Exploring Reverse Logistics of e-waste in Civil Engineering projects

Master Thesis

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Exploring Reverse Logistics of e-waste in Civil Engineering projects

While being relatively established concepts in other industries, Circular Economy (CE) and in particular Reverse Logistics (RL) have been underexposed in the construction industry. This paper aims at finding a way to implement RL of e-waste in practice in the construction industry, which is a gap in prior literature and to answer the question: What are the factors that influence the transitions between the end-of-life strategies of RL of e-waste and how can these be exploited by RWS? Through a literature study, a conceptual framework has been developed and this framework. Interviews have provided data about the three cases of the Velsertunnel, RITS and the Eerste Heinenoordtunnel, which was compared to the data from the literature in order to form an understanding of the differences. Finally, the initial framework has been refined by including factors from practice based on barriers and enablers. The most important factors that are of influence on the RL of e-waste are that the positive attitude towards CE is not widespread within the organisation and implementation is dependant on the project team, that there is a lack of accessible project data about installations and it is not possible to determine the behaviour and durability and that producers need to be contractually responsible for the RL of their own products
Keywords: Circular Economy, Reverse Logistics, construction industry, civil engineering

1. Introduction

The construction industry is characterized by a high intensity use of materials, which leads to a great amount of material and residual flows in the demolition phase, which are mostly heterogenous (Schultmann & Sunke, 2006). The large amounts of material and residual flows from the demolition phase, combined with their heterogeneous character, results in great difficulties when trying to organise the materials to be processed in the right manner. The experienced difficulties lead to a situation where material and residual flows are not reused, repaired, remanufactured or recycled. Because of this, the residual flows are often seen and processed as waste. Although recycling of this waste is considered important in many European countries, a large amount of potentially reusable or recyclable materials are dumped legally or illegally (Ghisselini, et al., 2018). However, in recent years, it has become increasingly important to process the residual flows in a different manner and to seek a different, useful destination for the materials (Agrawal, et al., 2015). The reasons behind this vary from environmental concerns, stricter legislation, and social responsibility to competitive pressure (Govindan & Bouzon, 2018).

A specific area of concern with regard to waste, is electrical installations, also referred to as e-waste. E-waste is the collective noun which includes broken and outdated electric installations and their electronic parts. Because the electronic parts of the installations consist of scarce materials, like metals, the risk arises that these materials become unavailable (PACE, 2019). Furthermore, e-waste is one of the fastest-growing pollution problems worldwide because of the presence of a variety of toxic substances which can contaminate the environment and threaten human health (Kiddee, et al., 2013). This means that it becomes increasingly important to find a way to reuse the scarce materials from e-waste, instead of wasting or dumping them.

Nonetheless, the trend in the Netherlands is that electrotechnical installations, which are acquired through renovations are among the least recycled materials. The reason behind this is that the usual governance method is the linear economy, meaning that materials are salvaged, crafted into products and the products are then used and after use disregarded as waste. As opposed to the linear economy, Circular Economy (CE), which aims at the closure of material loops, where used products are not disregarded as waste, but remain in the material flow (Leising, et al., 2018; Geissdoerfer, et al., 2018). CE is a fairly new concept, that may be acknowledged on a large scale in politics, economy and science, although there is still little knowledge about the application in practice (Leising, et al., 2018). This becomes particularly evident in the construction industry, as it remains unclear how CE can be applied to manage building projects (van den Berg, 2019). Reasons behind this may be that the construction industry is disintegrated and incoherent by nature, which causes knowledge to diffuse slowly (Esa, et al., 2017). Moreover, the focus of the sector has for a long time been on other aspects of sustainability, such as lowering energy consumption and searching for more efficient energy sources (Leising, et al., 2018), instead of material flows (van den Berg, 2019). Furthermore, there is little to no insight in the different material flows and particularly in the adaption of circular economics in practice. One way to enable CE in practice is by enabling Reverse Logistics (RL). As RL promotes recycling, reuse and resource conservation, it addresses various aspects of CE (Sarkis, et al., 2010), making RL a way to implement CE (Geng & Doberstein, 2008). Despite the great interest of the construction industry when it comes to CE, a well-organised RL network is still lacking (Hosseini, et al., 2015). Within the construction industry, RL means the movement of products and materials from (partly) demolished constructions to a new destination to be used (Hosseini, et al., 2015).

As the largest client in the Dutch civil engineering sector, Rijkswaterstaat also faces the challenge of how to move towards a more circular economy. This is especially important because in the coming decades there will be a major renovation task when it comes to civil structures from Rijkswaterstaat across the Netherlands. During these renovations, a great number of installations will be replaced and as a consequence, this means that the old installations need somehow to be taken care of. As the largest client and government body in the civil engineering industry, Rijkswaterstaat has the social responsibility to set an example of how waste can be repurposed in a sustainable way and therefore they have set a strategic goal of being fully circular in 2050 (Teodorascu-Arkesteijn, 2018).

This study will review existing literature on CE and RL, develop an analysis framework and confront this with practice to solve the imbalance that exists in the field of RL, where on the one hand the need for RL is endorsed by multiple sources in literature, but on the other hand little is known when it comes to RL in the practice of the construction industry. Although, RL is highly recognized in the manufacturing industry, adaption of RL within construction is scarce (Hosseini, et al., 2015). For the manufacturing industry several flowcharts and frameworks have been developed for the adaption of RL. However, within the construction industry, there is a shortage of insights as well as specific examples of how to implement and adapt RL. This research will therefore be an addition to existing literature, because it will apply RL to the construction industry and it will provide insight into the different barriers and enablers experienced by the construction industry regarding the RL of e-waste. Moreover, the research will relate to the different barriers and enablers to the R-principles. The R-principles are a practical way to represent RL, and hence RL is often represented within scientific literature as a combination of the terms *Reduce*, *Reuse* and *Recycle* (Kircherr, et al., 2017). The 3R-principle of *Reduce, Reuse* and *Recycle,* is a way to apply RL in practice (Huang, et al., 2018) and is based on the *Ladder van Lansink,* which has been developed by the Dutch government in 1979 (Potting, et al., 2016).

The goal of this study is therefore to answer the question: What are the factors that influence the transitions between the end-of-life strategies of RL of e-waste and how can these be exploited by RWS? This will be done by confronting existing knowledge from literature to civil engineering cases and to suggest possible directions for implementation in practice and future research possibilities.

2. Research method

For this research, a case study methodology has been chosen. The case study will be aimed at understanding the dynamics of certain situations, which means that the study will aim at understanding a decision or a set of decisions (Yin, 2014). Besides this, the case study will comprise of a small amount of research units and it will be aimed at qualitative data and research methods (Verschuren & Doorewaard, 2005). First, the preparation for the research will be presented, which includes the research questions and explains the choice for the three cases: the Velsertunnel, RITS project and Eerste Heinenoord Tunnel. This is followed by an elaboration on the data collection and analysis methods.

2.1. *Research questions*

What are the factors that influence the transitions between the end-of-life strategies of RL of e-waste and how can these be exploited by RWS?

To elaborate on the main research question, the following four sub-questions need to be answered:

(1) How is e-waste currently handled at RWS and what are the barriers and enablers that RWS faces?

(2) What does existing literature state about RL of e-waste and the barriers and enablers

for this in civil engineering?

(3) How does the situation of RWS compare to the literature and how can this be explained?

(4) Which factors influence the choice for the end-of-life process and how do these relate to RWS?

To answer these questions, three cases are researched. The cases are selected based on two criteria. The first criterion was that the case had to have some form of CE and RL of specifically e-waste. The reason behind this is that e-waste poses different challenges in the RL process than materials such as concrete and steel. Furthermore, the second criterion was that the cases had to fit within the area of interest of the problem owner. The problem owner is interested in specifically road infrastructure projects, because of the renovation plans for these assets in the near future. Because of these criteria, the choice of projects was limited and therefore three cases have been assigned to investigate and input from the experts will serve for validation of the results. In an ideal situation, more projects would be available, and cases could be selected based on their type, meaning for example only tunnels or bridges would be taken into consideration, which would become a third criterion. Furthermore, if there were more projects to choose from, the stage of the project would become a fourth criterion. This would mean that projects from different stages could be researched in order to determine what the impact is of decisions on RL in each stage of a project.

The first case that has been researched, is the Velsertunnel. The Velsertunnel is a bank connection that runs under the North Sea Channel near Velsen and through the tunnel runs the highway A22, with a total of four lanes. Through the Velsertunnel, a total of 20,7 million vehicles pass per year, making the tunnel an important thoroughfare and also important in terms of the case selection criteria. Between the spring of 2016 and January 2017, the tunnel was closed for renovation and a new ventilation system, fire resistant layer and operating system were installed. During this renovation, CE was an important project goal and more importantly, during the renovation, a great number of installations from this tunnel were reused in the same tunnel. Therefore, the case of the Velsertunnel meets the first criterion of the case selection criteria. However, this project faced several impediments as a result of the reuse of e-waste, therefore this case served as a learning opportunity where the 'lessons learned' from reuse of e-waste were looked into.

The second case that was researched, is the RITS project. RITS stands for Realisationbureau Intelligent Transport Systems and is a combination of many small projects where the digital transport management and intelligent transport systems on the Dutch national roads were renovated. This includes cameras, traffic control installations, traffic signalling and roadside systems. Within the RITS project there have been several examples of successful reuse of installations and/or components, meaning this case meets the two main criteria set earlier. The RITS project was therefore used to evaluate among others the positive 'lessons learned'.

Finally, the case of the Eerste Heinenoord Tunnel has been included into the research. This project is now in the phase of establishing the contract between client and contractor, which has to be ready in October 2019. Because of this, it gives insights into the process of how a contract is drawn up and why certain choices concerning CE and RL are made.

2.2. *Data collection*

For this research, data collection consists of four data sources. Firstly, a literature study has been performed. This systematic review provides the foundation for enhancing the knowledge of the research topic by reviewing the previous studies (Esa, et al., 2017). The search for this literature study has been performed during spring 2019 in Scopus database, Google and Google Scholar. The study was conducted in two stages. In the first stage, the goal was to improve the understanding of the topic and to set the boundaries of the research. Within this part of the search, the first three constructs from Table 1 were used. In the second stage of the study, the goal was to investigate the barriers and enablers for the implementation of CE and RL in order to form an understanding of the reasons behind the choice for the adaption of the different end-of-life processes. Here the fourth and fifth constructs were added to the search. The selected articles belong to the leading publishers Elsevier, Emerald, Springer, Taylor & Francis and Wiley. A screening of the literature has been performed directly during the search by reading the abstracts and discarding the documents where CE or RL have not been the main topic. A total of 45 articles were collected initially based on reading the title, abstract, introduction and conclusion. The relevance of the papers was determined by the fact that they mentioned either CE or RL in relation to the construction industry and barriers or enablers. Moreover, the field of search was limited to papers published in English or Dutch from 2000 to 2019. This number was brought down to 24 articles which were used for the building of the framework based on reading the papers and disregarding the ones that were too general or turned out to be mainly about the manufacturing industry.

Table 1: Keyword search

Constructs	Related terms	Broader terms	Narrower terms
Circular Economy	Closed loop economy, zero waste economy	Performance economy, cradle to cradle, industrial symbiosis	Reverse logistics
Reverse Logistics	Backward supply chain, recovery logistics	Green logistics, recycling, sustainable supply chain, green	R-principles, waste hierarchy

		supply chain management	
Construction industry	AEC sector, building industry/sector, construction industry/sector	Civil engineering	Dutch construction industry
Barriers	Hurdles, obstacles	Impediments, problems	Limitations
Enablers	Facilitators	Supporters, promoters	Solutions

Furthermore, to answer the sub-questions, two different sources of information have been used. The first source was archive files, which include project documentation, documentation of other researches and policy documents. These documents were provided by the problem-owner and were read to prepare for the interviews. The second and main source were semi-structured interviews. Four stakeholders were interviewed per case, resulting in a total of 12 interviews. Candidates represented actors involved in the selected cases covering the entire supply chain, consisting of the client, contractors and suppliers/subcontractors of each case. The technical managers provided information about material flows, the specifications of the projects and why certain choices concerning CE were made. The contract managers were included in the interviews to elaborate on the relationship between the client and the contractors as well as to provide information about further external interview candidates. The advisors of the three cases provided background information about sustainability and CE and pinpointed the exact moments where and why it went wrong or right. Moreover, they gave information about what the process should look like and how this ideal situation could be reached. Finally, the contractors and the suppliers were included to provide insights on their relationship with the client and the material flows from their perspective. During the interviews, a choice was made to interview up to three candidates at the same time, meaning a conversation between the candidates was made possible. This approach was chosen in order to simulate a project team meeting and to be able to observe the dynamics concerning RL of such a team. Moreover, by having more respondents answering at the same time, they could ask each other questions and provide new insights. An overview of all candidates and the organisations they work for, can be found in Table 2. The interview questions were semi-structured and can be found in Appendix 1.

Table 2: Interview candidates

	Case 1: Velsertunnel	**Case 2: RITS**	**Case 3: Eerste Heinenoord Tunnel**
Interview 1	Technical manager (RWS)	Contract manager (RWS)	Technical manager (RWS)
Interview 2	Contract manager (RWS)	Advisor sustainability (RWS)	Contract manager (RWS)
Interview 3	Advisor sustainability (RWS)	Contractor (Compass)	Advisor sustainability (RWS)
Interview 4	Advisor CE (COB)	Supplier (Vialis)	Advisor CE (RWS)

2.3. *Data analysis*

Following the data collection, the data analysis will depend on the data source. As there are two main sources of data, literature papers and interviews, the data from both sources has been analysed separately first in order to be able to compare the data afterwards. During the analysis, input from the researcher was used as a benchmark to determine which data needed to be taken into consideration.

The literature review was carried out first and comprises of two different stages of coding. The coding was done in order to be able to break down the text, understand it and to compare and group the collected data. First the papers were used to create an inventory of the occurring barriers and enablers with regard to the implementation of RL. The barriers and enablers found were then first open coded, providing a code for each set of barriers and enablers. This was followed by axial coding in which the previously formed open codes were grouped into larger sets in order to form categories for the barriers and enablers. This coding can be found in Appendix 2.

Secondly, the analysis of the interview data was performed. During interviews, the conversation was recorded and notes about the most important subjects, matching the interview questions, were taken. After each interview, the conversation was transcribed. Based on these transcriptions, answers on the interview questions were formulated and these documents were sent back to the respondents for validation. After minor alterations, the interviews were coded following the same principle as the literature review, open and axial coding of the barriers and enablers. This coding can be found in Appendix 4.

Hereafter the barriers and enablers from the literature were compared to the information from the interviews by means of pattern matching. The similarities and differences from the literature and the interviews were noted in order to explain them. Furthermore, based on the information from the interviews, the link between the barriers and enablers and the end-of-life processes that was made based on the literature has been revised. Hereafter, the data was read again to be able to sort the barriers and enablers to the different end-of-life stages. Based on this sorting, a list of factors influencing the different end-of-life stages could be comprised. After this, the data was read once again in order to determine the importance of the different factors and to incorporate them into the framework.

3. Theoretical framework

To be able to carry out the research, firstly the relevant concepts and definitions will be explained. Within this theoretical framework, the concepts of Circular Economy and Reverse Logistics will be further illustrated. Moreover, insights about the barriers and enablers for implementation of RL will be elaborated on.

3.1. *Circular Economy (CE) and Reverse Logistics (RL)*

CE has multiple approaches and therefore multiple definitions within scientific literature. It is defined as a concept depicting a system (Genovese, et al., 2017; Leising, et al., 2018). The system is defined as an economic and industrial system where material loops are closed and the preservation of value is essential (Leising, et al., 2018). More specifically, this means that the CE system aims for the prevention of waste and for the preservation of the inherent value of products for as long as possible (Geissdoerfer, et al., 2018). Therefore, the goal of CE within this research is to minimize the consumption of raw materials through the conservation of materials within the system. Thus, the negative effects on the climate can be mitigated without jeopardising the economic growth and prosperity.

Moreover, in a more practical way, CE is often represented within scientific literature as a combination of the terms *Reduce*, *Reuse* and *Recycle* (Kircherr, et al., 2017). The 3R-principle of *Reduce, Reuse* and *Recycle,* is a way to apply CE in practice (Huang, et al., 2018) and is based on the *Ladder van Lansink,* which has been developed by the Dutch government in 1979 (Potting, et al., 2016). In recent years, the R-principles have been expanded by the Dutch government in response to new technologies and innovative solutions, leading to a new ladder including ten R-principles: *Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle,* and *Recover.* The first three principles, *Refuse, Rethink,* and *Reduce* are part of the design phase in which the designer is made to reflect on refusing products, rethinking their purpose or reducing materials. Furthermore, the principles of *Reuse, Repair, Refurbish, Remanufacture,* and *Repurpose* are relevant in the case of a renovation, maintenance or dismantling. Finally, *Recycle* and *Recover* are last resorts in order to save materials from the landfill.

Therefore, the core idea of CE are material loops, which assume that products can be cascaded and reused, redistributed, remanufactured, refurbished or recycled, therefore requiring collection from the end-user and Reverse Logistics (Lewandowski, 2016). RL promotes reuse, recycling, and resource conservation and in this manner, it addresses various aspects of social sustainability and CE (Sarkis, et al., 2010), making RL part of CE (Geng & Doberstein, 2008). In most scientific literature, RL is seen as a process and is defined as a series of activities that are needed to collect the used product with the goal of reusing, repairing, recycling or processing (Agrawal, et al., 2015). Therefore, the RL-process includes the planning, implementation and transportation of a cost and time efficient cycle from raw materials to finished products and back during the entire lifecycle (Govindan & Bouzon, 2018; Hosseini, et al., 2015). The purpose of this is to preserve the products from the landfill and to preserve their value (Govindan & Bouzon, 2018).

Specifically, for the construction industry, RL means the movement of products and materials from (partly) demolished constructions to a new destination to be implemented (Hosseini, et al., 2015). This does not necessarily have to mean that the products or materials will remain within the construction industry, after all it is possible to move the products to secondary markets or to other industries. However, this does not imply that the products or materials have left the RL-boundaries or that they are not circular anymore (Hosseini, et al., 2015).

3.2. *RL framework*

In order to illustrate RL and material flows, the literature provides different flowcharts for the flow of materials, both forward and reverse. The majority of these flowcharts have been developed for the manufacturing industry, however they are to a lesser extent applicable in the construction industry.

Within this research, the chart of Agrawal, et al. (2015) has been used as a starting point for the theoretical framework. The choice has been made to use this framework because of its direct link with the end-of-life processes and because of its straightforwardness.

3.2.1. *Framework alteration*

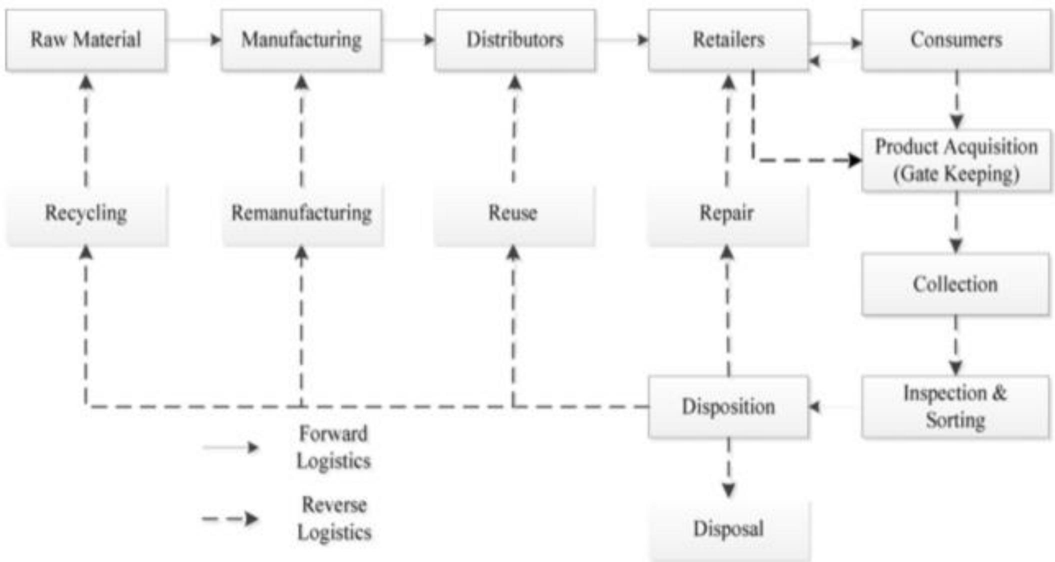

Figure 1: Framework of Agrawal, et al. (2015)

Although Agrawal, et al. (2015) have developed their framework for the manufacturing industry, it can be used for the construction industry as well with minor alterations. Within the flowchart of Agrawal, et al. (2015), represented in Figure 1, five main processes from the linear economy, or the forward logistics can be distinguished. These are raw material, manufacturing, distributors, retailers and consumers. These more or less correspond with the construction industry, as this also starts with the raw material extraction, the production (instead of manufacturing), and distributions by the suppliers. However, within the construction industry there are no retailers, which has to be replaced by contractors who do the assembly on site of products. The consumers of the construction industry can be defined as the client who is in charge of the operation and maintenance of the product. A difference in this is that there is often a limited number of clients compared to consumer products. Finally, another process that has to be added for the construction industry is deconstruction on site, as the products from this industry first need to be deconstructed on site by the contractor in order to retrieve the products and materials for the RL flow.

When it comes to Reverse Logistics, Agrawal, et al. (2015) describe four processes from the perspective of the consumer industry; product acquisition, product collection, product inspection and sorting and product disposition. Although this order is common in the manufacturing industry, within the construction industry the

inspection and sorting of materials and products comes before the collection, as the materials need to be extracted from building sites first (Schultmann & Sunke, 2006).
After the product disposition, the choice has to be made as to how the product will be processed further. In the framework of Agrawal, et al. (2015), this choice can lead to repairing, after which the product will go to the retailers again, or to reusing, after which the product will be sold as second hand. Moreover, the choice can be made to remanufacture the product, after which it is sold to the producer at a lower cost and recycling means that the product will be sold based on weight. Finally, the product can be disposed of, which means it will be taken out of the material loops. For the construction industry this process needs minor alterations as well, as here the contractor can reuse the products or materials on site directly and the repairing is done by the suppliers.

Therefore, the alterations that have to be made in order to adapt the framework to the construction industry, is that the retailers are replaced with contractors and the consumer is replaced with the client. Furthermore, a sixth process of deconstruction on site is added and the processes of sorting and collecting of materials are swapped. With these alterations, the framework in Figure 2 has been developed. Within this framework, the most important aspects are how to move from a lower R-principle to a higher one. Each R-principle has its barriers, enablers and factors that obstruct or allow it to be carried out. Logically, Reuse should have the greatest number of barriers, whereas Recycling is almost always carried out. Therefore, Recycling is seen as the lowest possible outcome within the flowchart, together with landfill, and Reuse will be the highest achievable goal. This framework will serve to illustrate RL to the interviewees during the interviews and to guide them in the process of answering detailed questions.

3.3. *Barriers for RL*

Although environmental concerns, stricter legislation, social responsibility and competitive pressure (Govindan & Bouzon, 2018) have made it increasingly important to process residual flows according to CE principles (Agrawal, et al., 2015), the actual implementation of RL lags behind at this point in time. Existing literature has started to problematise the transition towards circularity in construction and attributes this to numerous barriers concerning CE and RL (van den Berg, 2019). A mix of these barriers has been categorised by the researcher into five categories, namely legislation, attitude, risk, responsibility and technical.

Within the 'legislation' category, two barriers have been classified. Firstly, literature states that there is a lack of supportive legislation and regulations for the implementation of RL (Hosseini, et al., 2015; Govindan & Bouzon, 2018). More specifically this means that the existing laws are not supportive of RL and not motivating the implementation, resulting in the implementation of RL being an added difficulty for organisations (Govindan & Hasanagic, 2018). Furthermore, some authors take the extent of legislation further, arguing that existing laws and regulations even prevent RL (Mahpour, 2018; Schamne & Nagalli, 2016; Chinda, 2017). They argue that the current legislation is often too strict concerning safety, which renders the use of second-hand materials or products nearly impossible.

The second category is the 'attitude' category. Within this category, three barriers have been classified. Firstly, many authors mention other goals and ambitions, such as the management of cost and time, having a higher priority than RL (Mahpour, 2018; Hosseini, et al., 2015; Govindan & Bouzon, 2018; Govindan & Hasanagic, 2018). Because project teams perceive RL as having a lower priority than other requirements it becomes a complicating factor rather than added value to the project. The second barrier that is added within the 'attitude' category is that users often have an outspoken preference for new rather than second hand products or materials (Mahpour, 2018; Hosseini, et al., 2015; Govindan & Bouzon, 2018; Hosseini, et al., 2014; Govindan

& Hasanagic, 2018; Chinda, 2017). Second hand products or materials often have a stigma of being of lower quality than new ones and users want the best there is. Therefore, second hand products and materials are often disregarded, and a specific request is made for new products or materials within projects. This flawed consumer perception and attitude towards RL makes it more difficult to implement it. The final barrier from the 'attitude' category is that the reputation of RL is working against itself. Currently, the less environmentally friendly options of RL, such as recycling, are more appealing than the more environmentally friendly alternatives such as reuse (Hosseini, et al., 2014; Mahpour, 2018; Chinda, 2017). In the past, recycling was emphasized a great deal as being the ultimate environmentally friendly option and it is still perceived as such. Moreover, recycling does not have high initial costs as, for example, reuse does, while it does generate a profit for the owner of the materials that are recycled.

Furthermore, within the third category, barriers have been sorted which have been identified as a risk increase for organisations which implement RL. The 'risk' category includes a total of three barriers. Firstly, numerous authors have argued that the quality from second-hand materials is indeed doubtful (Hosseini, et al., 2015; Govindan & Bouzon, 2018; Hosseini, et al., 2014; Govindan & Hasanagic, 2018). It is not always clear what the quality is of second-hand materials or products because there is a lack of paperwork and the quality cannot always be perceived from looking at the outside. Because of this, the quality can vary among the same sorts of products or materials and therefore pose a risk for the user. Furthermore, another barrier from the 'risk' category is company oriented and this includes that there are not enough incentives by the government to make RL appealing for companies (Mahpour, 2018; Govindan & Bouzon, 2018; Hosseini, et al., 2014; Schamne & Nagalli, 2016). RL demand for an initial investment and have high initial costs, therefore without incentives from the government to support companies in taking this risk, RL will not be appealing to the vast majority. Finally, the last barrier is that it is unclear in which direction CE will develop (Govindan & Hasanagic, 2018; Mahpour, 2018). The literature provides a great number of paths and definitions of CE and the industry is insecure about the outcomes of this. It poses a high risk to invest in something without knowing whether it will be valued later on.

The next category, 'responsibility', includes three different barriers. The first 'responsibility' barrier is that there are ownership issues when it comes to reuse (Mahpour, 2018). Often it is the case that the ownership of waste is not specified correctly and when this waste is processed according to RL, it retains value and different parties want to participate in collecting the value. Furthermore, another 'responsibility' barrier is that organisations do not take their social responsibility and lack support for RL (Mahpour, 2018; Govindan & Bouzon, 2018; Chinda, 2017). They do not have clearly defined goals and visions to move to CE and the government does not provide enough support for this transition. On top of this, the industry does not take their responsibility either, which is the third barrier (Mahpour, 2018; Adams, et al., 2017; Hosseini, et al., 2014; Schamne & Nagalli, 2016; Govindan & Bouzon, 2018; Hosseini, et al., 2015). The reason behind this is that there is a lack of awareness of RL across the construction industry and this results in a lack of producer-based responsibility. The benefits are not stressed enough and therefore the interest in RL is falling behind.

The final category is the 'technical' category, in which a total of two barriers have been classified. Firstly, the supporting facilities for RL are not developed enough (Huang, et al., 2018; Mahpour 2018; Hosseini, et al., 2015). Because the market for products from RL is underdeveloped, the promoting of the acceptance and use of second-hand materials or products is not possible (Huang, et al., 2018). Furthermore, the technologies for effective dismantling, collection, sorting and transporting of waste are not developed (Mahpour, 2018; Adams, et al., 2017; Huang, et al., 2018). Besides this there is need for areas to sort and store materials as well as enough skilled manpower to do so (Hosseini, et al., 2015; Adams, et al., 2017). The second barrier from the 'technical' category includes the lack of standards imposed on second-hand products and materials (Huang, et al., 2018). As there are no proper guidelines to classify waste, there is limited potential for the implementation of RL.

In the below Table (Table 3) the barriers can be found summarized per category. A complete overview of the barriers and their mentioning in the literature can be found in Appendix 3.

Table 3: Barriers from the literature

Category	Barriers	Source
Legislation	There is a lack of support from legislations and regulations for CE/RL.	Hosseini, et al., 2015; Govindan & Bouzon, 2018; Govindan & Hasanagic, 2018
	Legislations and regulations prevent CE/RL.	Mahpour, 2018; Schamne & Nagalli, 2016; Chinda, 2017
Attitude	CE/RL is perceived as a lower priority than other requirements and becomes a complicating factor.	Mahpour, 2018; Hosseini, et al., 2015; Govindan & Bouzon, 2018; Govindan & Hasanagic, 2018
	Users often have an outspoken preference for new rather than second hand products or materials.	Mahpour, 2018; Hosseini, et al., 2015; Govindan & Bouzon, 2018; Hosseini, et al., 2014; Govindan & Hasanagic, 2018; Chinda, 2017
	The reputation of RL is working against itself.	Hosseini, et al., 2015; Mahpour, 2018; Chinda, 2017
Risk	The quality from second-hand products or materials is doubtful.	Hosseini, et al., 2015; Govindan & Bouzon, 2018; Hosseini, et al., 2014; Govindan & Hasanagic, 2018
	There are not enough incentives by the government to make RL appealing for companies.	Mahpour, 2018; Adams, et al., 2017; Govindan & Bouzon, 2018; Govindan & Bouzon, 2018; Hosseini, et al., 2014; Schamne & Nagalli, 2016
	It is unclear in which direction CE will develop.	Govindan & Hasanagic, 2018; Mahpour, 2018
Responsibility	There are ownership issues with second-hand materials and products.	Mahpour, 2018
	Organisations do not take their social responsibility and lack support for RL.	Mahpour, 2018; Govindan & Bouzon, 2018; Chinda, 2017

	The industry does not take their responsibility.	Mahpour, 2018; Adams, et al., 2017; Hosseini, et al., 2014; Schamne & Nagalli, 2016; Govindan & Bouzon, 2018; Hosseini, et al., 2015
Technical	The supporting facilities for CE/RL are not developed enough.	Huang, et al., 2018; Mahpour, 2018; Hosseini, et al., 2015; Adams, et al., 2017
	There is a lack of standards imposed on second-hand products and materials.	Huang, et al., 2018; Adams, et al., 2017

3.4. *Enablers of RL*

Despite the above-mentioned barriers, the literature provides enablers for RL as well. An enabler is defined in this research as a counter to the barrier and serves as an inspiration for solutions and incentives. Therefore, in line with the barriers, the researcher has categorised the enablers into five categories as well, namely legislation, attitude, risk, responsibility and technical enablers.

An enabler for the 'legislation' category is that new policies and legislation should be established to support RL (Mahpour, 2018). These new laws should be established according to the goals of CE.

For the 'attitude' category, the first enabler proposed by the literature is to teach the employees, and most importantly those who make the decisions, about the benefits of RL (Mahpour, 2018). This way they will be more inclined to implement RL and support it. Furthermore, another enabler is that the more environmentally friendly options such as reuse of materials should be made more appealing by making other alternatives such as recycling and landfill less appealing (Hosseini, et al., 2015; Mahpour, 2018). This could be done by increasing the cost of landfill or by promoting the benefits of reuse over recycling.

Furthermore, the 'risk' category includes two different enablers. Firstly, organisations and the government should focus on making RL more appealing from the outset. This support mechanism could be executed by providing the right budget, therefore making a larger budget available, or by incentives were companies receive discounts or are more likely to be selected when implementing RL (Huang, et al., 2018; Mahpour, 2018; Hosseini, et al., 2015). Furthermore, there is a great need for clear goals for the transition to a circular economy as opposed to the linear one. Companies need the certainty that their investments will pay off eventually, before they decide that they want to invest. Therefore, goals to move towards CE should be established nationally, in order to pave the way to the transition (Mahpour, 2018).

Moreover, within the 'responsibility' category, the enabler proposed by the literature is that the responsibility for RL should be for the supplier or manufacturer, as they are the ones that know their products the best (Huang, et al., 2018; Mahpour, 2018). Establishing this beforehand can stimulate RL, as all parties are well informed about the process of RL in projects and can anticipate on this when constructing their planning and budget. Involving the suppliers and manufacturers in the RL process and ultimately making them fully responsible for their products could be done by making agreements beforehand and specifying it in contracts.

Finally, the 'technical' enablers that are proposed by the literature include that there should be more research executed (and funded) in order to develop better technologies (Huang, et al., 2018; Mahpour, 2018). Technologies that classify and sort construction and demolition waste and facilitate quality control of recycled materials should be especially promoted (Huang, et al., 2018). Moreover, more standards should be developed in order to make the process of sorting, storing and classifying smoother and easier.

In the below Table (Table 4) the enablers can be found summarized per category. A complete overview of the enablers and their mentioning in the literature can be found in Appendix 5.

Table 4: Enablers from the literature

Category	Enablers	Source
Legislation	Establish new policies and legislation to support RL.	Mahpour, 2018
Attitude	Teach the employees, and most importantly those who make the decisions, about the benefits of RL.	Mahpour, 2018
	Make the more environmentally friendly options such as reuse of materials more appealing by making other alternatives such as recycling and landfill less appealing.	Mahpour, 2018; Hosseini, et al., 2015
Risk	Focus as organisations and the government on making RL more appealing by providing the right budget and incentives as a support mechanism.	Hosseini, et al., 2015; Mahpour, 2018; Huang, et al., 2018
	Establish clear goals to move towards CE nationally, in order to pave the way to the transition.	Mahpour, 2018
Responsibility	Give the responsibility for RL to the supplier or manufacturer, as they are the ones that know their products the best.	Mahpour, 2018; Huang, et al., 2018
Technical	Execute (and fund) more research in order to develop better technologies.	Mahpour, 2018; Huang, et al., 2018
	Develop more standards in order to make the process of sorting, storing and classifying smoother and easier.	Hosseini, et al., 2015; Mahpour, 2018

3.5. *Framework transitions*

Below the barriers and enablers are described for each transition, these barriers and enablers have been translated into aiding and complicating factors which can be found listed in Table 5. The factors have been listed according to their relative importance per transition, which is based on an a priori assumption of the researcher. On the one hand, factors can be binary, making them conditions that can either be fulfilled or not. When the condition is not fulfilled, the transition is held back until the condition becomes fulfilled. On the other hand factors can be non-binary, and these factors can extend the transition to more products and materials or accelerate the transitions between the end-of-life processes.

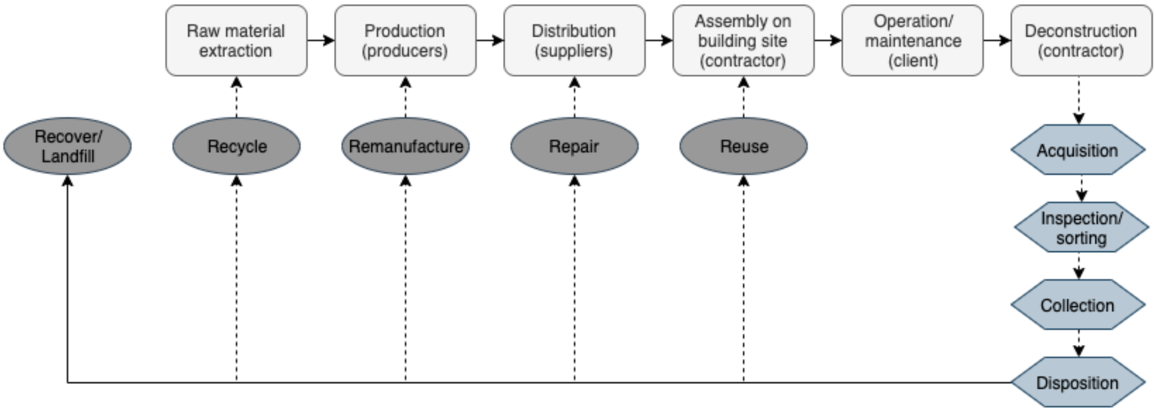

Figure 2: Literature framework

3.5.1. *From landfill to Recycle*

As mentioned above, the factors influencing recycling are very limited, as there are just two barriers from the 'attitude' and 'risk' categories. These include the user preference, as users often might think that recycled materials are of a lower quality than new ones, which causes them to prefer new materials over recycled materials (Hosseini, et al., 2015; Govindan & Bouzon, 2018; Hosseini, et al., 2014; Govindan & Hasanagic, 2018; Chinda, 2017). Moreover, in line with this 'attitude' barrier, a 'risk' barrier for recycling is indeed that the quality of recycled materials is not as easy guaranteeable as that of new materials and the quality is furthermore not consistent and dependent on a great number of factors that cannot be easily influenced by users (Hosseini, et al., 2015; Govindan & Bouzon, 2018; Govindan & Hasanagic, 2018).

On the other hand, Recycle does not have many enablers either, because it is sufficient that recycling is financially more attractive than landfill, as materials have value (Hosseini, et al., 2014; Chinda, 2017).

3.5.2. *From Recycle to Remanufacture*

To transition from Recycle to Remanufacture, there are more barriers than for the transition from landfill to Recycle, namely five. These belong to the 'risk', 'responsibility' and 'technical' categories respectively. Firstly, a lack of supporting facilities, such as recovery facilities, infrastructure, technical facilities and developed markets can hold back the transition to Remanufacture (Huang, et al., 2018; Hosseini, et al., 2015). Furthermore, another barrier for Remanufacture is that the vision of CE is unclear, and the aftermaths of a transition are not researched well enough (Govindan & Bouzon, 2018; Huang, et al., 2015). When it comes to 'responsibility', two barriers arise as well, including ownership issues of salvaged items (Mahpour, 2018) and the lack of awareness within the industry that causes producers to not take their responsibility as they simply do not know yet how to take back their products (Mahpour, 2018; Adams, et al., 2017; Hosseini, et al., 2014; Schamne & Nagalli, 2016; Govindan & Bouzon, 2018; Hosseini, et al., 2015). Finally, a 'technical' barrier is that the technologies for effective collection and sorting are underdeveloped, which causes a lack of standards imposed on the remanufactured items and no proper guidelines (Huang, et al., 2018; Mahpour, 2018; Adams, et al., 2017).

Enablers for remanufacturing can be found among the 'attitude', 'risk', 'responsibility' and 'technical' categories. Firstly, the attitude of employees and in particular decision-makers can stimulate remanufacturing (Mahpour, 2018). Furthermore, the risk can be lowered by providing incentives of financial or regulatory nature for the use of Remanufacture in projects (Huang, et al., 2018; Mahpour, 2018; Hosseini, et al., 2015) and by national action plans designed to clarify goals, targets and visions to move to a circular economy (Mahpour, 2018). Moreover, producers can be made contractually responsible for treating wastes of their own products (Mahpour, 2018). Finally, more research into technologies for classifying and sorting of materials and the facilitating of quality control can aid in reaching more standardised processes (Huang, et al., 2018; Mahpour, 2018; Hosseini, et al., 2015).

3.5.3. *From Remanufacture to Repair*

When moving from Remanufacture to Repair, two added barriers arise. These include existing laws, legislations and regulations not supporting the better end-of-life processes such as Repair and Reuse because of the extreme and too strict safety regulations that have to be implemented (Mahpour, 2018; Hosseini, et al., 2015; Govindan & Bouzon, 2018; Govindan & Hasanagic, 2018; Schamne & Nagalli, 2016; Chinda, 2017). Furthermore, the 'attitude' barrier includes that the better end-of-life processes are mostly seen as a complicating factor and are often conflicting with project goals. This causes repairing to be a low priority in projects and to be left out in order to reach the higher priority goals such as saving time and money (Mahpour, 2018; Hosseini, et al., 2015; Govindan & Bouzon, 2018; Govindan & Hasanagic, 2018).

Moreover, the 'legislation' category offers an enabler for the transition from Remanufacture to Repair as well. This includes the enactment of policies and legislations which induce Repair according to the CE and RL goals (Mahpour, 2018).

3.5.4. *From Repair to Reuse*

Finally, whether Reuse is reached or not, depends on two barriers from the 'risk' and 'responsibility' categories. Firstly, there are not enough financial and regulatory incentives to motivate projects and customers and to make Reuse an appealing alternative (Mahpour, 2018; Adams, et al., 2017; Govindan & Bouzon, 2018, Hosseini, et al., 2014; Schamne & Nagalli, 2016). In line with this barrier, is the 'responsibility' barrier, which states that organisations do not support Reuse enough, resulting in a lack of clearly defined goals, targets and visions concerning Reuse and an overall poor coordination of the process (Mahpour, 2018; Govindan & Bouzon, 2018; Chinda, 2017).

On the other hand, an enabler from the 'risk' category for Reuse is that other alternatives can be made less appealing than Reuse by making them cost more and promote Reuse (Hosseini, et al., 2015; Mahpour, 2018).

Table 5: Conditions from literature

Factor	Recycle	Re-manufacture	Repair	Reuse
Users have to accept second-hand materials	✓	✓	✓	✓
The quality of the materials has to be guaranteed	✓	✓	✓	✓
R-principle has to be financially more attractive than landfill	✓	✓	✓	✓
Producers need to be made contractually responsible for their own products		✓	✓	✓
Supporting facilities have to be in place		✓	✓	✓
Attitudes of employees and decision-makers need to support RL		✓	✓	✓
Technologies have to be developed further		✓	✓	✓
Vision of CE has to be clear and aftermaths have to be thoroughly researched		✓	✓	✓
Ownership issues have to be sorted		✓	✓	✓
Incentives have to be in place		✓	✓	✓
Industry has to be aware of the possibilities		✓	✓	✓
Existing laws have to be altered in order to nullify the restrictions that are currently in the way of Repair/Reuse			✓	✓
The project priorities need to be altered to facilitate sustainability and ultimately RL as a higher priority			✓	✓
New laws and legislations need to be implemented which stimulate RL			✓	✓
Financial and regulatory incentives need to be provided specifically for Reuse				✓
Other alternatives need to be made less appealing by making them more expensive and promoting Reuse				✓
Support from organisations needs to be provided				✓

4. Results

In this chapter the results of the research are presented. The section starts with a description of the results per case and eventually combines the cases in a cross-case analysis. The results gathered through interviews, document searches and literature will be used in order to improve the flowchart presented in Figure 2. The data that was used to receive these results can be found in Appendices 3 through 6.

4.1. *Within cases*

The reuse of e-waste at RWS is currently project specific, meaning in one project Reuse could be an important goal, whereas in the other project it could not receive any recognition at all. The reason behind this is that RL is not widespread within the organisation and it depends on the project manager whether RL will be implemented or not. This means that not all benefits of RL are being experienced by RWS. Taking the ambition of RWS to be fully circular in 2050 into account, it is important to determine what the reasons are behind the lack of implementation of RL. The reasons for rejecting RL within a project are multiple barriers that the project teams within RWS have faced throughout the years and that are currently still in place. From the literature it became evident that these barriers can be categorised into five categories, namely legislation, attitude, risk, responsibility and technical barriers. Moreover, project teams have identified enablers as well, which they see as possibilities for the improvement of RL implementation. The enablers have been categorised following the categorisation of the barriers.

4.1.1. *Case 1: Velsertunnel*

Within the case of the Velsertunnel, interview candidates have not suggested barriers or enablers specifically for the transition from landfill to Recycle. They have, however, identified barriers and enablers for the other transitions.

For the transition from Recycle to Remanufacture, respondents from the first case have identified two barriers. The first barrier belongs to the 'attitude' category and states that the attitude towards RL differs within the organisation of RWS [I5] and for many people it is something they do not wish to have in their project, simply because they believe it will complicate their project scope. This means that the attitude of employees towards RL is not consistent and can prevent RL in certain situations [I5]. Moreover, it sends a confusing image towards contractors about the ambitions of RWS. Furthermore, the second barrier belongs to the 'risk' category and includes that there is a great data loss when it comes to the installations in the projects of RWS [I2; I7]. Often project data about the installations is missing, such as their structure, components or programming. This causes great insecurities in the prediction of the behaviour and durability of installations [I2]. Moreover, the suppliers of the installations are also not in the possession of these data, meaning that there is no way of acquiring the data [I2]. Thus, RWS did not and still does not monitor well enough what installations and software they are installing in their assets [I7]. On the other hand, respondents have suggested four enablers for the transition from Recycle to Remanufacture as well. Firstly, an enabler from the 'attitude' category that was suggested within this case is that RWS needs to be flexible in formulating their requirements, as RL needs flexibility [I1]. RWS needs to reconsider some strict requirements, for example the requirement that there can only be three different kinds of light fixtures used in RWS projects, in order to make the transition to CE easier and to make it easier and more appealing to implement RL. Moreover, another enabler was identified in the 'risk' category and states that crucial components from installations cannot be considered for RL at this point in time. Because the process of RL is relatively new, low impact components are more suitable for learning the ropes and making mistakes [I2]. This is because electrical parts of installations are tricky when it comes to assessing the durability, because this cannot be determined from looking at the outside of the material. However, electrical parts which pose a smaller risk when failure occurs can be more easily incorporated into RL [I3]. Furthermore, another 'risk' enabler is that requirements concerning RL can be specified in the contracts and therefore this needs to be done [I1; I3; I8]. For example, in the contract with the suppliers could be mentioned that they are responsible for the collection, certification and reuse of their products and requirements could be set where it is stated that products need to be second hand or where a maximum amount of waste is specified [I1]. The reason behind this is that if it is written in a contract or a legislation, it becomes impossible for the project team or contractor to not obey it [I3]. Within this project a choice was made for strict requirements instead of leaving it up to the market because there were many stake- and shareholders and leaving it up to the market would cost too much time. Moreover, it could mean that certain important factors would be left out. The contractor was awarded room for creativity; however, the greatest risks were strictly prescribed. Moreover, RWS has given certain factors a lot of thought, which means it would be unnecessary to leave it up to the market [I8]. Finally, the project team has stated that the RL of installations should be regulated by the supplier [I1; I2]. Suppliers should be made responsible for their own products and their circularity, because they are the ones that know best how their products work and what is to be expected about the durability [I1]. This way the supplier could determine which components to reuse, repair, or remanufacture and RWS could receive finished products in return [I2]. However, RWS should in their turn accept these 'second-hand' products in their projects [I1].

Furthermore, the transition from Remanufacture to Repair adds two additional barriers according to the respondents from the Velsertunnel case. Firstly, belonging to the 'risk' category a barrier is that RL is contractually not appealing [I2]. Second-hand installations are not as cost efficient as is desired, often costing 60 to 70% of that of a completely new installation. Furthermore, the contracting procedure does not stimulate the use of second-hand materials from the perspective of RWS, as the contractor only has an obligated two years of maintenance [I2]. Moreover, respondents have stated that law and legislation are "too strict when it comes to CE" [I1]. This includes for example legislation concerning safety, these laws often have a great number of additional safety standards on top of the regular standards. The additional standards are often abundant and prevent RL [I1]. On the other hand, the case of the Velsertunnel has produced one enabler for the transition from Remanufacture to Repair as well, this includes that e-waste needs to be reused for maintenance of other projects [I2; I8]. When project teams know that installations are not outdated, they can take them into account for the maintenance of other structures which are equipped with the same materials. This means that they ask for certain materials back from the contractor, which they then use for maintenance [I2].

Finally, for the transition from Repair to Reuse, two barriers have been identified within the first case. A barrier belonging to the 'attitude' category is that project goals do not include RL in the same way as time and scope [I1; I2]. RL is often just an ambition, which is seen as a lower priority than project goals such as "a renovated tunnel which is safe and accessible" [I2]. This causes RL to be seen as a complicating factor instead of a requirement or creator of value [I1]. The second barrier for this transition belongs to the 'technical' category and states that not all installations are at the end of lifecycle at the same time, as every installation has its own 'heartbeat' [I2]. This means that the sorting and classification processes will take a lot of time and the durability of the installations cannot be adjusted to accommodate the project goals regarding time and cost efficiency. Besides this, the enabler mentioned in this case for this transition is from the 'risk' category and states that it needs to be mapped precisely what materials are available from which project and what their destination can be [I1]. Because if RWS has a database with information about all materials that are in their structures and links this with the renovations of those structures, it becomes clear what materials will be available at what time and also what materials will be needed at what time. This partly eliminates the need for storage, because second-hand materials from one project could be implemented in another one.

4.1.2. *Case 2: RITS*

Within the RITS case, interview candidates have not acknowledged barriers or enablers for the transition from landfill to Recycle. They have, however, identified barriers and enablers for the other transitions.

For the transition from Recycle to Remanufacture, interviews have identified two barriers belonging to the 'attitude' and 'risk' categories respectively. Firstly, the positive attitude towards RL is not organisation-wide [I4; I6]. Within the main offices, RL is promoted and supported, while the people at the district offices are not all in favour of RL (yet) [I4]. This results in situations where the proposals of contractors are reviewed and approved at the main office, while the contractor experiences limitations from the district office regarding the implementation of RL [I4; I6]. Furthermore, the market does not know what path to take as RWS is also still working this out [I7]. The goals that RWS has set are "not defined clearly, there is a lack of technical boundaries and benchmarks and there is no scientific argumentation" [I7]. In other words, RWS has ambitions and goals, but they do not have a clearly written plan on how to achieve those and this causes the market to become passive and wait for more information.

On the other hand, respondents have suggested four enablers for the transition from Recycle to Remanufacture. Firstly, an enabler belonging to the 'risk' category is that requirements can and therefore need to be always specified in the contract. This includes agreements being made beforehand about how the contractor needs to handle the waste. Everything needs to be written down in the contract [I7]. Moreover, three enablers have been suggested belonging to the 'responsibility' category. These include that the RL of installations needs to be regulated by the supplier [I6]. This means that e-waste goes directly back to the suppliers after the supposed end of life. The future would be that the suppliers are responsible for their products and take them back in order to process the materials further following RL principles [I6]. Furthermore, respondents have stated that RWS needs stress the agreements with contractors more [I7]. RWS has an agreement with the contractors that they need to improve themselves continually. However, RWS does not check upon this agreement as often and as thorough as they should. They can keep addressing the contractors about this, even if the contractors have reached the highest level of sustainability maintained by RWS [I7]. Finally, the third enabler from the 'responsibility' category is that RWS needs to leave certain innovations to the market [I7]. This is a way for RWS to achieve their goals without having to invest too much. They should challenge the market to come up with innovations and this way RWS can use the knowledge that is already present in the market. It is not useful for RWS to try to innovate on their own as this is not their core business [I7].

Besides this, for the transition from Remanufacture to Repair, the RITS case provides one barrier, which states that requirements are known to conflict with one another [I4]. An example is that the contractor is only allowed to choose from three different kinds of lighting fixtures, which are not state of the art, while another requirement is that the installation needs to be as energy efficient as possible with current technology [I4].

On the other hand, the second case has identified an enabler for this transition as well, including that the RL destination of e-waste needs to be maintenance of other projects [I4].

Finally, for the transition from Repair to Reuse two additional barriers can be added from the RITS case. Firstly, respondents from the RITS case have stated that RL is not seen as equally important as other project goals, if it is a project goal to begin with [I7]. Safety, for example, is valued a great deal, as there are posters, speeches

and overall a great amount of attention for safety. A similar situation should be created for RL, as it is now seen as a burden instead of an added value [I7]. Moreover, a 'technical' barrier is that not all suppliers are capable of taking back their products [I6]. There is a great number of small organisations and suppliers of a few parts, which are not yet technically ready to accommodate the processes RL demands, such as repairing or recycling the products or materials.
Moreover, the interviews within the RITS case have identified one enabler for this transition as well, stating there is a need for a central data bank where materials can be exchanged [I6]. The role of RWS is to organise a central data bank where materials could be exchanged in order to trigger RL for the entire sector [I6].

4.1.3. *Case 3: Eerste Heinenoordtunnel*

Within the Eerste Heinenoordtunnel case two barriers were mentioned for the transition from landfill to Recycle. The first barrier is from the 'attitude' category and states that project members have indicated that they have a preference for new installations rather than second-hand installations [I3]. This outspoken preference of project teams for new instead of second-hand materials causes the implementation of RL to be held back from the outset. Furthermore, a barrier from the 'responsibility' category that was mentioned in regard to this transition, is that RWS has certain responsibilities as a government institution and as the main client in the sector, such as setting an example for the entire sector. Therefore, it is important that they act upon these responsibilities [I1; I3]. RWS is the example for many organisations and cannot leave everything up to the market, as there are a lot of organisations that strive for financial gain instead of social value [I3]. This could result in situations where harmful substances are deported to third world countries and reported as recycling.
On the other hand, one enabler has been identified for the transition from landfill to Recycle as well. This includes that RWS takes their responsibility in the field by deciding what the final destination is of all material flows [I2; I3]. When considering RL, within the Eerste Heinenoordtunnel case, the project team has considered awarding the value of the materials to the contractor, however stating that RWS decides what ultimately happens with the materials. This means that RWS decides what the final destination of certain materials is and how these should be processed [I2]. It is important to steer the outcome by deciding what ultimately happens with the materials, by deciding the final destination [I3].

For the transition from Recycle to Remanufacture, two enablers have been identified within the case of the Eerste Heinenoordtunnel. These include using a financial incentive or a share of risks to trigger RL [I3; I5]. There needs to be an incentive (maybe of financial nature) to deliver quality within projects. This could be reached through the contract, where the contractor could be forced not to deliver cheap products [I3]. Furthermore, in the contract could be specified that there is a sharing of risks between the client and the contractor when it comes to RL [I5]. Furthermore, the second enabler is that in certain cases it is better to let the market figure certain barriers out to stimulate innovation and spare RWS resources [I3; I5]. This way RWS can steer towards a certain solution, while letting the market figure it out on their own. This sparks innovation and saves resources for RWS [I3]. The reason behind this is that innovation should not only be concentrated at RWS as there are a lot of people there who want to stay safe. This could be solved by including the market, as their knowledge would enrich RWS. An example would be to state that: this and this solution will not be excluded (this way the contractor will have a guideline to form his ideas) [I5].

When it comes to the transition from Repair to Reuse, the Eerste Heinenoordtunnel case offers two enablers. These include 'lessons learned' being a way to easily integrate RL in projects [I9]. It is useful to consider other projects and their 'lessons learned' because certain innovations have been implemented there already. This way the innovations become 'state of the art' and are not innovations anymore. This means that it has already been done and it is possible. This way specifications can be transferred to a new contract fairly easily and innovation becomes standardisation [I9]. Moreover, respondents from the Eerste Heinenoordtunnel case have stated that the supplier should be made responsible for the entire lifecycle of their products [I5]. This way the responsibility for RL will be for the party that has the greatest knowledge about the products and their capabilities.

4.2. *Cross-case*

In this section, the three reviewed cases are compared to one another and the barriers and enablers are all allocated to a transition.

4.2.1. *Transitions*

Below the barriers and enablers are described for each transition, these barriers and enablers have been translated into aiding and complicating factors which can be found listed in Table 6. The factors have been listed according to their relative importance per transition, which is based on an a priori assumption of the researcher. On the one hand, factors can be binary, making them conditions that can either be fulfilled or not. When the condition is not fulfilled, the transition is held back until the condition becomes fulfilled. On the other hand factors can be non-binary, and these factors can extend the transition to more products and materials or accelerate the transitions between the end-of-life processes.

4.2.1.1. *From landfill to Recycle*

The conditions for recycling are limited, as there are just two barriers from the 'attitude' and 'responsibility' categories. These include user preference, as users often might think that recycled materials are of a lower quality than new ones, which causes them to prefer new materials over recycled materials [C3]. Furthermore, RWS has a social responsibility to fulfill, meaning they must be gatekeepers as to which materials are kept in the loop, therefore they need to remove harmful substances from the circular economy [C3].
On the other hand, Recycle does not have many enablers either. From the 'responsibility' category there is however one enabler, stating that RWS can take their responsibility by deciding what the final destination of their products is. This way RWS can steer towards a certain solution [C3].

4.2.1.2. *From Recycle to Remanufacture*

To transition from Recycle to Remanufacture, there are more barriers than for the transition from landfill to Recycle, namely three. These belong to the 'risk' and 'attitude' categories respectively. Firstly, the vision of CE is unclear and RWS does not have a clearly defined path or goals regarding RL [C2]. This causes the market to be hesitant with their innovations as well. Moreover, another barrier from the 'risk' category is that there is a lack of project data from the installations within the projects of RWS [C1]. This means that the behaviour of the installations cannot be predicted and thus the durability and quality cannot be guaranteed. Finally, the positive attitude towards RL is not organisation-wide, causing confusion amongst contractors [C1; C2]. Often RL measures are set up and arranged with the contractors at the main offices, while the district offices have no interest in carrying out these measures. Therefore, the attitude towards RL is not consistent throughout RWS, which sends a confusing image to their partners.
On the other hand, enablers for remanufacturing arise from the 'responsibility', 'attitude' and 'risk' categories. Firstly, RL being regulated by the producer, and making the producer contractually responsible is preferred by many [C1; C2; C3]. Furthermore, the 'responsibility' category includes leaving several aspects to be figured out by the market to spare resources and spark innovation as the market already contains a great amount of knowledge [C2; C3]. Moreover, another enabler from the 'responsibility' category is the stressing of agreements

with contractors, as RWS has an agreement with each contractor in which they demand continual improvement [C2]. This needs to be done even when contractors have reached the highest level of sustainability [C2]. When it comes to the ‘attitude’ category, RWS can enable Remanufacture by being flexible in their requirements and accepting the offered products [C1]. Furthermore, the ‘risk’ category includes three enablers for Remanufacture. Firstly, if only low-risk and non-crucial installations are eligible for RL, the risk for the contractor and client in implementing RL is considerably lower [C1]. Besides this, requirements can and therefore always need to be specified in the contract, for example stating a maximum amount of waste or a minimum number of second-hand products [C1; C2]. Finally, a financial incentive or a share of risks can trigger CE and RL [C3].

4.2.1.3. *From Remanufacture to Repair*

When moving from Remanufacture to Repair, three added barriers arise. These include existing laws, legislations and regulations not supporting the better end-of-life processes such as Repair and Reuse because of the extreme and too strict safety regulations that have to be implemented [C1]. Furthermore, the ‘risk’ barrier includes that the better end-of-life processes are contractually not appealing, as repaired or reused installations cost almost as much as new ones and contractors have just a mere two years of maintenance [C1]. Finally, requirements within projects often conflict with each other, demanding sustainability on one hand while limiting it on the other [C2].

Moreover, the ‘technical’ category offers an enabler for the transition from Remanufacture to Repair as well. This includes repaired or reused e-waste being an option for maintenance in other projects which are equipped with the same products [C1; C2].

4.2.1.4. *From Repair to Reuse*

Finally, whether Reuse is reached or not, depends on two barriers from the ‘attitude’ and ‘technical’ categories. Firstly, RL does not have the same priority as other project goals, often being of lower importance. This causes RL to become a complicating factor instead of added value to projects [C1; C2]. Furthermore, supporting facilities for reuse, such as collecting, inspecting and sorting facilities, are often not developed enough, meaning suppliers are not capable of taking back their own products [C2].

On the other hand, there are three enablers for Reuse from the ‘attitude’, ‘risk’ and ‘technical’ categories. Firstly, ‘lessons learned’ can be used to integrate Reuse in projects by passing innovations off as state of the art and thus not innovations anymore, making standardisation between projects possible [C3]. Furthermore, if it is mapped precisely what materials and products are located at which projects and when these will become available will aid in the process of Reuse [C1]. Finally, RWS can manage or support a central data bank for the exchange of left-over products [C2].

Table 6: Conditions from practice

Factor	Recycle	Re-manufacture	Repair	Reuse
The materials cannot contain any harmful substances	✓	✓	✓	✓
RWS has to accept recycled materials	✓	✓	✓	✓

RWS has to decide the final destination of the products and materials	✓	✓	✓	✓
Producers are contractually responsible for the RL of their own products		✓	✓	✓
Only low-risk and non-crucial installations are considered for RL initially		✓	✓	✓
Quality of the items can be guaranteed, supported with data		✓	✓	✓
Support organisation-wide from RWS within projects for RL		✓	✓	✓
A financial incentive or a share of risks is set in place		✓	✓	✓
RWS needs to be flexible in their requirements and accept second-hand products		✓	✓	✓
Agreements with contractors are enforced, even if they have reached the highest level of RL		✓	✓	✓
Vision of CE is clear, and goals are specified clearly		✓	✓	✓
Requirements for maximum amounts of waste or minimum amounts of second-hand are specified in the contracts		✓	✓	✓
Innovations need to be left to the market to figure out as they have more knowledge		✓	✓	✓
E-waste needs to be an option for the maintenance of other projects			✓	✓
Requirements need to be formulated in a way where there is no conflict with RL			✓	✓
Existing laws have to be altered in order to nullify the restrictions that are currently in the way of Repair and Reuse			✓	✓
Repair and Reuse need to be contractually appealing			✓	✓
RL should have the same priority as other project goals				✓
Supporting facilities need to be developed enough				✓

RWS should map precisely what materials are in which projects and when these will become available				✓
Lessons learned should be used to integrate innovations into projects				✓
RWS should work with a central data bank for the exchange of products				✓

4.3. ***Framework***

Within the framework from Figure 3 the most important aspects lie in the movements from a lower R-principle to a higher one. Each R-principle has its barriers and enablers that obstruct it, or allow it to be carried out. Logically, Reuse has the greatest number of barriers, whereas Recycling is almost always carried out. Therefore, Recycling is seen as the lowest possible outcome within the framework, together with landfill. As Reuse is the main strategy to close material loops for buildings at the end of their lifetime (van den Berg, et al., 2019), Reuse will be the highest achievable goal. In section 4.2 the conditions are described for each transition. These have been incorporated in Figure 3 together with their importance consequences.

When a product or material is about to become available through a renovation (after the deconstruction), the RL cycle starts at acquisition. After this, the inspection and sorting of the materials will take place, followed by collection of useful materials, which are then ready for disposition. The forward logistics logical next step would then be to proceed the materials to landfill or Recover in order to burn them for energy. In order to prevent this, and keep the materials in the cycle, several factors need to be taken into consideration. To be able to recycle a material, it must not contain any harmful substances, RWS needs to accept the second-hand materials back into their projects and RWS needs to stay in control by deciding the final destination of the material. After this, a material can proceed to Remanufacture, where it needs to fit the factors listed there as well as the factors listed with Recycle. This continues until a material does not fit the factors or it reaches the highest possible goal, which is Reuse.

The framework as it is presented now, is a general flowchart for materials, which has not been specified to tailor every possible e-waste material. This framework is an example and a starting point, which needs to be specified per material through further research. Therefore, this framework is generally applicable for every material, however the conditions will differ for light fixtures and sprinkler systems for example, because light fixtures are not crucial components and sprinkler systems are.

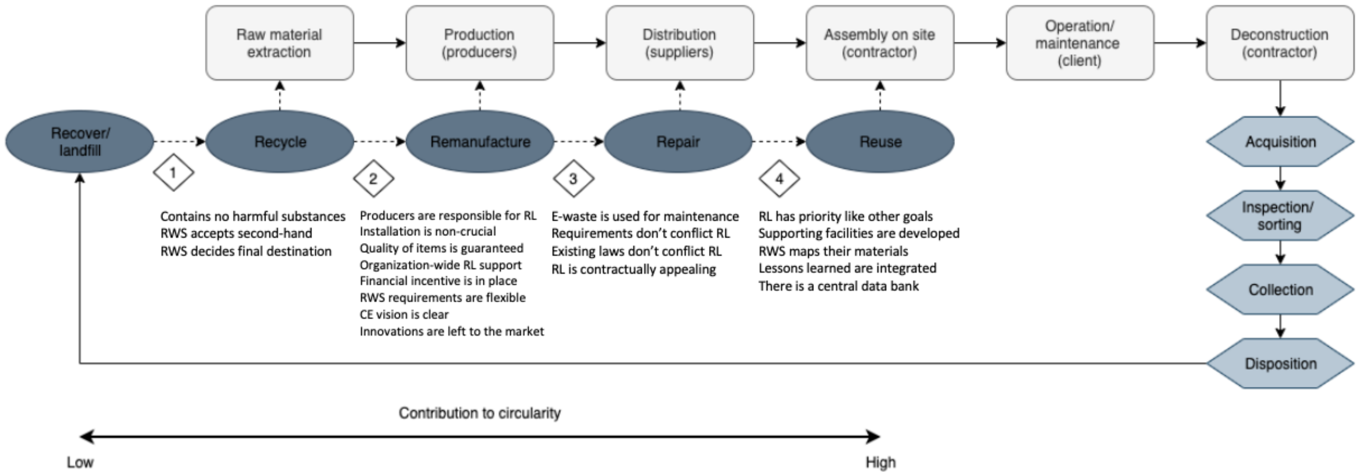

Figure 3: Decision framework

5. Discussion, limitations and further research

Within this section, the results presented in earlier sections will be discussed in a comparison between literature and practice and unexpected results will be elucidated. This comparison can be found summarised in Table 7. Furthermore, the limitations of the research will be discussed, alongside recommendations for further research.

5.1. *Comparison conditions literature and practice*

When compared to the literature, the conditions stated by RWS resemble as well as differ from the conditions defined in scientific literature. The comparison is elaborated below and can be found in Appendix 6.

When it comes to the transition from landfill to Recycle, literature and practice have three conditions in common. Firstly, the preference for new products or materials occurs as a barrier in both literature and practice (Mahpour, 2018; Hosseini, et al., 2015; Govindan & Bouzon, 2018; Hosseini, et al., 2014; Govindan & Hasanagic, 2018; Chinda, 2017; C3). Therefore, a condition in both cases is to have users accept recycled materials. Furthermore, the barrier referring to doubtful quality was not mentioned explicitly in practice. However, missing data was mentioned, which implies that doubtful quality is a barrier which is experienced in practice, only failed to be directly recognised. Hence, it is a condition in both literature and practice that the quality of items needs to be guaranteed (Hosseini, et al., 2015; Govindan & Bouzon, 2018; Hosseini, et al., 2014; Govindan & Hasanagic, 2018; C1). Finally, the last corresponding condition is that RL needs to be contractually appealing. The literature is more specific concerning this condition, mentioning only financial incentives, while practice includes more contractual barriers. However, both literature and practice agree that a lack of financial incentives discourages RL (Mahpour, 2018; Adams, et al., 2017; Govindan & Bouzon, 2018; Hosseini, et al., 2014; Schamne & Nagalli, 2016; C3).
Furthermore, there are two conditions which are mentioned in practice, however, not found in literature. These include the condition of materials containing harmful substances and the condition that RWS needs to decide the final destination of products and materials (C1). The reason behind this is that literature about the construction sector often does not include e-waste and therefore the particular harmful substances referred to in practice such as lithium or cobalt from batteries are not mentioned in literature. Moreover, the second condition is directly linked to the harmful substances and has therefore not been mentioned either.

The transition from Recycle to Remanufacture includes seven matching conditions. Firstly, both literature and practice recognise the lack of supporting facilities, such as markets, storage spaces and labels, as a barrier for RL (Huang, et al., 2018; Mahpour, 2018; Hosseini, et al., 2015; C2). Hence the further development of these facilities is a condition in both cases. Moreover, both literature and practice mention a lack of clear goals for the transition to CE as a barrier (Govindan & Hasanagic, 2018; Mahpour, 2018; C2). Therefore, both literature and practice have a condition to specify goals regarding CE clearly and support it. Furthermore, both literature and practice agree that the attitude of employees and decision-makers is important in the success of RL (Mahpour, 2018; C1; C3). However, practice adds to this that the support can be reached through flexibility in requirements. Moreover, a distinct match appears when literature and practice both agree that it is of great importance to make producers of products contractually responsible for the RL of their own products (Huang, et al., 2018; Mahpour, 2018; C1; C2; C3). Finally, the condition that there needs to be support from organisations is recognised by both literature and practice (Mahpour, 2018; Govindan & Bouzon, 2018; Chinda, 2017; C1; C2). However, practice adds to this that the support needs to be organisation-wide and that the organisation as a whole, needs to send one message to the outer world concerning RL.
Furthermore, when it comes to making the industry aware of the possibilities of RL, there is no direct match between the conditions as stated by literature and practice. The literature mentions a more general condition

stating that the industry simply has to be made aware of the possibilities regarding RL (Mahpour, 2018; Adams, et al., 2017). However, practice has conditioned that the agreements with the industry, for example, that they need to continuously strive for improvement, have to be enforced, even if the highest level of RL seems to be reached (C2). Another indirect match is when the literature mentions a more general barrier, stating that technologies for easy and reliable sorting and processing are not developed enough (Huang, et al., 2018; Mahpour, 2018; Adams, et al., 2017; Hosseini, et al., 2015). Whereas practice mentions specific barriers that have been faced, leading to only considering low-risk and non-crucial installations initially (C1). However, in the end, both agree that the technologies for RL are underdeveloped and that a condition for Remanufacture is that technologies have to be developed further to be able to incorporate all materials in RL. On the other hand, there are two conditions that do not occur in both cases. Firstly, ownership issues concerning second-hand items (Mahpour, 2018) do not occur at RWS, because the ownership is mentioned in the contract explicitly, taking any issues that may occur away immediately. Furthermore, the condition to leave innovations to the market because they have more expertise and knowledge (C1; C3) is not mentioned by literature. The reason behind this is that the perspective of the literature does not distinguish between different stakeholders and therefore does not distinguish were innovations need to come from.

Moreover, when transitioning from Remanufacture to Repair, two agreeing conditions are added. Firstly, both literature and practice agree on the condition that existing laws are in need of alterations in order to support RL (Mahpour, 2018; Hosseini, et al., 2015; Govindan & Bouzon, 2018; Govindan & Hasanagic, 2018; Schamne & Nagalli, 2016; Chinda, 2017; C1; C2). However, practice does not make a distinction between unsupportive legislation and preventive legislation, as the literature does. It is simply stated that legislation is 'too strict'. This can be either interpreted as unsupportive or preventive, depending on the context. Furthermore, both theory and practice mention a culturally embedded assumption in which CE and RL are assumed to be complicating factors and thus receive no support, while other project goals are valued more (Mahpour, 2018; Hosseini, et al., 2015; Govindan & Bouzon, 2018; Hosseini, et al., 2014; Govindan & Hasanagic, 2018; Chinda, 2017; C2; C3). Therefore, a condition in both cases is to make RL equally or even more important as other project goals. Finally, one condition is added from practice that does not occur in the literature, as the literature does not mention het use of e-waste as a maintenance option (C1; C3). The reason behind this is that the literature does not mention e-waste in the construction sector specifically at all, hence not distinguishing any direct uses for it.

Lastly, for the transition from Repair to Reuse, three conditions are added, which all mismatch. Firstly, the literature mentions that other alternatives need to be made less appealing by making them more expensive and promoting Reuse (Hosseini, et al., 2015; Mahpour, 2018). Practice does not mention this condition however, as the benefits of recycling are already incorporated in the contracts of RWS (i.e. a contractor offers the profit gained with recycling as a 'discount' in his budget). On the other hand, practice adds two conditions that are nog recognised by literature. These include that lessons learned should be used to integrate innovations into projects (C1) and that RWS should work with a central data bank for the exchange of products (C2). The reason that these conditions are not mentioned by literature is that literature rarely reviews more than one project or consecutive projects at one organisation. Furthermore, a central data bank is something that is only useful in a small country like the Netherlands, because although data can travel long distances easily, the products that are needed cannot. Thus, while it is good to know that there is a material available, to transport it for more than 500 km, is straining for the environment as well. On top of this, most countries do not have a government organisation like RWS that carries out so many projects, therefore a central data bank is not as relevant for them.

Table 7: Comparison literature and practice

Transition	Conditions literature	Conditions practice	Match?
Landfill to Recycle/ Remanufacture/ Repair/Reuse	Users have to accept second-hand materials	RWS has to accept recycled materials	Yes
	The quality of the materials has to be guaranteed	Quality of the items can be guaranteed, supported with data	Yes
	R-principle has to be financially more attractive than landfill	RL needs to be contractually appealing	Yes
		The materials cannot contain any harmful substances	No
		RWS has to decide the final destination of the products and materials	No
Recycle to Remanufacture/ Repair/Reuse	Supporting facilities have to be in place	Supporting facilities need to be developed enough	Yes
	Vision of CE has to be clear and aftermaths have to be thoroughly researched	Vision of CE is clear, and goals are specified clearly	Yes
	Ownership issues have to be sorted		No
	Industry has to be aware of the possibilities	Agreements with contractors are enforced, even if they have reached the highest level of RL	Partly
	Technologies have to be developed further	Only low-risk and non-crucial installations are considered for RL initially	Partly
	Attitudes of employees and decision-makers need to support RL	RWS needs to be flexible in their requirements and accept second-hand products	Yes
	Producers need to be made contractually responsible for their own products	Producers are contractually responsible for the RL of their own products	Yes
	Support from organisations needs to be provided	Support organisation-wide from RWS within projects for RL	Yes
		Innovations need to be left to the market to figure out as they have more knowledge	No

Remanufacture to Repair/Reuse	Existing laws are in need of alterations in order to support RL	Existing laws have to be altered in order to nullify the restrictions that are currently in the way of Repair and Reuse	Yes
	The project priorities need to be altered to facilitate sustainability and ultimately RL as a higher priority	RL should have the same priority as other project goals	Yes
		E-waste needs to be an option for the maintenance of other projects	No
Repair to Reuse	Other alternatives need to be made less appealing by making them more expensive and promoting Reuse		No
		Lessons learned should be used to integrate innovations into projects	No
		RWS should work with a central data bank for the exchange of products	No

5.2. *Limitations and further research*

This research was based on the case study approach and is subject to several limitations. Firstly, limitations lie in the choice of data source. As the acquired data is exclusively based on literature documents and interviews, the triangulation of data was not possible and therefore the results need to be considered as preliminary until further research is performed with more data sources. Moreover, because of the limited timespan and limited amount of cases, the performed interviews were restricted to only two external interviews. Because of this, there is not a great amount of input from the contractors or the suppliers and their side of the story has remained underexposed. Further research should be carried out which focuses on external data sources more and includes more contractors and suppliers and their stories.

Furthermore, another limitation can be found in the case selection process. Because the focus of this research was not to find new implementations for reused or recycled products and materials, rather on improving the organisational process of the implementation, only three cases have been studied. The case selection was dependent on the RL of specifically e-waste within a project and the area of interest of the problem owner. Therefore, the limitation that lies within the limited number of cases is that it is not clear whether the results of this study are applicable in other situations. It would be beneficial for further research to improve the external validity and to extend the number of cases not only to more cases, but to take the comparability of cases into account and to vary the cases in times and places as well.

Lastly, limitations of this research can be found within the assessment of the results. Firstly, using a different model instead of the one of Agrawal, et al. (2015) could lead to different results. Therefore, further research could focus on developing the theoretical framework further and incorporating more end-of-life processes and the lifecycle of a particular material or product. Furthermore, the definition for the enablers that was used in this research poses a limitation. Enablers were defined as being the opposite of barriers, limiting the number of enablers and underexposing enablers that are not the direct opposite of the found barriers. A recommendation for further research is therefore to redefine the term ‘enabler’ and to expose more enablers. Besides this, the relative importance of the factors was based on an a priori assumption of the researcher and not supported by a qualitative measuring tool. In order to improve the validity of the relative importance, further research should focus on developing a measuring tool for the relative importance of the factors that influence the transitions.

6. Conclusion

As the construction industry is a large contributor to the development of waste, the implementation of RL would help keep the effects on the environment to a minimum and would take care of the social responsibility. The barriers and enablers of RL have already been widely exploited in literature, however little of that research was focused on the construction industry and e-waste. As the largest client in the Dutch industry, RWS plays a great role in the implementation of RL in the Netherlands. Hence, this research has aimed to fill out the missing blanks when it comes to RL in the construction industry and e-waste and to concretise this by offering a flowchart to RWS for the adaption of RL concerning e-waste in the construction industry. In order to do so, the main question that was answered is: What are the factors that influence the transitions between the end-of-life strategies of RL of e-waste and how can these be exploited by RWS? To elaborate on the main research question, four sub-questions need to be answered, which are elaborated on below.

6.1. *RL at RWS*

The RL of e-waste at RWS is currently project specific, meaning in one project Reuse could be an important goal, whereas in the other project it could not receive any recognition at all. The reason behind this is that RL is not widespread within the organisation and it depends on the project manager whether RL will be implemented or not. This means that not all benefits of RL are being experienced by RWS. The reasons for rejecting RL within a project are multiple barriers that the project teams within RWS have faced throughout the years and that are currently still in place. Moreover, project teams have identified enablers as well, which they see as possibilities for the improvement of RL implementation.

For the transition from landfill to Recycle, the most important barrier is that the materials can contain harmful substances. When transitioning from Recycle to Remanufacture, the most important enabler was that producers are contractually responsible for the RL of their own products. Furthermore, when the transition from Remanufacture to Repair is considered, the most important enabler is that e-waste is best considered as an option for the maintenance of other projects. Finally, for the transition from Repair to Reuse, the enabler that stands out most is that RL should have the same priority as other project goals.

6.2. *RL in literature*

When transitioning from landfill to Recycle, the literature has recognised that the most important barrier is that users do not seem to accept second-hand materials out of principle. Furthermore, for the transition from Recycle to Remanufacture, the most important enabler is that producers are made contractually responsible for their own products. When it comes to the transition from Remanufacture to Repair, the most important barrier is that existing laws hold back or even prevent the better end-of-life processes due to extreme and often abundant safety conditions. Finally, when transitioning from Repair to Reuse, the most important enabler is that financial and regulatory incentives need to be provided specifically for Reuse.

6.3. *Comparison RL literature and RWS*

When it comes to the transition from landfill to Recycle, literature and practice have three conditions in common: accept recycled materials, guarantee quality of materials and make RL contractually appealing. Furthermore, there are two conditions which are mentioned in practice, however, not found in literature. These include materials not containing harmful substances and RWS deciding the final destination of products and materials. The reason behind this is that literature about the construction sector often does not include e-waste and therefore the harmful substances referred to in practice such as lithium or cobalt from batteries is not relevant. Moreover, the second condition is directly linked to the harmful substances and has therefore not been mentioned either.

The transition from Recycle to Remanufacture includes nine matching conditions: further development of supporting facilities, specification of clear goals for the transition to CE, making the industry aware of the possibilities regarding RL, further development of technologies, teaching of employees and decision-makers about the benefits of RL, make producers responsible for the RL of their own products and provide support from organisations.
On the other hand, there are two conditions that do not occur in both cases. Ownership issues concerning second-hand items do not occur at RWS, because the ownership is mentioned in the contract explicitly, taking any issues that may occur away immediately. Furthermore, leaving innovations to the market because they have more expertise and knowledge is not mentioned by literature because the perspective of the literature does not distinguish between different stakeholders.

When transitioning from Remanufacture to Repair, two agreeing conditions are added: alteration of existing laws in order to support RL and making RL equally or even more important as other project goals. Contrarily, one condition is added from the practice that does not occur in the literature, as the literature does not mention het use of e-waste as a maintenance option. The reason behind this is that the literature does not mention e-waste in the construction sector specifically at all, hence not distinguishing any direct uses for it.

Lastly, for the transition from Repair to Reuse, three mismatching conditions are added. Firstly, the literature mentions that other alternatives need to be made less appealing by making them more expensive and promoting Reuse. The practice does not mention this condition however, as the benefits of recycling are already incorporated in the contracts of RWS. On the other hand, the practice adds two conditions that are not recognised by literature: lessons learned should be used to integrate innovations into projects and RWS should work with a central data bank for the exchange of products. The reason that these conditions are not mentioned by literature is that literature rarely reviews more than one project or consecutive projects at one organisation. Furthermore, a central data bank is something that is only useful in a small country like the Netherlands.

6.4. *Factors influencing end-of-life process choice*

Below the factors that are of influence on the choice for the end-of-life process are presented. These factors have been composed by taking the barriers and enablers that were identified by the practice as a starting point and complementing these with factors from the literature, based on the enablers. These factors have been categorised per transition.

Landfill to Recycle:

- Decision makers are familiarised with the concepts of RL and its benefits, in order to take away the employees' preference for new products.
- The quality of items is guaranteed and supported with data.
- Financial and regulatory incentives being in place, encouraging the use of salvaged materials in new construction and thus making RL contractually appealing.
- No harmful substances are kept in the material loop.
- RWS ultimately deciding what the final destination is of all material flows and specifying this as such in contracts.

Recycle to Remanufacture:

- The supporting facilities and technologies for RL are developed further, meaning more research is executed and funded in order to develop better technologies for the treatment, sorting and classifying of e-waste.
- The goals that are set for RL are clearly formulated and substantiated in a scientific way.
- The industry is made aware of the possibilities by enforcing the agreements with contractors more, specifically that contractors ought to continuously improve their performances.
- Only non-crucial and low-risk installations are initially considered for reuse, such as light fixtures or cameras.
- RWS is flexible in their requirements and positive towards RL in order to stimulate the market to pursue it.
- The producers of electronics are made responsible for treating e-wastes of their own products and this policy is maintained by RWS.
- One image about RL is provided to the outside world and hence RL is supported throughout the entire organisation.
- Some aspects are left to the market to figure out, in order to spare RWS resources and stimulate innovation.

Remanufacture to Repair:

- The legislations and requirements affecting the projects at RWS are formulated in such a way that RL is not only supported, but promoted as well.
- The project priorities are arranged in a way where RL is equally important as safety and availability.
- E-waste is used as a maintenance options for other projects.

Repair to Reuse:

- Lessons learned from other projects are used to incorporate RL in future projects and presented as ‘state of the art’, as the used methods have been incorporated before.
- There is need for a central data bank were materials can be exchanged.

References

Papers

Adams, K., Osmani, M., Thorpe, T., & Thornback, J. (2017). Circular economy in construction: current awareness, challenges and enablers. *Waste and Resource Management, 170(1)* , 15–24.

Agrawal, S., Singh, R., & Murtaza, Q. (2015). A literature review and perspectives in reverse logistics. *Resources, Conservation and Recycling, 97*, 76–92.

Chinda, T. (2017). Examination of Factors Influencing the Successful Implementation of Reverse Logistics in the Construction Industry: Pilot Study. *Procedia Engineering, 182*, 99–105.

Esa, M., Halog, A., & Rigamonti, L. (2017). Developing strategies for managing construction and demolition wastes in Malaysia based on the concept of circular economy. *Journal of Material Cycles Waste Management, 19*, 1144–1154.

Geissdoerfer, M., Morioka, S., Monteiro de Carvalho, M., & Evans, S. (2018). Business models and supply chains for the circular economy. *Journal of Cleaner Production, 190*, 712-721.

Geng, Y., & Doberstein, B. (2008). Developing the circular economy in China: Challenges and opportunities for achieving 'leapfrog development'. *The International Journal of Sustainable Development & World Ecology, 15(3)*, 231-239.

Genovese, A., Acquaye, A., Figueroa, A., & Lenny Koh, S. (2017). Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications. *Omega, 66*, 344-357.

Ghisellini, P., Ripa, M., & Ulgiati, S. (2018). Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review. *Journal of Cleaner Production, 178*, 618-643.

Govindan, K., & Bouzon, M. (2018). From a literature review to a multi-perspective framework for reverse logistics barriers and drivers. *Journal of Cleaner Production, 187*, 318-337.

Govindan, K., & Hasanagić, M. (2018). A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective. *International Journal of Production Research*, 278-311.

Hosseini, M., Chileshe, N., Rameezdeen, R., & Lehmann, S. (2014). Reverse Logistics for the Construction Industry: Lessons from the Manufacturing Context. *International Journal of Construction Engineering and Management, 3(3)*, 75-90.

Hosseini, M., Rameezdeen, R., Chileshe, N., & Lehmann, S. (2015). Reverse logistics in the construction industry. *Waste Management & Research, 33(6)*, 499–514.

Huang, B., Wang, X., Kua, H., Geng, Y., Bleischwitz, R., & Ren, J. (2018). Construction and demolition waste management in China through the 3R principle. *Resources, Conservation & Recycling, 129*, 36-44.

Kalmykova, Y., Sadagopan, M., & Rosado, L. (2018). Circular economy – From review of theories and practices to development of implementation tools. *Resources, Conservation & Recycling, 135*, 190-201.

Kiddee, P., Naidu, R., & Wong, M. (2013). Electronic waste management approaches: An overview. *Waste Management, 33*, 1237–1250.

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation & Recycling, 127*, 221-232.

Leising, E., Quist, J., & Bocken, N. (2018). Circular Economy in the building sector: Three cases and a collaboration tool. *Journal of Cleaner Production, 176*, 976-989.

Lewandowski, M. (2016). Designing the Business Models for Circular Economy - Towards the Conceptual Framework. *Sustainability, 8(43)*, 1-28.

Mahpour, A. (2018). Prioritizing barriers to adopt circular economy in construction and demolition waste management. *Resources, Conservation & Recycling, 134*, 216-227.

Sarkis, J., Helms, M., & Hervani, A. (2010). Reverse Logistics and Social Sustainability. *Corporate Social Responsibility and Environmental Management, 17*, 337–354.
Schamne, A., & Nagalli, A. (2016). Reverse Logistics in the Construction Sector: A Literature Review. *Electronic Journal of Geotechnical Engineering, 21*, 691-702.
Schultmann, F., & Sunke, N. (2007). *Organisation of reverse logistics tasks in the construction industry.* Siegen, Germany: University of Siegen.
Tafaghodi Khajavi, L., Seyed-Hosseini, S., & Makui, A. (2011). An Integrated Forward/Reverse Logistics Network Optimization Model for Multi-Stage Capacitated Supply Chain. *iBusiness*, 229-235.
Verschuren, P., & Doorewaard, H. (2015). Het ontwerpen van een onderzoek. Amsterdam: Boom Lemma Uitgevers.
van den Berg, M. (2019). *Managing Circular Building Projects.* Enschede: University of Twente.
Yin, R. (2014). Case Study Research. Los Angeles, California: SAGE.
Zucker, D. (2009). How to Do Case Study Research. Massachusetts: University of Massachusetts Amherst.

Interviews

[I1] De Haas, K., Advisor CE, Centrum voor Ondergronds Bouwen, 21 May 2019, Delft
[I2] Van Maris, T., Technical manager, Rijkswaterstaat, 25 June 2019, Rotterdam
[I3] Minholts, G., Contract manager, Rijkswaterstaat, 25 June 2019, Rotterdam
[I4] Wesselink, T., Contractor, Compass, 11 July 2019, Utrecht
[I5] Bouten, J., Advisor sustainability, Rijkswaterstaat
[I6] van Blijswijk, J., Supplier, Vialis, 3 July 2019, Schiphol
[I7] Poutsma, E., Contract manager, Rijkswaterstaat, 3 June 2019, Utrecht
[I8] Naber, J., Specialist TTI, Rijkswaterstaat, 16 July 2019, Utrecht
[I9] Van Offenbeek, B., Advisor CE, Rijkswaterstaat, 16 July 2019, Utrecht

Documents

PACE. (2019). *A New Circular Vision for Electronics Time for a Global Reboot.* Geneva, Switzerland: World Economic Forum.
Potting, J., Hekkert, M., Worrell, E., & Hanemaaijer, A. (2016). *Circulaire Economie: Innovatie Meten in de Keten.* Den Haag: Uitgeverij PBL.
Provincie Zeeland. (10 april 2019). Circulair installeren in de praktijk. *Van RWS kantoor naar kinderkliniek*. RAI Amsterdam: Building Holland.
Teodorascu-Arkesteijn, P. (2018, Juli 19). Duurzaamheid. Recalled on February 14, 2019, from Intranet Rijkswaterstaat: http://corporate.intranet.rws.nl/Kennis_en_Expertise/Kennisvelden/Leefomgeving/Duurzaamheid/