategies. Every selective code, which is equal to a category, consist of multiple axial codes. These axial codes are equal to the strategies within this thesis. The interview terms are directly abstracted from the interview transcripts and are assigned to an open code.

Selective code "Economical"

Selective Code	Axial Code	Open Codes	Interview terms	Occurrence	
				Open code	Axial code
Economical	Financial management	Accept development costs	"Ontwikkelingskosten accepteren" [4]	1	4
		Circularity investments	"Circulariteitsinvesteringen" [5]	1	
		Flexible budget	"Flexibeler budget" [3]	1	
		Non-price request	"Behoefte in plaats van prijs" [4]	1	
	Market innovations	Circular competitiveness	"Circulariteit concurrentie" [4], "Concurrentie op de markt" [4], "Toenemende schaarste" [7]	3	3
		Online marketplace	"Online grondstoffenmarkt" [7]	1	1
				Total	8

Table 24: Selective code "Economical" strategies

Selective code "Technical"

Selective Code	Axial Code	Open Codes	Interview terms	Occurrence	
				Open code	Axial code
Technical	Innovative measurements	Preliminary investigation	"Vooronderzoek" [1] [1] [7]	3	13
		Quality checks	"Asfaltonderzoek" [7] [7], "Meer grondtesten" [7], "Kwaliteit testen" [1], "Grondkwaliteit meten" [1]	5	
		New metrics	"Goed doorrekenen" [3], "BCI" [7], "Circulariteitsmetingen" [2]	3	
		Pilot projects	"Oefen project" [7]	1	
		System engineering	"System engineering" [10]	1	
	Disassembling improvements	Disassembling possibility	"Ontmantelingsmogelijkheid" [7]	1	5
		Disassembling	"Demonteren i.p.v. slopen" [7], "Modulair werken" [7]	2	
		Disassembling plan	"Demontage plan" [7]	1	
		Separating qualities	"Kwaliteiten scheiden" [3]	1	
	Monitoring and inspections	Monitoring and inspections	"Digitaal monitoren" [1], "Monitoren en inspecties" [1]	2	2
	Project design	Innovative design	"Innovatief ontwerp" [7]	1	1
		New building principles	"Vernieuwende bouw principes" [7]	1	
	Materialization	Timely materialization	"Tijdige materialisatie" [7]	1	12
		Online overview	"Online overzicht" [1], "Materialen overzicht" [9], "Materialen bibliotheek" [9], "Materialenpaspoort [9]	4	
		Prescribing less material	"Minder materiaal voorschrijven" [6] [10]	2	
		Standardization	"Materialen standaardiseren" [7], "Standaardisatie" [7] [4]	3	
				Total	33

Table 25: Selective code "Technical" strategies

Selective code “Regulatory”

Selective Code	Axial Code	Open Codes	Interview terms	Occurrence	
				Open code	Axial code
Regulatory	Update requirements	Change quality requirements	“Veranderen kwaliteitseisen” [3]	1	3
		Innovative quality requirements	“Andere kwaliteitsniveau eisen” [7]	1	
		Circular requirements	“Circulaire eisen” [9]	1	
	Stimulate government control	Governmental control	“Overheidssturing” [4]	1	1
				Total	4

Table 26: Selective code "Regulatory" strategies

Selective code “Organizational”

Selective Code	Axial Code	Open Codes	Interview terms	Occurrence	
				Open code	Axial code
Organizational	Risk improvements	Accept risk	“Risico accepteren” [3] [3] [8]	3	6
		Buy off warranty	“Garantie afkopen” [7], “Risico vergoede [7]”	2	
		Compensate risk	“Risico vergoeden” [6]	1	
	Client contractor	Increase partnership	“Samenwerkingsverband” [8], “Goede samenwerking” [2], “Verbeteren aannemer klant relatie” [4]	3	9
		Share insights	“Inzichten delen” [3]	1	
		Suggest improvements	“Verbeteringen voorstellen” [2]	1	
		Vision client	“Visie opdrachtgever” [4]	1	
		Broader involvement	“Meer betrekken bij circulariteit” [3]	1	
		Early involvement	“Aannemer-klant vroeg betrekken” [3]	1	
	Contractual improvements	Best-value procurement	“Best-value procurement” [8]	1	9
		Long-term contract	“Langdurig contract” [3]	1	
		Joint responsibility	“Gezamenlijke verantwoordelijkheid” [7]	1	
		Knowledge at contractor	“Aannemer als expert” [10], “Inspraak aannemer” [1], “Kennis bij aannemer” [8], “Vrijheid aannemer” [10]	4	
		Circularity plans	“Circulariteitsplannen” [4]	1	
		Requirements of suppliers	“Eisen stellen aan leveranciers” [7]	1	
	Stimulate CE operations	Expanding experts	“Vergroten CE experts” [5], “Circulariteitsgroep [9], “Goede systeembeheerder” [9], “Geen technische achtergrond” [10]	4	7
		Stimulate creativity	“Innovatief denken stimuleren” [5]	1	
		Refuse project	“Niet uitvoeren” [3]	1	
		Postponement of maintenance	“Uitstel van onderhoud” [7]	1	
	Enhance planning	Good preparation	“Goede voorbereiding” [7]	1	7
		Extra "CE" time	“Extra tijd voor werknemers” [6]	1	
		Determining circularity in time	“Rol circulariteit afwegen” [7], “CE vroegtijdig betrekken” [9], “Achteraf niet mogelijk” [9]	3	
		Pre-prioritize	“Prioriteiten stellen” [7], “Eisen rangschikken” [9]	2	
				Total	38

Table 27: Selective code "Organizational" strategies

Selective code “Social”

Selective Code	Axial Code	Open Codes	Interview terms	Occurrence	
				Open code	Axial code
Social	Create awareness	Awareness	“Bewustwording” [4], “Zorgen over milieu” [3]	2	10
		Willingness	“Mentaliteitsverandering” [3], “Motivatie” [7], “Welwillendheid” [7]	3	
		Motivate	“Mensen motiveren” [7], “Circulaire technieken demonstreren” [4]	2	
		Introducing initiatives	“Initiatieven introduceren” [8], “Versnelde testen” [9], Innovatieve technieken implementeren [10]	3	
	Communication	Communicate with client	“Dialoog aan gaan” [8], “Gesprek aangaan [3] [7] [7]”. “Gesprek met klant” [6], “Klantgesprek” [2] [2], “Overleg met klant” [2]	8	12
		Convincing client	“Klant overtuigen” [3], “Opdrachtgever overtuigen” [4], “Overtuigen” [3] [9]	4	
	Stimulate trust	Openness	“Mogelijkheden openlaten” [6], “Open staan voor aannemers advies” [4], “Openheid” [6]	3	4
		Trust	“Vertrouwensband” [8]	1	
				Total	26

Table 28: Selective code "Social" strategies

Selective code “Environmental”

“Not applicable in this thesis”

APPENDIX I: RESIDUAL STREAM

To comprehend what the most important materials are that are used for the landside infrastructure at Schiphol, the waste stream of the previous year is set out below. This gives a clear overview of what materials are used and what parts of these materials are reused. In addition, it can be seen what third party waste processors are processing the waste.

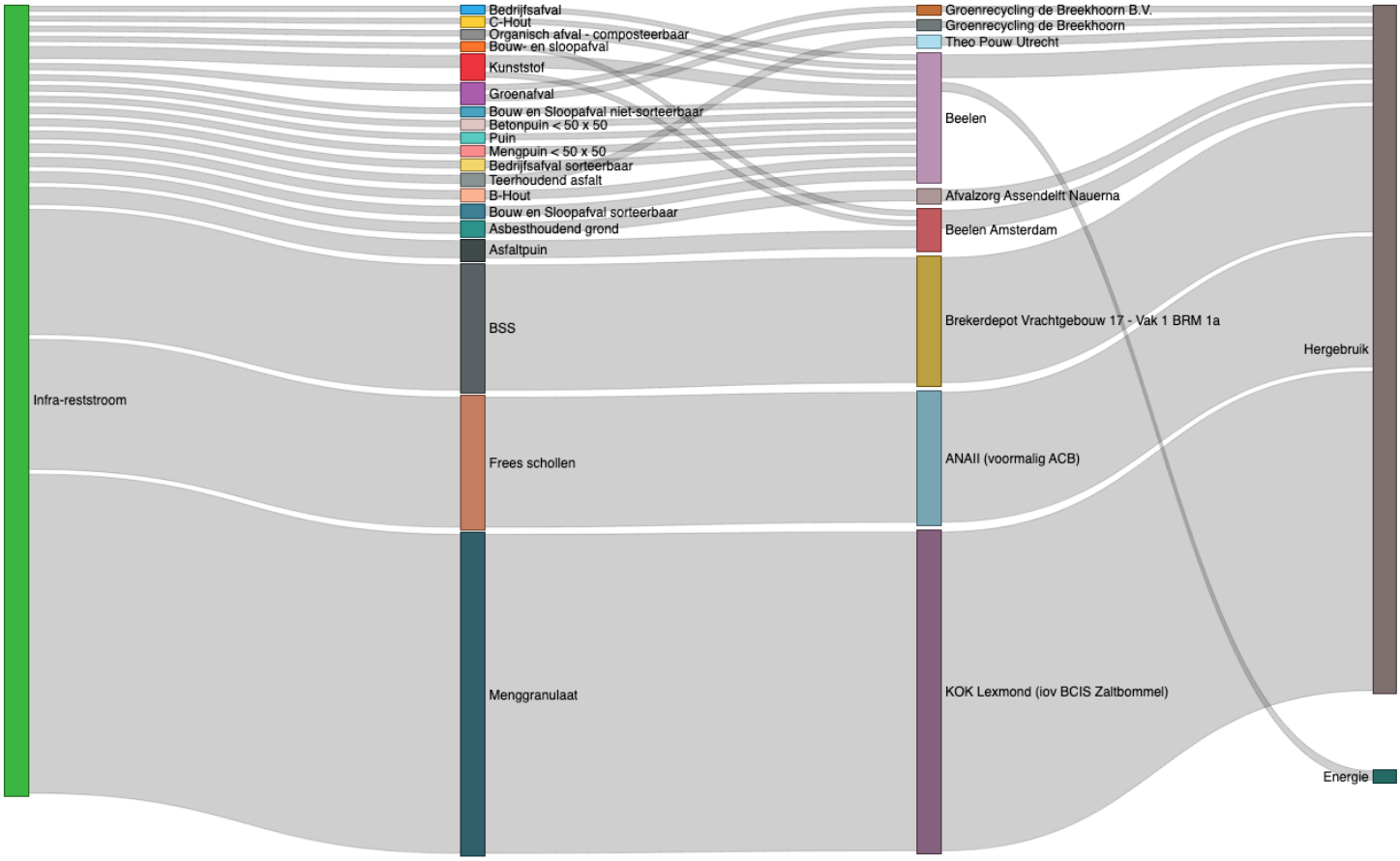

Figure 24: Residual stream landside Schiphol Airport

Waste overview (2021-01 till 2022-01)

In this overview, the residual stream from January 2021 till January 2022 is displayed from the highest to the lowest sum. The amount of waste produced on the landside of Schiphol Airport can be seen in this table.

Material	Process	Sum of the weight (Tonnage)
mixed granulate	Recycled	2273,4
Milling plaice	Recycled	904,62
BSS	Recycled	870
asphalt rubble	Partly recycled	88,52
asphalt rubble	Recycled	88,52
Synthetic	Recycled	51,4
Synthetic	Recycled	48,64
Asbestos soil	Recycled	42,58
Construction and Demolition waste (can be sorted)	Partly recycled	31,92
Company waste	Combustion	29,6528
B-Wood	Recycled	26,48
Infra residual current	Recycled	26,48
Tar-containing asphalt	Recycled	22,7
Sortable industrial waste	Recycled	16,36
Mixed rubble < 50 x 50	Recycled	13,96
green waste	Recycled	11,5
green waste	Recycled	8,64
Concrete rubble < 50 x 50	Recycled	7,2
rubble	Recycled	7,2
Construction and Demolition waste cannot be sorted	Recycled	4,3
green waste	Recycled	2,86
Synthetic	Recycled	2,76
Construction and demolition waste	Recycled	2,26
Organic waste - compostable	Recycled	1,92
C-Wood	Recycled	1,2
Industrial waste	Recycled	0,132

Table 29: Infra Residual streams

APPENDIX J: CE-PRINCIPLES AND STRATEGIES APPLIED AT THE LANDSIDE OF SCHIPHOL AIRPORT

Civil engineering structure "KW41"
The REFUSE was applied. The civil engineering structure "KW41" was nearing the end of its lifespan. The planning contained plans to demolish the civil engineering structure and place new work. However, by continuously monitoring the state of quality and safety, the renewal of this civil engineering structure was postponed.

Figure 25: Civil engineering structure"KW41"

"Rijkerstreek"
For the determination of the MKI and CO2 values, the Rijkerstreek project consists of 35% sand transport and 28% newly delivered asphalt from our asphalt plant in Amsterdam. The focus on reduction has therefore focused on these two. The following optimizations have been made:

- Getting supplies of sand and soil from nearby depots, especially their share in the transport kilometers has a major impact.
- Thinner asphalt construction, which means 37.75 tons less asphalt has been turned
- Addition of 40% PA stone in the top layer. PA-stone is a secondary high-quality crushed stone developed by BAM, which is recovered from old ZOAB pavements. Addition of 70% PR (Partial Recycling) in the intermediate and lower layer.
- Application of Low Energy Asphalt Concrete (LEAB) in the asphalt substrate.
- Applying a circular temporary bridge.

"Terreininrichting LVNL"
For the LVNL site layout, the center of gravity is the layout with element hardening. The tiles as well as the stones and tires are made of concrete and this determines the largest part of the environmental impact. For the site layout, the specific MKI values of the concrete products of our supplier have been determined. This had not been done before and with this insight the greatest profit has been achieved for this project. Supplier-specific data is not always available, so it is unknown whether a supplier scores better or worse than the industry averages with which the comparison is made. For the LVNL site layout, the environmental impact of the concrete products used has been made supplier-specific for the first time.

“Loevesteinse Randweg”
The center of gravity of the Loevesteinse Randweg is entirely on the asphalt and on the surface layer. The measures are therefore also in the asphalt, but there is also a broader look at emission-free equipment. Two main concepts are set out: the application of a durable SMA for the coating and the deployment of the 1st fully electric roller on site. This zero-emission roller has been unique to date and has run its first meters at Schiphol.

Figure 26: SMA with electric roller