Transition to a circular Dutch infrastructure sector

A mission-oriented innovation system (MIS) approach to study the transition

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By

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Preface

Before you lies the final product of my master thesis. This thesis marks the end of my time at Delft University of Technology as it comprises the final part of in the curriculum of the Master Construction Management and Engineering at the Faculty of Civil Engineering and Geosciences. The research was conducted in collaboration with Rijkswaterstaat and Utrecht University. I got the opportunity to expand my knowledge in the field of circular economy in the construction sector.

I would like to deliver my gratitude to all the member of my graduation committee. From Delft University of Technology Dr Thomas Hoppe, Dr Daan Schraven, Dr Martijn Leijten for their academical guidance and feedback which encouraged me to improve the quality of my thesis. Their expertise and advice guided me to finish this research. Furthermore from Rijkswaterstaat Claartje Vorstman as company supervisor for the support, critical feedback, check-ins and providing me with contacts in the company and industry.

All of this would never been possible without the unconditional support of those who are dear to me. I would like to thank my parents, family and friends. For encouraging and motivating me during the process and for helping me to put things in perspective when I needed it. Your motivation and support means a lot to me. I enjoyed writing the report and I hope the person reading this experiences the same.

Enjoy reading my thesis!

Lucia van Leeuwen
Den Haag, February 2023

Executive summary

The environmental impact of human actions on the planet has received increasing attention. On different levels goals have been set to limit the environmental impact. Goals and objectives have been formulated on European and national scale. The Dutch government aims to achieve a 100% circular economy in 2050. The circular economy is seen as a promising concept to tackle climate change. To achieve the ambitious goals, steps have to be taken to initiate the transition from a linear to circular economy. This transition requires the researcher to look beyond national, regional, technological and sectoral boundaries. To look beyond these boundaries and provide directionality, the concept of missions has proven to be very helpful. Missions are central in the Mission-oriented Innovation System (MIS) framework.

Reason for this research

The global impact of the consumption of resources and CO_2 emissions in the construction sector makes a transition in this sector key in achieving the climate goals. In 2021, the Netherlands Environmental Assessment Agency (PBL) presented the first Integral Circular Economy Report (ICER). The report reflects the current state of the transition to a circular economy in the Netherlands. According to academic literature a MIS analysis has already provided insightful information for other sectors (i.e. plastic packages and matrasses). Although the significant environmental impact of the sector, this analysis was still lacking for the infrastructure sector. The Copernicus Institute of Sustainable development of Utrecht University is one of the collaborating knowledge institutes that provides PBL with knowledge for the ICER. By analyzing three often used material streams in the construction sector for this research, the ICER has been enriched with more in-depth information.

Scope of the research

This research specifically focusses on the transition process of the Dutch infrastructure sector. This research will contribute to the existing literature by adding more in-depth knowledge about three notable social agreements established in recent years. The selected cases are all voluntary agreements between parties in the entire chain aimed at the transition to a circular infrastructure sector. The aim of this research is to provide the best to date comparison of three social agreements with circular ambitions in the Dutch infrastructure sector by taking the perspective of MIS. Therefore, main research question is: "*What can be learned about targeting the transition to a 100% circular Dutch infrastructure sector in 2050, through three social agreements if we take the perspective of Mission-oriented Innovation System (MIS)?"*

Research method

A qualitative approach, with a comparative case study, has been utilized for this research. Given the research method, this approach fits the aim of the research. A qualitative research approach enables to provide in-depth information to explore, understand and explain the cases. The identified case studies are about social agreements on concrete, wood and steel in the Dutch infrastructure sector. Data for these three cases has been retrieved by an extensive document analysis, two group sessions with experts in the field and semi-structured interviews. For each case study firstly, the problem and solution space was identified. Secondly the actors, networks and institutions were identified in the structural analysis and the MIS arena was established. Lastly in the functional analysis, the level of fulfilment of the nine system functions from the MIS analysis has been discussed.

Results

The results have shown that employing the MIS framework allowed an in-depth analysis of the cases. Using this framework has proven to be useful and clear. Awareness, urgency and flexibility seem three important keywords to keep in mind when targeting the transition to a 100% Dutch infrastructure sector. The non-binding nature of current initiatives has proven to be useful in taking the first steps in the transition. Getting different parties around the table to listen to each other is important. In a later phase, the non-binding nature has to change. The importance of destabilization of incumbent markets in order to make room for innovative ideas has also been emphasized by this research.

Yet to be introduced materials versus already established materials

To conclude the results obtained from this research, a distinction between yet to be introduced materials and already established materials has been made. This categorization makes the findings more general applicable. Research has shown that the focus and interaction between the MIS system functions for both categories is different. For the already established materials a negative feedback loop between the market formation and destabilization, availability of financial and human resources and the lack of directionality has been observed. The negative feedback loop suggests that this is something which requires attention for established materials in order to accelerate the transition in future initiatives. Unlike the already established materials, the yet to be introduced materials are mainly facing problems with the overall image and the level of knowledge. For the yet to be introduced materials the non-supportive socio-technical environment is the root cause of many negatively influenced system functions. Due to the lack of a supportive environment, there is a lack of financial resources which causes insufficient development of new knowledge. The lack of knowledge has as a result no clear direction for the transition and little possibilities to create a market for the yet to be introduced material.

Learning, transition, circular Dutch infrastructure sector and MIS are the four keywords in the main research question.

Learning

By pursuing the four dimensions of sustainability-oriented learning of Wals (2020), properties have been developed to take steps towards building a circular infrastructure sector. Learning stimulates creating, enriching and sharing of knowledge which is required in the mission to fight climate change. In terms of learning dimensions, it can be advised to utilize diversity and dissonance to break with existing routines and systems. Utilizing differences and conflicting opinions can actually lead to a tipping point. Reaching the tipping point can trigger to break with existing routines and systems. Also the transformative dimension to adapt to new situations and the power to oppose to unsustainable development requires attention.

Transition

Transitions take place in socio-technical systems. Changing an existing socio-technical system is often a slow process. Both technical and non-technical innovations should be considered to successfully complete a mission. Most of the recent societal problems cannot be solved by linear, rational or scientific methods of problem solved. Taking the entire playing field into account and the awareness that projects have to be seen as a transition is a first step into enabling upscaling of pilot projects.

Circular Dutch infrastructure sector

The R-ladder has been categorized in four strategies. Substitute, narrow the loop, slow the loop and close the loop are the four categories. Wood can clearly be classified in the substitute category. Steel and concrete can mainly be classified in slow and close the loop. It is important to notice that every strategy is required in the transition. The goal is not only to aim for the R-strategy highest on the ladder. Difficult to note successes that narrow the loop. More intensive or efficient use of a product will normally not be noticed. To show the progress in the transition process it is important to pay attention to these successes.

Mission-oriented Innovation System approach

Initially, the MIS perspective has been taken as research approach because it complements the research from Utrecht University on this subject. By taking the mission as demarcation for the selected cases, the national-, regional-, sectoral- and technological boundaries were crossed. In such a wicked problem as the transition to a circular Dutch infrastructure sector, crossing these boundaries is inevitable. The MIS perspective has proven to be a useful and well-structured approach for this research. The three steps in the MIS analysis provided a clear guideline. By taking the MIS perspective as research method, data has been collected in a well-organized way in order to answer the research question.

Concluding remarks

The extensive analysis makes this research the best to date comparison between social agreements in the infrastructure sector. This knowledge adds to the literature by examining the useability of social agreements to target to a 100% circular Dutch infrastructure sector. By analyzing three material agreements in the Dutch infrastructure sector, this thesis has shown how the selected agreements contributed in the transition to a fully circular infrastructure sector in 2050. To accelerate the transition process, the four learning dimensions of Wals should be taken into account. Diversity and conflicting opinions can be utilized to enable learning. Adaptation to new routines and opposing to unsustainable development also requires attention. This market formation and destabilization is reflected in both the learning dimensions Wals and the system function of the MIS analysis. Also special attention should be given to the successes achieved in the strategy narrow the loop. This is a highly promising strategy, but the achieved successes can easily be overseen. Highlighting these successes and The practical recommendations can be adopted by policy makers to accelerate the transition to a 100% circular Dutch infrastructure sector.

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1. Introduction

The transition to a Circular Economy (CE) in the Dutch infrastructure sector has been studied in this thesis. In the first chapter, the subject is introduced in general. It starts with an elaboration of the background and the urgency of the subject. After introducing the context, the problem has been defined in section 1.2. Next, the research goals and objectives were identified in section 1.3, followed by the set of research questions, presented in section 1.4. The scope of this research has been described in section 1.5 and in section 1.6 the social relevance and the connection of this research with other studies is elaborated. Finally, in section 1.7, the outline of the following chapters of this research is presented.

1.1 Context

Environmental impact of a growing population

Human population is growing rapidly and it is causing a significant impact on the environment. Since the Industrial Revolution the world is facing environmental change, mainly due to human actions (Steffen, Crutzen, & McNeill, 2007). Overpopulation and overconsumption causes an increase in the consumption of raw materials, along with the emission of greenhouse gases. To keep the earth in a stable state, the use of natural resources should be kept within planetary boundaries (Rockström, et al., 2009).

European measures enshrined in the Paris Agreement

To prevent serious environmental, economic and societal impacts of climate change, all United Nations Framework Convention on Climate Change (UNFCCC) member countries have committed, in the Paris Agreement, to limit global temperature increase to 2 degree Celsius above pre-industrial level by 2050 (European Environmental Agency (EEA), 2021). In December 2015, the European Commission adopted the first circular economy action plan. The conclusion of the top UN climate officials at the World Circular Economy Forum (WCEF) was the urgency to speed up the transition to a circular economy in order to achieve the international agreed climate goals (United Nations, 2021). In December 2019, the European Green Deal was presented. All EU Member States committed to make Europe the first climate neutral continent in the world (European Commission, 2020a). A climate-neutral, resource-efficient and competitive economy is what the strategy of the European Green Deal aims for (European Commission, 2020b). The goal is to be climate neutral by 2050. By 2030 the EU has the ambition to deliver a reduction of at least 55% of the greenhouse gas emissions, compared to the year 1990. This indicates the need for strategies to achieve the climate goals. The European Union strives towards a regenerative growth model that gives back more to the planet than it takes (European Commission, 2020b).

Dutch national measures to combat climate change

Based on the international ambition, the Dutch government set the goals to achieve a 100% circular economy by the year 2050 (Dutch Ministry of Economic Affairs and Climate, 2019). In 2018, the Dutch government set up the national action plan "*Rijksbrede programma Nederland circulair in 2050*" and included five priority chains, called transition agendas. The five sectors, categorized in these priority chains are important for our economy and have a high impact on the environment. The five transition agendas are: biomass and food, plastics, manufacturing industry, construction and consumer goods. The construction sector is one of the five transition agendas and consists of the residential building and utility sector and the infrastructure sector. Of all industrial sectors, the construction industry uses the most

resources, produces the most waste and accounts for a large part of greenhouse gas emissions (Stegemann & Rose, 2018). The Dutch constructions sector can be held accountable for 50% of the total use of raw materials, 40% of the total national energy usage, 30% of the total water usage and 35% of the carbon dioxide (CO_2) emissions (Transitieteam Circulaire Bouweconomie , 2021).

Three objectives of the government to make the Dutch economy circular

The Dutch government aims at completing the transition towards a circular economy by 2050 (Rijksoverheid, 2020). The government is working with many organizations to make the use of raw materials more efficient and smart. To reach this goal, the government has formulated three objectives:

1. More efficient use of raw materials. Making existing production processes more efficient, fewer raw materials are needed;
2. Using as much as possible sustainable produced materials. When new materials are required, renewable and sustainable produced materials are used as much as possible;
3. Developing new manufacturing methods and design new products circular.

1.2 Problem definition

Need for (new) infrastructure

As prosperity continues to grow, the need for new physical infrastructure worldwide has grown remarkably in the last decades (Gil & Beckman, 2009). Infrastructure is essential for the economic and social activities of modern society (Hartmann & Ling, 2016). In addition to the demand for new infrastructure, the existing civil infrastructure must be properly maintained to meet the demands of today's society. Many infrastructural elements in Europe were constructed in the 1960s, along with the introduction of the car. In addition to aging, the strong growth of freight traffic in number and weight was not foreseen at the time (TNO, 2021). Because of this, a major maintenance operation is coming up.

Need for circular economy

The global demand for materials is increasing rapidly and resources are depleting. In the current situation, the degree of economic growth is directly linked to the use of resources. Because of the impact of the construction sector on the consumption of resources and CO_2 emissions, the transition in the infrastructure sector is key in achieving the climate goals. Current mitigating measures in the construction sector will not be able to deliver sufficient emission reductions to limit the increase in global temperature below 2 degrees Celsius (Hoogzaad, 2016). The Ellen MacArthur Foundation (EMF) is an organization which is developing and promoting the idea of a circular economy. In 2019, they published a paper substantiating that moving to renewable energy can only address 55% of global greenhouse gas emissions (EMF, 2019). To achieve the UN climate goals, a solution for the remaining 45% is also required. The paper "*Completing the picture: how the circular economy tackles climate change"* from the EMF is addressing this issue. It shows greenhouse gas emissions can be reduced by 9.3 billion tons by implementing the concept of circular economy only on the five key areas (cement, plastics, steel, aluminum and food).

Wide variety of definitions of circular economy

There is a lack of coherence when it comes to defining circular economy. In 2017, Kirchher did a comprehensive analysis on 114 definitions of circular economy in the current discourse. In

most cases, the definitions of a circular economy are characterized by a combination of reduce, reuse and recycle activities (Kirchher, Reike, & Hekkert, 2017). The emphasis on the need of a systemic shift is often lacking in the definitions. A wide variety of definitions might lead to the collapse of the concept. The conceptualization of CE will be elaborated in chapter two of this research. Currently 24.5% of the Dutch economy is yet considered circular (Circle Economy, 2020). Worldwide the Netherlands is one of the most circular countries. Nevertheless, much remains to be done before we achieve a fully circular economy. Monitoring the *effects* on circularity, the environment and the economy can be done by a variety of measuring instruments. Measuring the *process* of the CE transition is more challenging (Potting et al., 2017).

Need for a transition

There are too many unsustainable production- and consumption processes which have environmental problems as a consequence. Incremental improvements on these processes are not enough to tackle global challenges, such as climate change. A radical change, a transition, is required. In the process of a transition, the goal is to turn the current -often undesirable- situation into something that is desirable in the future. To achieve the ambitious climate goals, steps must be taken to initiate the transition from a linear to circular economy. To get to a 100% circular economy, innovation has to take place to explore many potentials solution pathways (Hekkert, Janssen, Wesseling, & Negro, 2020a). Adoption of these pathways will not go naturally. The transition requires not only technological innovations, it also requires a shift in the way of thinking. Public and private parties have to work together and new forms of collaboration should be adopted. The circular way of thinking has to be embedded in every part of the system, from initiation, to procurement, to construction, to the final stage and even after that. Because of the great diversity of solution directions to address the problem, it is difficult to measure progress.

1.3 Research goal and objective

The concept of a circular economy has recently received increasing attention in academic research. The aim of this research is to enrich the current research into the circular ambitions in the Dutch infrastructure sector and provide the best to date comparison between social agreements in this sector. The Dutch Ministry of Infrastructure and Water management is interested in the progress of the transition from a (partly) linear economy to a 100% circular economy by 2050. Together with the residential and utility building sector, the infrastructure sector forms the construction sector. Both subsectors show similarities, but they also differ an on number of points. According to TNO, it is assumed that the CO_2 emissions from infrastructure can be reduced by 40% by transitioning to a circular economy (TNO, n.d.). One of the recommendations of the platform CB'23 ("*Circulair Bouwen in 2023"*) is to consider the construction sector as a whole as much as possible and, where necessary, look at both sub sectors separately. CB'23 is a platform set up with the aim of connecting all links in the circular construction chain. It aims at developing unambiguous sectorwide working agreements with representatives from the whole sector to help speed up the transition.

Literature review shows that so far only a few researchers have studied this transition process in the Dutch infrastructure sector (e.g. Coenen et al., 2021). Current research in this area aims to describe the entire sector. This approach will give an overview of the sector, but due to the wider scope, details in specific projects or initiatives from the sector itself will be overlooked.

This research will contribute to the existing literature by adding more in-depth knowledge about three notable social agreements established in recent years. Each of these social agreements focuses on one of the most commonly used material in the construction sector. The initiatives are notable for (a combination of) their technical-, social-, political- or economic approaches. Insights gained from analyzing particular projects within the sector will enrich research on the entire construction sector.

Missions to address issues related to the area of energy transition and sustainability

The aim of the New Circular Economy Action Plan (CEAP) (European Commission, 2020b), is to initiate a radical change from a linear system to a circular system. This transition requires the researcher to look beyond national, regional, technological and sectoral boundaries. To look beyond these boundaries and provide directionality, the concept of missions has proven to be very helpful. Currently, a mission can be described as: "*an urgent strategic goal that requires transformative systems change directed towards overcoming a wicked societal problem*" (Hekkert, Janssen, Wesseling, & Negro, 2020a). Due to the wicked nature of the mission, it requires the development, diffusion and embedding of technological, institutional and/or behavioral solutions to accomplish it (Wanzenböck et al., 2020). The Dutch government formulated 25 missions in four societal challenge areas. "*Missions are helping the top sectors to join forces, even more than before"* (Ministry of Economic Affairs and Climate Policy, 2019). The four societal challenge areas are:

- Energy transition and sustainability;
- Agriculture, water, food;
- Health and healthcare;
- Security.

Missions are defined by the government for each area. The formulated missions challenge parties to develop innovative solutions and contribute to the competitiveness of the Netherlands. The missions defined for the energy transition and sustainability area are presented in table 1-1.

Area	Missions
Energy transition & sustainability	• 49% reduction of national greenhouse gas emissions by 2030, aiming for 95% lower emissions by 2050 compared to 1990; • An entirely carbon-free electricity system by 2050; • A carbon-free built environment by 2050; • Carbon-neutral industry with reuse of raw materials and products by 2050; • Zero-emission mobility of people and goods by 2050; • A sustainable and completely circular economy by 2050, with primary resource use halved by 2030.

Table 1-1: Missions on energy transition and sustainability (Ministry of Economic Affairs and Climate Policy, 2019)

Theoretical substantiation to use missions for this research

Using the concept "*missions*" to measure the process of a transition, the mission-oriented innovation system (MIS) framework has been developed. The MIS-framework looks beyond national, regional, sectoral and technological boundaries of other innovation system approaches. MIS is a relatively new phenomenon. The first MIS studies have only just been completed (Elzinga et al., 2021). The MIS framework is applied in a few sectors (e.g. textile

industry, plastic packaging and water authorities). Because of the characteristics and the impact of the construction sector on the goal towards a complete circular economy, it is interesting to apply a MIS analysis to several social agreements in the Dutch infrastructure sector. A well-functioning MIS can speed up the process towards the successful completion of a mission (Hekkert et al., 2020b). Application of the new innovation system approach on more cases is valuable and conducting more empirical studies will help to understand the MIS dynamics better and improve the model.

1.4 Research questions

Requirements for a good research question

From the previous section, it became clear that there is still little knowledge about the transition process to a circular Dutch infrastructure sector. By researching several recent social agreements, this research will contribute to filling the knowledge gap. To analyze the transition process towards a 100% circular Dutch infrastructure sector, the MIS approach is applied on three societal agreements to understand and systematically assess the impact of the mission. Based on the previous information, the main research question is formulated. Because using the MIS method was pre-determined, the method is also mentioned in the main research question. Function requirements of an adequate set of research questions relate to the *efficiency* and *steering function* (Verschuren & Doorewaard, 2010). Efficiency refers back to the research objective, formulated in the previous chapter. The efficiency of the research question is to what extent these questions contribute towards achieving the research objective. The steering function refers to the research activities and can be formulated in terms of the following two criteria. The first criterion is that the questions indicate the different types of knowledge that are required. The second criterion is that the questions give clarity regarding the material to be gathered during the research project.

The main- and sub-questions are formulated, keeping those requirements in mind. The focus of the main question is on what can be learned from adopting the MIS perspective and formulated to close the knowledge gap:

> *What can be learned about targeting the transition to a 100% circular Dutch infrastructure sector in 2050, through three social agreements if we take the perspective of Mission-oriented Innovation System (MIS)?*

In order to answer the main research question in a structured way, four sub-questions (SQs) are formulated.

- *SQ 1: How can the concept of the Circular Economy be defined in the Dutch infrastructure sector?*

This sub-question is formulated with the aim to explore the theoretical current state of knowledge on this topic. Crucial elements here are Circular Economy and the Dutch infrastructure sector. Also literature on transitions and innovation systems is relevant and will be studied here. An overview of the state-of-the-art literature on these topics will be presented and the gap in the current literature will be highlighted.

- *SQ 2: How to map and analyze the circular transition process of the three recent social agreements in the Dutch infrastructure sector by employing the Mission-oriented Innovation Systems approach?*

The aim of this sub-question is to give a clear description of the intended methodology. In line with the research from Utrecht University, the MIS framework is used for this research. This section provides a detailed description of how the research is done, guided by the consecutive steps in the MIS framework. The rationale of the decision-making process, of certain choices that give substance to the method, is clearly explained here. An overview of what data is used, how this data is collected and the limitations of the data collection is given, followed by a description of how the collected data is analyzed.

- *SQ 3: Which factors are promoting the transition and which factors are hindering the transition of the social agreements towards a circular infrastructure sector?*

The third sub-question is a result of the previous question. Given the methodological choices made in the previous sub-question, the research will be carried out and results will be obtained. The transition process of three social agreements in the Dutch infrastructure sector has been analyzed. By employing a separate MIS analysis on all three cases, promoting and hindering factors are recognized per case. Main findings per case have been presented here. To answer this sub-question, the results from the analysis have been reported objectively per case.

- *SQ 4: What insights do the three social agreements provide for other initiatives to accelerate circular transition in the Dutch infrastructure sector?*

The last sub-question is focused on the implications of the results. Two characteristics the three cases have in common are the fact that they are social initiatives and they are all demarcated by a specific material. After separately analyzing the three cases, the findings will be generalized to enable the application to other (future) initiatives as well. More general outcomes about the possibility for initiatives to accelerate the transition have been discussed. The aim of this sub-question is to discuss how to deal with barriers in transition processes in the future. On the other hand, positive interactions in the innovation system will be highlighted and can be applied in future agreements or transitions. To answer this sub-question, an interpretation and evaluation of the results is given.

1.5 Scope

The transition towards a circular economy is a global issue and is relevant in almost every sector. In terms of reaching the climate goals, the construction sector is highly relevant because of their significant impact. Figure 1-1 gives an overview of the overall scope of the problem. The focus of this research will be on mainly on project level through analyzing the selected social agreements in the Netherlands. The scope of this research is narrowed down on the level of materials and on social agreements. Based on the results from the social agreements on project level, the findings are carefully generalized to the national level of the circular infrastructure sector. So, the main focus of this research will be on the lowest (circular initiatives), and the second lowest (circular infrastructure sector) level. Because the scope of the agreements on concrete and steel concerns the whole construction sector and not specifically the infrastructure sector, the scope is here also related to the middle level (circular construction sector).

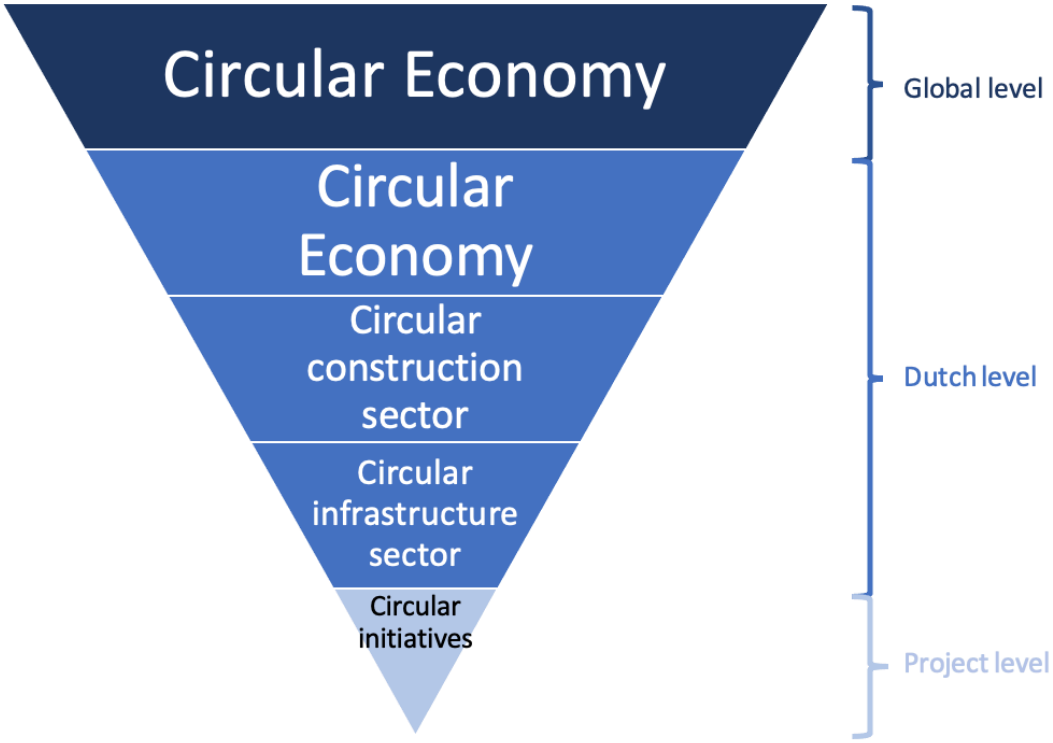


Figure 1-1 Scope of the research

1.6 Social relevance

The transition to an increasingly circular economy is a highly relevant topic nowadays. The use of several material resources has become more efficient over the past years, but still the trend of the total use of it is going in the wrong direction. In 2021, PBL (Netherlands Environmental Assessment Agency) presented the first Integral Circular Economy Report (ICER). The report reflects the current state of the transition to a circular economy in the Netherlands. The ICER contains guidelines for Dutch government policy for the transition to a circular economy (PBL, 2021).

The Copernicus Institute of Sustainable development of Utrecht University is one of the collaborating knowledge institutes that provides PBL with knowledge for the ICER. From the Copernicus Institute of Sustainable Development, professor Hekkert is transition and innovation (systems) expert, professor of Dynamics of Innovation Systems and also director PBL since the beginning of 2023. One of his PhD students is researching the transition to a circular economy, using his mission-oriented innovation systems (MIS) approach, to contribute to the ICER. The transition to a circular economy in the Dutch infrastructure sector is one of the cases selected for this research. This research has recently been published (Bours, Swartjes, & Hekkert, 2022).

In order to align this research with the research program from Utrecht University, MIS as theoretical framework was predetermined. This research report will provide in-depth knowledge for the general study done by Utrecht University on the Dutch infrastructure sector. By analyzing three streams of material resources, the ICER will be enriched with this information.

1.7 Thesis outline

Part one provided an introduction to the research by introducing the topic and formulating the main research question and the four sub questions. The next chapters are guided by the four sub questions. Each chapter ends with the answer to the sub question discussed in that chapter. Part two of the research starts with a broad exploration of theoretical concepts related to the research question. The methodological chapter uses this theory to elaborate on the line of reasoning for methodological choices that are being made. The research is narrowed to specific details about the execution of the research. In part three, three cases are studied and the results are reported here, guided by the choices from the methodological chapter. In the research review the aim is to broaden the research and generalize the findings of the case study to the scope of the research question. The discussion chapter looks back at the theory from chapter two. The relation between the theory and the research results is interpreted. The conclusion refers back to the introduction where the main research question was formulated. In this chapter the overall conclusion is presented and future recommendations are formulated. The table below provides an overview of the structure of the rest of this thesis.

PART I: Research introduction		
Chapter	**Key elements of the chapter**	
1. Introduction	• Introduce the topic • Identify the research gap • Formulation of research questions • Scope of research	
PART II: Initial Research		
Chapter	**Key elements of the chapter**	**Research question**
2. Theoretical framework	• Discuss relevant theoretical concepts	SQ 1
3. Methodology	• How to investigate the research question using the MIS framework • Method of data collection and analysis	SQ 2
PART III: Case study		
Chapter	**Key elements of the chapter**	**Research question**
4. Results	• Reporting the key findings per case	SQ 3
PART IV: Research review		
Chapter	**Key elements of the chapter**	**Research question**
5. Discussion	• General interpretation of results • Discussion of the relation between literature review, research question and outcome • Interpretation of case specific results	SQ 4
6. Conclusion	• Answer to the main research questions • Recommendations	Main question

2. Literature review

The previous chapter gave an introduction to the topic of this research and the research questions were formulated. Building on the information presented previously, this chapter presents the theoretical concepts relevant for this research. After introducing the theoretical concepts required for this research, this chapter will conclude with an answer to the first sub-question: *How can the concept of circular economy be defined and how can it be applied in the Dutch infrastructure sector?* This question is formulated to explore and understand the main concepts by means of literature review. First, the general concept of circular economy is introduced and applied to the Dutch infrastructure sector in the section on circular construction. Thereafter, the innovation systems theory will be introduced, followed by a detailed explanation about the relatively new Mission-oriented Innovation Systems (MIS) framework. The chapter ends with literature review about learning in sustainability transitions. The aim of this chapter is to provide a literature-based foundation for this research.

2.1 Circular Transition

In the current system two economic systems can be distinguished. On the one hand the linear economy and on the other hand the circular economy. To understand which economic system we are now and why there is a need for a transition, the concept of both economic systems have to be explained first.

2.1.1 Linear economy

The opposite of a circular economy is a linear economy. The linear economy is based on the "take-make-dispose" principle. As seen in figure 2-1, first raw materials are collected (*take*), then the material(s) are transformed to products (*make*) and finally the product will be disposed (*waste*).

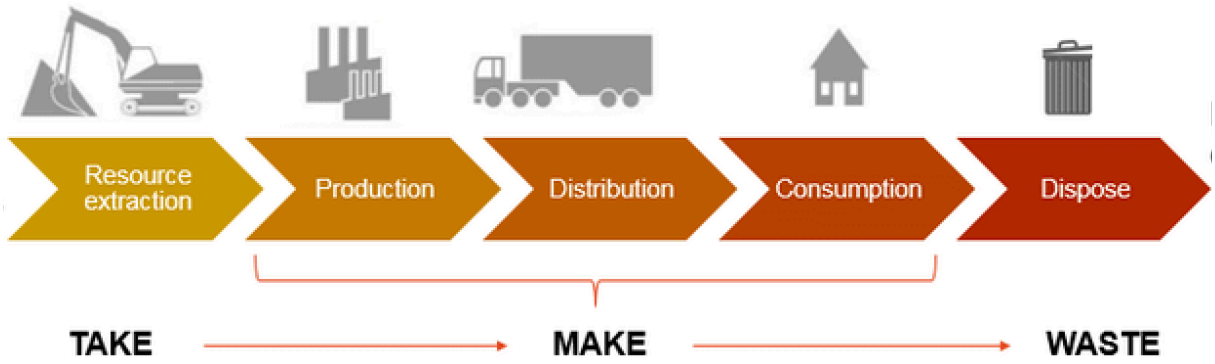


Figure 2-1: Linear economy, take-make-waste approach (Wautelet, 2018)

To make this work, a constant supply of natural resources is presumed. Continuously growing population and the limited regenerative capacity of the earth make the linear model unsustainable. The realization that this fully linear model is not sustainable was fueled years ago. In response to this, an intermediate form has emerged in which a lot of attention was paid to recycling. Recycling is the process in which a waste product, is completely or party processed into a new product. Recycling in this intermediate form of the linear economy is often accompanied by a loss of quality. When a product is reprocessed in less valuable product, it is called downcycling (Lee, Lye, & Khoo, 2001). The limits of the (predominantly)

linear approach are becoming visible. This model has multiple disadvantages from an economic, environmental and social point of view. The linear economy highly relies on the constant supply of raw materials. Fluctuating prices, scarcity and geopolitical dependencies are threatening the constant supply of materials. If Europe wants to achieve the goal of being the first climate neutral continent and have a positive impact on the ecological systems, a transformation of the production- and consumption patterns is necessary (Schroeder, Anggraeni, & Weber, 2018).

2.1.2 Circular Economy

To make our economic model no longer dependent on the constant supply of raw materials, the (predominantly) linear model must be converted into a circular model. The concept of the circular economy has been gaining momentum and is seen as a promising approach to help reduce the pressure on the planet (European Commission, 2020b). In a circular economy, the emphasis is on the conservation of raw materials. The circular economy is based on three principles (EMF, 2013):

- Eliminate waste and pollution;
- Circulate products and materials and;
- Regenerate nature.

Circularity is seen as an operationalization to sustainable development and requires a change in the way natural resources are used. The definition of circular economy is still under development and no consensus has yet been reached. In 2017 a comprehensive analysis of 114 definitions to conceptualize the circular economy was done (Kirchher, Reike, & Hekkert, 2017). This indicates that the concept of the circular economy lacks coherence. The findings from this report indicate that circular economy is most frequently defined as a combination of reduce, reuse and recycle activities. Circular economy means many different things to different people. For the rest of the research it is important to choose a clear definition. Kirchher (2017) emphasizes that CE necessitates a systemic shift. One of the definitions of circular economy used by the platform CB'23 is (CB'23, 2021):

> *"an economic system that optimizes the use and value of resource flows without hampering the functioning of the biosphere and the integrity of society"*

Climate change and resource depletion are two important challenges which can be addressed by the transition towards a circular economy (Murray, Skene, & Haynes, 2017). This transition has both economic and environmental benefits. Economic growth has to be decoupled from the consumption of raw materials. In a linear economy, value is created by producing and selling products. In a circular economy the focus is on services rather than products. Value is created by focusing on preserving value. Residual streams must be reused for a function which is at least equal to the original function. Preferably the function of reused materials will be even higher than the original value, which is called upcycling. The Dutch system is currently somewhere between a linear and a circular economy (Figure 2-2).

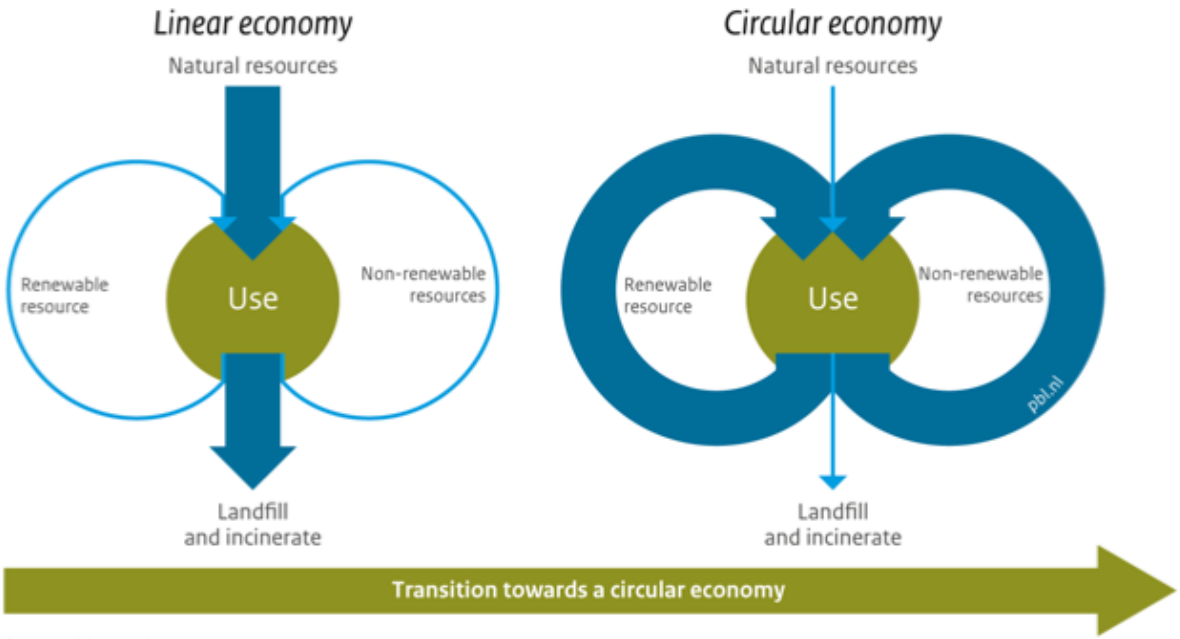


Figure 2-2: From a linear to a circular economy (PBL, 2016)

2.1.3 Ladder of Circularity

The PBL ladder of circularity by Potting (2018) focusses on the function of a product. Focusing on the function of a product, rather than the product itself, makes it is possible to consider radically different "*products*". The circularity ladder helps to make conscious decisions in the design process about the use of raw materials and the function of a product. In an "*ultimate circularity*", a product chain is closed and materials can be applied over and over again. A product chain goes from extraction of natural resources to waste treatment after the discarding phase. As a rule of thumb, circular strategies higher up the ladder require fewer materials and these materials are often made from recycled materials. This does not mean that the lower R-strategies should be avoided. All R-strategies are needed to achieve a circular economy. Recycling is still a possible circularity strategy when a product can no longer be (re)used.

Categorization in four comprehensive strategies

The six Rs are categorized in four circular strategies (Figure 2-3), namely: narrow the loop, slow the loop and close the loop. Substitute is a fourth circular strategy included in the figure which does not directly refer to one of the Rs, but is an important strategy to include in the transition to a circular economy. For narrowing the loop the goal is to use fewer resources per product. This strategy is useful in the purchase phase. Slowing the loops means to extend the useful life of a product in order to slow the overall flow of resources down and is relevant in the usage phase. Closing the loop is the biggest loop in figure 2-3 and means to create a circular flow through recycling of resources. Because closing the loop focusses on recycling, it is relevant in the discard phase.

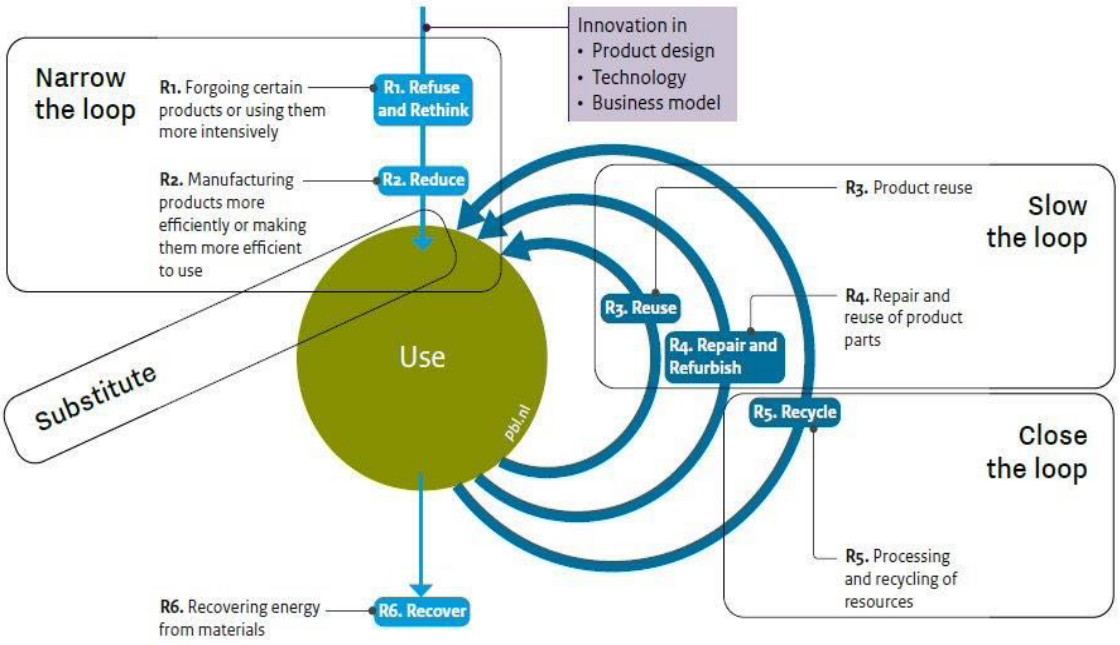


Figure 2-3: R-ladder of circular strategies (Potting et al., (2018)) – Edited by the Ministry of Infrastructure and Water Management

Circular initiatives per priority chain

Figure 2-4 shows that the majority of innovative circular initiatives in all five of the priority chains indicated by the Dutch government, still focus on recycling. Recycling is already common practice in the construction industry. Nevertheless, in many cases only a part of the value of the material is preserved when recycled. So in many cases recycling refers to *down*cycling. To make the transition to a 100% circular economy in 2050, the focus should shift to *up*cycling in which the product has preferably a higher value than the original value. Already in the design process of a product, all R strategies should be considered. This does not only require technical innovation but also social innovations.

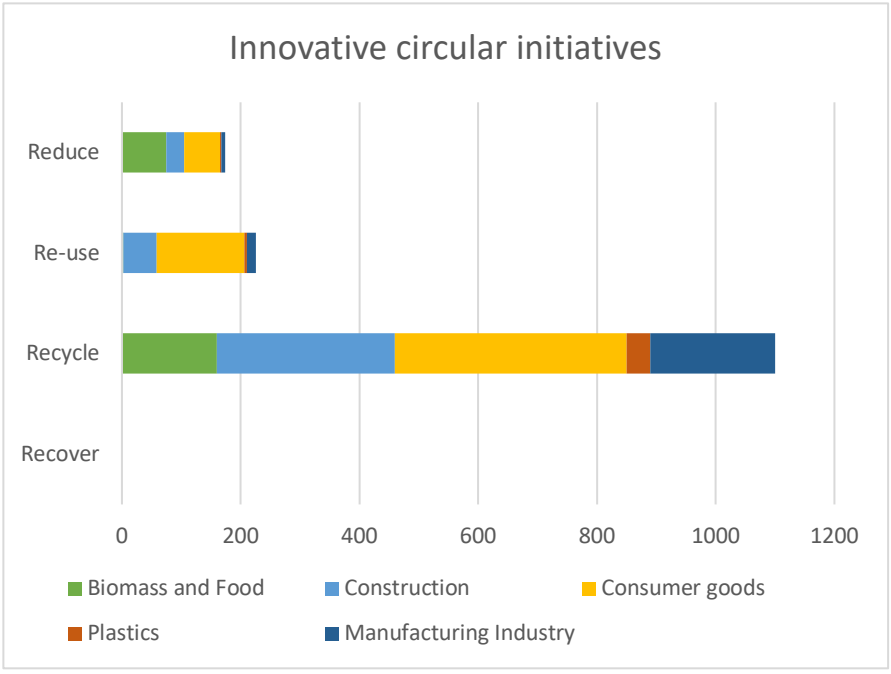


Figure 2-4: Number of innovative circular initiatives categorized per R-strategy, adapted from (PBL, 2019)

2.1.4 Circular Infrastructure

There are multiple factors which make the infrastructure a unique and challenging sector in the transition (NL Platform, 2022). The sector is highly governmental dominated because clients in infrastructural projects are often public clients. Safety and availability must be guaranteed at all times. There is often a risk averse attitude to infrastructure projects due to the strong focus on delivery within scope, within budget and on time. From a technical point of view, most project are not very complex. What makes the infrastructure sector challenging to change is the usually very long lifespan of projects. The long planning process of infrastructural projects makes innovation challenging. Due to the long lifespan of projects, implementing circularity is not only about taking this into account from the first phase of the project lifecycle. Because of the large renovation task in the Netherlands, it also means dealing with infrastructure that has been built years ago. The application of innovative ideas should not be hindered by choices made in the past, when little or no attention was paid to circularity.

The infrastructure sector is operating highly on a project basis. Contractors do not have the certainty whether their innovative knowledge or investment can be used in a future project. Major investments need to be done to contribute in the transition to a circular economy. Before making informed investments, a long-term vision is needed. In general, contractors cannot depreciated such a large investment on one project. Also the validation process of innovative ideas in the infrastructure sector, for example a new concrete mixture, is slow and stiff.

2.1.5 Circular Construction

The Dutch construction sector can be split into the residential building and utility sector and the infrastructure sector. Although both sectors have their own characteristics, in many policy documents the construction sector is analyzed as one. There are challenges that can be tackled for both sectors together. A remarkable fact for both sectors is the fact that the technical lifespan of infrastructure and buildings is often much longer than the functional or economical lifespan, which offers the opportunity for high-quality reuse. Besides the similarities, there are some unique characteristics for both sectors (figure 2-5). The focus of this research is on the infrastructure sector. However, the interdependence of the two sectors is important to keep in mind. Approximately 97% of the construction and demolition waste from the residential building and utility sector is for an important part low-grade reused in the infrastructure sector (Transitieteam Circulaire Bouweconomie , 2021). Only 3% of the raw materials return to their original function in the residential building and utility sector. This makes the inflow of primary materials here still high. Also in the infrastructure sector the inflow of primary raw materials is still substantial, especially for the production of concrete.

Many definitions of circular construction have been formulated over the years. The definition of circular construction, used by the transition agenda is all-encompassing and is as follows (Transitieteam Circulaire Bouweconomie , 2021):

> *"Circular construction means developing, using and reusing buildings, areas and infrastructure, without unnecessarily depleting natural resources, polluting the living environment and damaging ecosystems. Building in a way that is economically responsible and contributes to the well-being of humans and animals. Here and there, now and later."*

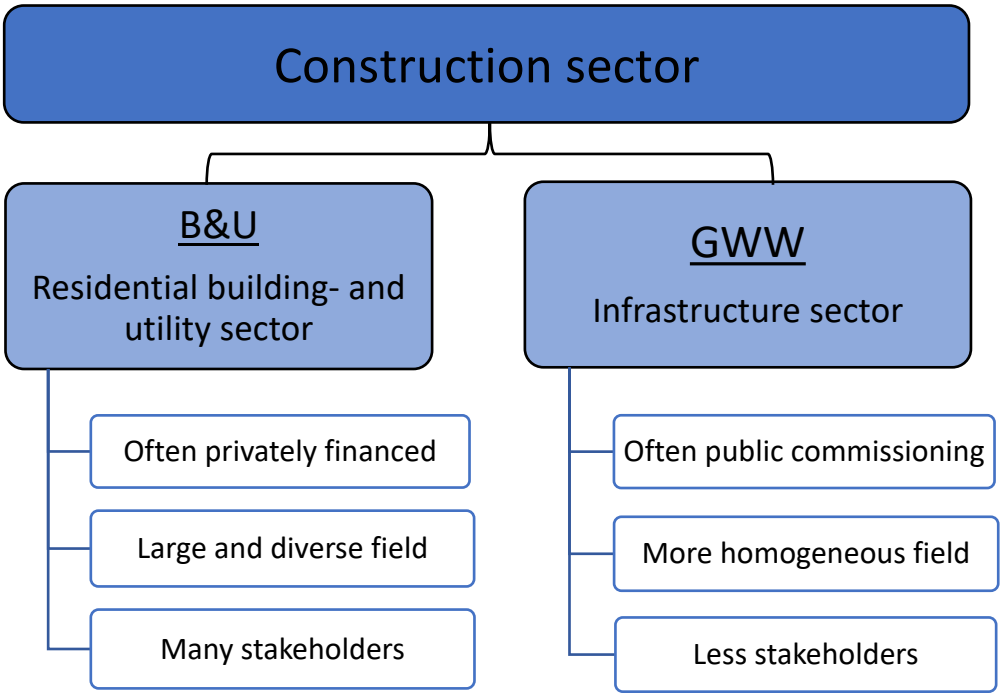


Figure 2-5: Overview of the Dutch construction sector

2.2 Transition studies

Recently, the academic domain of transition theory has received a lot of attention. A transition can be defined as (Geels F. W., The multi-level perspective on sustainability transitions: responses to seven criticisms, 2011):

"a complex and long-term process with multiple actors involved"

Transitions take place in multiple socio-technical systems, such as energy, mobility and healthcare. It is a result of co-evolution of technologies, practices, institutions and society changing in a particular direction (Geels F. , 2005). It is not easy to change an existing socio-technical system, it is often a very slow process. This can be attributed to the large number and variety of actors and the interests involved, which makes the transformation process highly complex. With the sustainability challenges we are facing today, research on transition theory has a high societal relevance. A sustainable transition can be defined as: "*a radical transformation towards a sustainable society, as a response to a number of persistent problems confronting contemporary modern societies*" (Grin, Rotmans, & Schot, 2011).

The four central frameworks on sustainability transitions

Given the high social relevance of transitions studies, many theoretical frameworks have been developed to study transition processes in the past 10-15 year. In transition studies, four central theoretical frameworks on sustainability transitions can be identified (Markard, Raven, & Truffer, 2012). The four prominent frameworks are transition management (TM), strategic niche management (SNM), multi-level perspective (MLP) and the innovation systems approach (IS). One of the key concepts in transition studies is transition management. TM strategically uses transitions arenas (TA) to develop visions and goals and to identify transition paths in collaboration with multiple stakeholders (Hyysalo, et al., 2019). This framework is

useful, but one of the drawback is, it lacks the analytics systems perspective (Loorbach, 2009). SNM uses the pivotal role of niches. Niches are protected spaces in which radical innovations can develop without being subject to the prevailing regime (Kemp et al., 1998). In SNM, the creation of such niches is seen as a way to trigger regime changes. MLP explains transitions by an interaction at the level of niche, regime and landscape (Geels, 2002). Unfavorable landscapes might put pressure on existing regimes. This can cause an open window of opportunity for a niche to break through in order to contribute to a shift in socio-technical regime. Interaction between the three different levels and the timing shows how transitions can evolve.

The transition to a circular economy requires a change in the intention of innovation policies (Wanzenböck et al., 2020). One of the central theoretical frameworks in sustainability transitions is the concept of (technological) innovation systems. The first generation of innovation policy was focused on fixing market failures through increasing investments in R&D. In the second generation, the importance of a strong national innovation network was highlighted. The focus of the first two generations of innovation policy was mainly on innovation for economic growth (Schot & Steinmueller, 2018). To address wicked, societal problem, such as climate change, there is a need for a change in the socio-technical system. The third generation of innovation policy is aimed at dealing with societal challenges (Haddad et al., 2019). Hekkert defines a societal challenge-based mission as (Hekkert et al., 2020):

"an urgent strategic goal that requires transformative systems change directed towards overcoming a wicked societal problem".

Both technological and non-technical innovations, such as institutional changes, should be considered to successfully complete a mission. A considerable body of literature is available to understand and explain how transitions to more sustainable systems are possible. Other innovation systems, defined at global (GIS), national (NIS), sectoral (SIS) and regional (RIS) levels, have been developed. These innovation systems are all limited in some way. A framework to map and evaluate innovation dynamics that contributes to completing a societal mission, was missing. To study more limited issues, one of the innovation system approaches mentioned above may suffice. However, studying such a wicked social problem requires an approach that looks beyond the boundaries of the aforementioned systems.

2.3 Innovation Systems approach

Transition from a linear to a circular system requires organizational changes, different behavior and different forms of collaboration (Sustainability University Foundation, 2020). An innovation system is an analytical framework to analyze and understand system dynamics and the performance of the system (Bergek et al., 2008, Hekkert et al., 2007). An innovation system can be defined as (Edquist & Lundvall, 1993):

"all institutions and economic structures that affect both rate and direction of technological change in society"

Components of an innovation system are the actors, networks and institutions (Carlsson & Stankiewicz, 1991). The definition of these structural elements can be found in Table 2-1. All components contribute in the development, diffusion and utilization of new products and processes.

Actors	Individuals, institutes or organizations that have a decisive influence in a particular process
Networks	An intermediate form of organization between hierarchies (internal organization within entities such as firms) and markets (Carlsson & Stankiewicz, 1991)
Institutions	The normative structures which promote stable patterns of social interactions/transactions necessary for the performance of vital societal functions (Carlsson & Stankiewicz, 1991)

Table 2-1: Definitions of the structural elements of an Innovation System

Building up of a new innovation system

In a system, the group of components is working together towards a common objective. Opposing interests among actors may cause tension in the dynamics of the innovation system. In order to direct the components better, several innovation system concepts are developed. To achieve transformational change it is important to shape the direction of a given innovation. Innovation policy tries to shape innovations in the right direction in order to tackle grand societal challenges (Mazzucato, 2016). Once an innovation system is present, it is much easier to innovate within the boundaries of the innovation system because structural elements are aligned. In an early stage of development, greater attention should be paid to more radical innovations to challenge the yet existing socio-technical systems. However, radical innovations that overthrow the stability of an established innovation system run into systemic problems. This has to do with the competition between multiple existing innovation systems. Inertia can lead to a lock-in of mature innovation systems when structural components are unable or unwilling to facilitate radical innovation. In existing innovation systems, actors, networks and institutions are already developed and optimized in terms of costs and performance.

2.3.1 Technological Innovation Systems (TIS)

Innovation systems can be demarcated in many ways. As mentioned before, global, national, sectoral and regional are commonly used demarcations. It used to be thought that radical innovations were always of a technical nature which makes TIS one of the early branches of the concept of innovation systems. TIS is concerned with the generation, diffusion and utilization of novel technologies and the institutional and organizational changes (Carlsson & Stankiewicz, 1991). The focus of this framework is on new technologies as a basis for fundamental socio-technical transitions, rather than new technologies contributing to economic growth. For TIS there are seven key functions identified. These functions help to evaluate the performance of the innovation system. All function need to be fulfilled in order to have a well-functioning innovation system.

An important step in a TIS-analysis, is to identify drivers and barriers in the system's performance based on the so-called system functions. The analytical focus of TIS is on a new technological solution and little to no attention is given to the one that has to be replaced. Therefore, TIS is not a holistic transition framework and not suitably qualified to understand the impact of missions (Haddad & Bergek, 2020). The TIS framework is particularly helpful to deal with the emergence and diffusion of innovations. Innovations do not take place in a vacuum as it will be influenced by the system they are embedded in (Carlsson & Stankiewicz,

1991). In the research on sustainability transitions, TIS have acquired a strong position (Markard et al., 2012).

Limitations of TIS

After applying the TIS framework on multiple cases, a few limitations of the model became clear. When there is a large variety of solutions available, the TIS framework is less suitable (Bergek et al., 2008). The goal of a TIS is to converge actors in a specific technological trajectory (Schaile et al., 2017). It is also not a holistic transition framework because the analytical focus is on new technological solutions and not on what has to be replaced (Wesseling & Meijerhof, 2021). To develop and adopt new ways of production, distribution and consumption, first the current regime has to be destabilized. When trying to solve more complex societal challenges, the models needs to be expanded. This has been done with the introduction of missions.

2.4 Mission-oriented Innovation Systems

2.4.1 Missions

A promising approach to address complex societal challenges is the concept of missions. This is not a new concept as it was already used in the 1960s. At that time, missions often had a well-defined problem and corresponding solution(s), and were mainly technically complicated. A classic example is the "Man on the Moon" mission (Nelson, 1974). The mission can be formulated in technological milestones and the general dissemination of the innovations was not a main concern. In the past decade, interest in missions aroused again. Three generations of missions can be identified (Table 2-2)

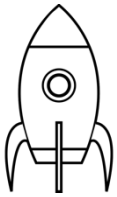
		
First generation Economic catch-up missions	**Second generation** Defense, nuclear and aerospace missions	**Third generation** Tackling grand societal challenges
Example: Industrial and technological revolutions	Example: Apollo Mission	Example: Sustainable Development Goals
Late 19th / early 20th centuries	Mid- to late 20th century	21st century

Table 2-2: Three generations of mission-oriented innovation policies, based on (Kattel & Mazzucato, 2018)

Current societal problems are much more complex and therefore require a third generation mission. Table 2.3 shows that the meaning of the concept has changed over time. Missions are currently understood as (Hekkert et al., 2020a):

> *"emerging governance mechanisms supposed to afford the engagement of a wide spectrum of stakeholders around a mobilizing goal of societal relevance, with the objective of activating or catalyzing these stakeholders' (innovative) activity in service of that goal"*

Current societal problems cannot be solved by purely scientific solutions. Multidimensional challenges of societal relevance should be tackled. Addressing these type of third generation

missions require a combination of sociology, politics, economics and technology (Mazzucato, 2018b). In modern missions, the outcome is less clearly defined (Foray, Mowery, & Nelson, 2012). Non-technological innovations have become more important (Fagerberg, 2018).

Importance of correct formulation of missions

Because of the magnitude of the problems, the majority of the missions are formulated by the government. Using the concept of missions has proven to be an effective approach to mobilize innovative activities (Mazzucato, 2018a). It is of great importance to use the right formulation. The trade-off is always on the one hand how to make the missions broad enough to engage stakeholders and attract cross-sectoral investments, but on the other hand to keep it also focused enough to achieve measurable successes and involve industry. On a European level key criteria for missions are described as (Mazzucato, 2018a):

1. Missions should be inspirational and have wide societal relevance;
2. Missions should have a clear direction, including a target, a timeframe and being measurable;
3. Missions should have a balance between an ambitious and a realistic targets;
4. Missions should address multiple disciplinaries, sectors and actors;
5. Missions should have multiple, bottom-up solutions.

Based on these five criteria, it already shows that boundaries between dimensions (national, regional, sectoral and technological) are crossed. Societal challenges cannot be considered individually in a vacuum, they will not stop at a geographical border. It also requires engaging a diverse group of organizations and stakeholders in new forms of collaboration.

The three dimensions of wickedness

Wicked problems are opposite to routine problems. Missions are wicked, temporarily and provide directionality. Mazzucato (2018b) highlights the need for many perspectives in these complex problems. "*Wicked problems are societal problems that are complex, unpredictable and have poorly defined boundaries.*" (Wanzenböck et al., 2020). The level of wickedness of a problem can be described by three dimensions:

1. Divergence;
2. Complexity;
3. Uncertainty.

The transition towards a circular economy scores high on all three dimensions which makes it a wicked problem. Therefore a third generation mission is required to address this transition.

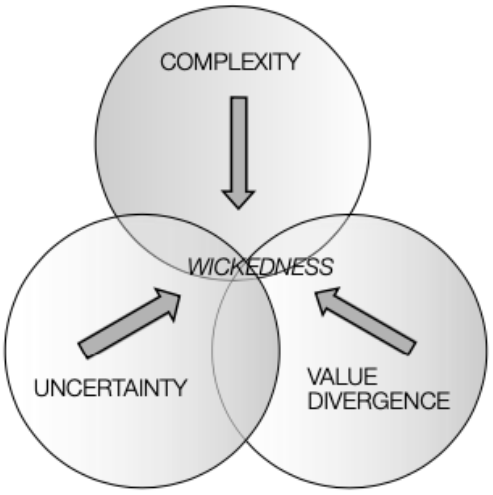


Figure 2-6: The dimensions of wickedness (Head, 2008)

2.4.2 Mission-oriented Innovation System

As Newman and Head (2017) point out, most of the recent societal problems cannot be solved by linear, rational or scientific methods of problem solving. Innovation systems have been delineated by national, sectoral, regional and technological boundaries. Wicked problems require a new type of delineation, crossing the previously mentioned boundaries. A new, promising framework, to comprehend innovation dynamics related to grand societal missions has been introduced (Haddad & Bergek 2020). Mission-oriented Innovation System (MIS) is described as (Hekkert et al., 2020a, pp. 76-79):

> *"the network of agents and set of institutions that contribute to the development and diffusion of innovative solutions with the aim to define, pursue and complete a societal mission"*

In case of MIS, the innovation system is bounded by the formulated mission. The missions are likely to cut through other dimensions, making it a promising research method in dealing with grand societal challenges. As Siderius (2022) mentioned in his paper, it is important to be aware of the difference between changes *within* the system and solutions that actually *change* the system. The goal of MIS is to combine multiple solution trajectories to provide directionality to successfully complete the mission by changing the system (Schaile, et al., 2017). This can be regarded as one of the main advantages of a MIS analysis. On the other hand, it is important to keep track of the course of the innovation process. For that reason continuous and dynamic monitoring and steering is required (Mazzucato, 2018b).

Not only the emergence of new technological and societal innovative solutions is important, also the phasing out of existing practices and technologies. This makes MIS a transformative, rather than only an innovative system (Janssen et al., 2021). One of the drawbacks of TIS is that it lacked the transformative approach. A MIS emerges around problems rather than solutions. The aim is to mobilize existing actors, networks, institutions and materiality and realign these innovation system structures into a well-functioning MIS (Wesseling & Meijerhof, 2021). The attention for both problem- as solution directionalities is also an improvement in the model.

Innovation system failures in most literature focuses on the weakness in the composition of the structural elements of the system. However, to identify the strength or weakness of an element in the system, one should look at the effects of the element(s) on the innovation process (Bergek et al., 2008). These processes are labeled as functions in the MIS framework. The introduction of these functions helps to shift the focus from the dynamics in the structural elements to the contribution of structural elements to the overall function of the innovation system. Structure and content are separated. The performance of an innovation system can be assessed by analyzing how well the system functions have been served (Johnson, 2001). The system functions are based on the seven functions from TIS, supplemented with the unique MIS functions. The nine different MIS system functions are mentioned in Table 2-3. Using the functions perspective provides a systematic method which increases the analytical power of the innovation systems approach (Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007).

Function	Description
F1: Entrepreneurial activities	Activities, initiatives, experiments, pilot projects, market introductions, novel business models of market players regarding new (clusters of) solutions towards the mission.
F2: Knowledge development	Creating knowledge on the problems and solutions "by research" and "by doing", including forecast studies, lab work, working groups and strategic studies
F3: Knowledge diffusion (through networks)	Dissemination of knowledge regarding the problems and solutions through media, stakeholder meetings, knowledge networks, governance structures, publications and "learning by interaction".
F4a: Problem directionality	Formulation of the societal problems with respect to the mission and the priority in relation to other (societal) challenges.
F4b: Solution directionality	The efforts made to provide direction towards the mission goals in terms of (clusters of and coordination between) solutions and their priorities.
F5: Market formulation and destabilization	Creation of conditions such that new solutions can compete with existing practices, e.g. by the creation of "mission arenas", business models and pricing mechanisms, as well as phasing out and destabilizing undesired markets with respect to the mission.
F6: Resource (re)allocation	Mobilization of financial, human and material resources to facilitate the other system functions and withdrawal of resources that support undesired activities with respect to the mission.
F7: Creation and withdrawal of legitimacy	Establishing and eliminating legitimacy for the initiation and prioritization of problems and solutions through raising awareness, stakeholder engagement, lobbying, championing, etc.
F8: Coordination	The effort from actors to steer and align the various actions taken to accelerate the transition over the different pathways and the phase-out of the current system. This also includes monitoring and evaluating the mission and subsequently take appropriate measures.

Table 2-3: Description of MIS-functions (based on Wesseling and Meijerhof, 2020)

2.4.3 Mission-oriented innovation policy

In previous missions, policy was focused on fixing market failures to enhance economic growth, because it had the development of new technological solutions with economic growth as ultimate objective (Schot & Steinmueller, 2018). In the new innovation policy, the objective shifted from economic growth to solving societal challenges. It is about solving problems that call for a system-wide transformation. The definition of mission-oriented innovation policy (MIP) by (Wanzenböck et al., 2020):

> *"a directional policy that starts from the perspective of a societal problem, and focuses on the formulation and implementation of a goal-oriented strategy by acknowledging the degree of wickedness of the underlying challenge, and the active role of policy in ensuring coordinated action and legitimacy of both problems and innovative solutions across multiple actors."*

Because of the nature of the problems that can be addressed by MIP, policy should stimulate innovation across multiple sectors (Mazzucato, 2018b). MIP is about fixing existing markets, but it is also about creating new ones. Bottom-up experimentation and learning should be enabled. Investing in early stages of research is risky because the creation of a new market is uncertain in terms of cost and performance (Sandén & Azar, 2005). Because incumbent

technologies are widely used and diffused, they have an advantage over new entrants. This does not necessarily mean that the incumbent technology is better. An important factor in designing policy, is to prevent lock-in of a specific technological trajectory (Fagerberg, 2018). Policy to enable funding of innovation in an early stage of research is important to create new markets (Mazzucato, 2018b). The development of a new market does not automatically imply the destabilization of the incumbent market. Other than supporting the development of new markets, the policy should also take the disruption of old markets into account (Kivimaa & Kern, 2016).

2.5 Sustainability-oriented learning

Connection between circular economy and sustainability

Sustainability is related to people, the planet and the economy. An integral part of achieving the Sustainable Development Goals (SDGs) is the transition towards a circular economy. The goal of implementing circular economy is ideally to strive for a more sustainable world (Walker, et al., 2021). Circular economy can contribute to the implementation of multiple SDGs. Sustainable development can be operationalized through the implementation of circular economy, among other things (Kirchher, Reike, & Hekkert, 2017). Circular economy is one of the tools to achieve sustainable development.

Conceptualization of "learning" in sustainability transitions

The aim of this research is to learn something about targeting the transition to a 100% circular Dutch infrastructure sector by taking the perspective of MIS. To indicate whether something has been learned, the notion of "*learning*" has to be conceptualized. Sustainability is a collective good, which makes learning in this transition different from traditional learning approaches. The goal of this transition is related to a collective good and it does not directly offer user benefits, which makes it different from other transitions (Geels, 2011). A structural change is required, where good practices should keep going and unsustainable processes should be destabilized (Wals, 2020). Sustainable development is not only about ideas, it also requires the power to transform in the envisioned direction. As Stirling mentions, sustainability is an ambiguous and contested concept and because of that there will be disagreement and debate about the directionality of sustainability transitions (Stirling, 2009). From a learning point of view this can both be seen as challenging and interesting. The disagreement about the directionality makes learning in this field challenging. On the other hand, this creates an environment where learning and reflection are invited and stimulated. Sustainability-oriented learning can be defined as (Wals, 2020):

> *"an organic and relational process of continuous framing, reframing, tuning and fine-tuning, disruption and accommodation, and action and reflection, guided by a moral compass of doing what is right and inspired by an ethic of care"*

To make sure not to exclude the development of innovation trajectories by a specific formulation of the final goal, the goal has to involve vague elements. The definition of sustainability is dependent on time, place, socio-cultural and economic circumstances. What used to be seen as a sustainable solution, can now be seen as unsustainable.

Learning stimulates creating, enriching and sharing of knowledge (March, 1991). To design a learning space that enables people and organizations to contribute to sustainable development, Wals (2020) defines four related dimensions that refer to both the process and the outcomes of the learning process (Figure 2-7). Pursuing these four dimensions, helps to develop properties to take steps towards building a sustainable, circular world. Under these conditions, sustainability-oriented learning is stimulated by the organic and relational process of adjusting frames and meanings.

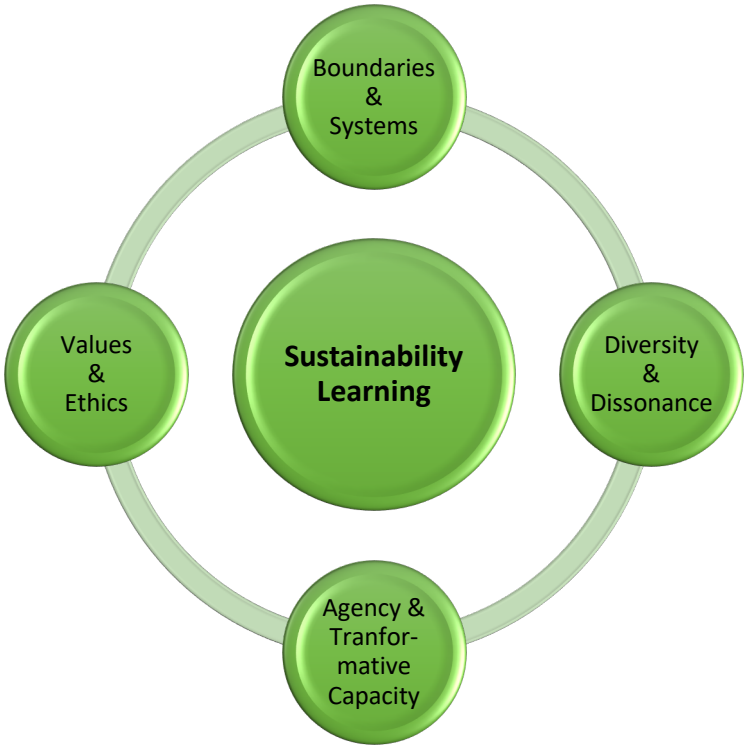


Figure 2-7: Key characteristics of sustainability-oriented learning, adapted from (Wals, 2020)

Ethics and values

First, sustainability learning stresses the importance of considering ethics and values. Not everyone has the same values and ethics. In this first dimension in sustainability-oriented learning, citizens are made aware of the direction in which they move and their contribution and position in the world. Education helps how to move in another direction, when they are uncomfortable with the current direction they move in.

Boundaries and systems

The second dimension concerns boundary crossing and systems thinking. Keeping an overview of the entire system rather than just focusing on relatively small parts in the systems is important. Broadening your view and breaking through boundaries is key. Boundaries can be defined as: "*socio-cultural differences leading to discontinuity in action or a discontinuity of interaction*" (Akkerman & Bakker, 2011). Barriers can be seen as spaces with potential for learning. The emergence of friction creates a window of opportunity to reframe the way of thinking, to learn something new and to expand the horizon (Wenger, 2010).

Diversity and dissonance

The third dimension relates to utilizing diversity and dissonance. Educational psychology has shown that conflict and dissonance are crucial for learning (Berlyne, 1960). Dissonance can

lead to a tipping point, which triggers change in the way of thinking or to break with existing routines and systems. It is important for actors in the system to appreciate and utilize differences. To utilize conflict and dissent, there has to be respect and social cohesion in the group to avoid unhealthy tensions, but conflicting opinions are valued (Wals, 2010).

Agency and transformative capacity

The fourth dimension in Wals' (2020) model on sustainability-oriented learning is the transformative dimension. This concerns the ability to adapt to new situations and the power to oppose to unsustainable development (Jickling, 2013). Transformation is different from optimization. Two fundamental learning processes to create knowledge are exploitation and exploration (March, 1991). In exploitation, the values upon which a system is based are left intact and the focus is on efficiency. Exploration focusses on radical innovations. This refers to rethinking and redesigning of prevailing systems. Both learning processes are essential, but they are both at the expenses of each other. Organizations make explicit and implicit choices between the two.

2.6 Conclusion on the first sub-question

In this chapter a theoretical foundation has been built to continue the rest of this research. After elaborating on theoretical concepts, the first sub-question can be answered. The question is:

How can the concept of the Circular Economy be defined in the Dutch infrastructure sector?

Subsequently the concepts of circular transitions, transition studies, innovation systems, MIS and sustainably-oriented learning have been explored. The starting point of a linear economy is the take-make-waste idea. A fully circular economy is based on these three principles:

- Eliminate waste and pollution;
- Circulate products and materials and;
- Regenerate nature.

Currently the society is somewhere in between a linear and circular economy. Circular activities can be categorized in four comprehensive categories, namely close the loop, slow the loop, narrow the loop and substitute.

A transition is required to get to a circular economy. The field of transition theory has received a lot of attention recently. Four prominent transition frameworks can be noticed. From these four frameworks, the innovation system approach has been further elaborated. The definition of an innovation system is:

"all institutions and economic structures that affect both rate and direction of technological change in society"

Important structural elements in innovation systems are: actors, networks and institutions. One of the early branches in the innovation system approach is the technological innovation system (TIS). The focus of this framework is on new technologies as a basis for fundamental socio-technical transitions. When facing a wicked problem with a large variety of solutions,

the TIS framework is not sufficient. With the introduction of third generation missions, societal problems can be addressed. The TIS framework has been expanded to a mission-oriented innovation system (MIS). Taking a mission as a starting point will cut through national, regional, sectoral and technological dimensions, making it a promising research method in dealing with grand societal challenges.

Learning in the field of sustainability is different from traditional learning approach because sustainability is a collective good. The four dimensions that refer to both the process and the outcomes of sustainability learning are:

- Ethics and values;
- Boundaries and systems;
- Diversity and dissonance;
- Agency and transformative capacity.

3. Methodology

In this chapter, the research methodology is explained and methodological choices are explained and justified in detail. The aim of this chapter is to answer the second sub-question: "*How to map and analyze the circular transition process of three recent social agreements in the Dutch infrastructure sector, by employing the Mission-oriented Innovation Systems approach?*" In this chapter, the methodological approach is explained and a clear overview of how data will be collected and analyzed in relation to the sub-question is given. The MIS approach was already highlighted in the previous chapter. To structure this chapter, it has been divided into the three phases of the MIS. Per phase the key objectives and methodological choices have been elaborated. It will elaborate on the question how the application of the MIS framework contributes to answering the research question.

3.1 Research design

The objective of this research is to learn about the application of the relatively new MIS framework in the transition towards a circular Dutch infrastructure sector. First, the scope is narrowed down to the level of social agreements. The second narrowing of the scope is based on a material. Applying these scope limitations, the cases include social agreements per material. For this research, three social agreements are analyzed in detail to complement the overall research on the infrastructure sector. Multiple research methods are available to study transitions. To understand change, insight in the static structure of the innovation system is not sufficient. The dynamics within the system are important to take into account. Even though it was predetermined that MIS would be used for this research, as it would perfectly match the general research from Utrecht University, there are multiple reasons that substantiate that this is a very suitable research method. The MIS framework is selected because it appears a promising, qualitative research method for solving grand societal issues and because of its ability to deal with a large variety of problem- and solution directions. The MIS method elaborates in three successive phases (Elzinga et al., 2021).

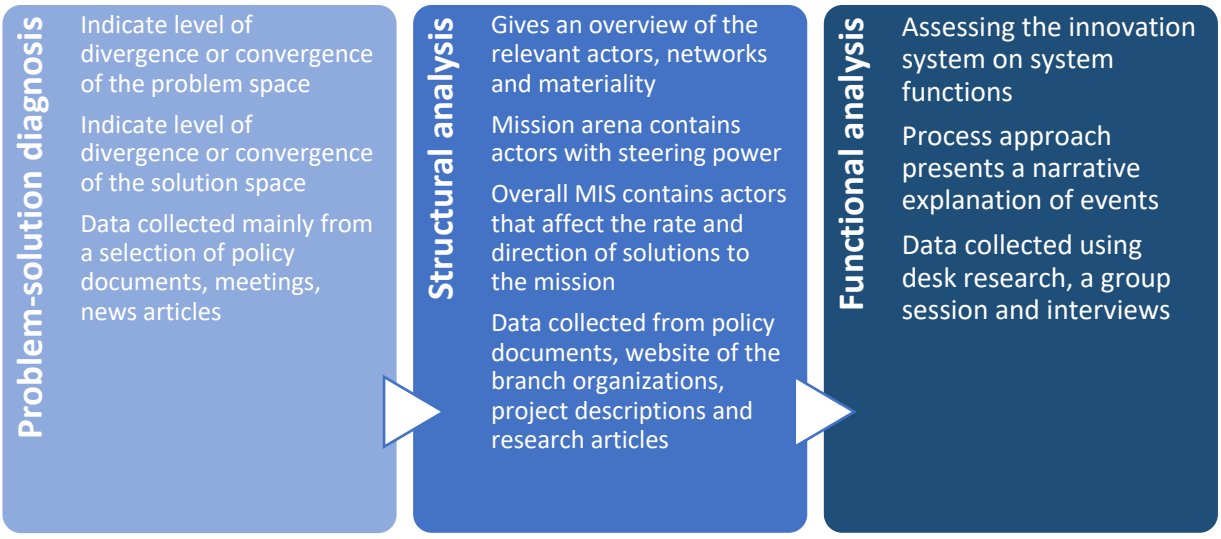


Figure 3-1: Phases of the MIS-analysis

The aim is to mobilize actors, networks, institutions and materiality and realign these innovation system structures into a well-functioning MIS (Wesseling & Meijerhof, 2021). Before being able to create a well-functioning innovation system, the separate elements in the system have to be analyzed. The three phases of the MIS method ensure a clear structure in this research report. Each phase will be followed per case. For every phase, the focus is on different aspects of the system. In this chapter the main focus per phase is highlighted. It also elaborates on how the analysis of every single phase contributes to answering the main research question. In every phase, methodological choices are made to obtain the necessary data to perform the analysis. This chapter is an important guideline to ensure that the necessary information is available to successfully conduct the analysis and reach a conclusion.

3.1.1 Case selection

The Dutch Ministry of Infrastructure and Water Management ("*IenW*") has set the general mission to be completely climate neutral and operate fully circular by 2030. IenW defines climate neutral as, "*no net CO_2 emissions by contractors and other partners in the chain*" and they define circular as "*high quality reuse of raw materials and producing as little waste as possible*". In 2017, Rijkswaterstaat did an inventory on the environmental impact of the materials they use (Rijkswaterstaat, 2022). The aim of this research is to provide more in-depth and specific information to complements the general research on the infrastructure sector. Because of that, three social agreements on high impact material flows are selected to analyze in this research. Per case, smaller sub-missions are formulated.

Choices in delineating the cases

As Mazzucato stated, the trade-off in formulating a mission is always that it should be broad enough to engage stakeholders, but focused enough to achieve measurable successes (Mazzucato, 2018a). This indicates the trade-off on the level of detail for the cases. Each case is a social agreement based on a specific material in the infrastructure sector. In this way enough stakeholders are involved and concrete, measurable goals can be formulated. Per case smaller sub-missions are formulated to contribute to the general mission. The cases for this research concern the materials concrete, wood and steel. These cases have been selected to explore the endeavor of each sector to speed up the transition towards a circular economy. To analyze the cases, three separate MIS-analyses will be performed. It is important that the cases show a certain degree of mutual coherence, in order to systematically compare the results. Results will be compared using a cross-case analysis. The cross-case analysis helps to identify differences and similarities in the three cases (Cruzes et al., 2014).

Characteristics of a social agreement

A social agreement is an instrument under private law. It is a policy instrument with an informal character. A social agreement is: "*an agreement between the government and one or more parties aimed at achieving certain (policy) objectives. Written agreements about the delivery of services are laid down in a social agreement.*" (Rijksoverheid, 2021). Parties in a social agreement are equal. Behavioral changes are initiated because parties make agreements that are primarily stimulating in nature. By using horizontal relationships between parties, more realistic objectives are set. An advantage is that covenants can be established relatively quickly. A disadvantage is the risk of non-compliance by some of the parties.

Characteristics of the selected cases

The selected cases for this research are recently signed social agreements for the materials concrete, wood and steel. Table 3-1 provides an overview of a few key characteristics of the selected cases. Creation of social agreements helps to put important social issues on the political- and public agenda. These types of agreements are morally binding, but not legally enforceable. The agreements ideally provide an impetus for co-creation, innovation and increasing implementation possibilities (Raad voor het Openbaar Bestuur, 2020). This allows social organizations, companies and citizens to make use of their knowledge, experience, innovative ideas and gives them opportunities to influence. The current duration of the three cases is different, this implies every case is at a different stage of development and execution. Every case can be seen as a sub-innovation system with its own actors, institutions, networks and materiality. Each of these elements can appear in more than one of the cases.

	Case I	Case II	Case III
Material	Concrete	Wood	Steel
Initiation of the agreement	Mid 2016	Mid 2018	End of 2021
Agreement signed	July 2018	February 2020	March 2022
Current leading party	Rijkswaterstaat	De Bouwcampus	Bouwen met Staal
Sector	Residential building and utility sector and Infrastructure sector	Infrastructure sector	Residential building and utility sector and Infrastructure sector

Table 3-1: Key characteristics of the three cases

3.2 Application of the MIS methodology

3.2.1 Problem-solution diagnosis

The first step in a MIS analysis is an exploration of the problem(s) and possible solutions related to the mission. A mission is formulated to solve a wicked, third generation problem. In this first step it is important to clearly identify the problem(s) to be addressed by the mission, according to the different actors.

First, it is important to have a clear understanding of level of divergence or convergence of the problem. This can be determined by exploring the different formulations of the mission in different policy documents and from a point of view of different actors. When the analysis shows divergence in the problem-directionality, different actors aim to solve different problems. Mapping the currently explored solution trajectories is another important step in this first phase of the MIS analysis. Because of the wicked nature of the problem, solving the mission requires often more than one single solution. The directionality in a mission does not specify how to achieve success, it rather stimulates the exploration of a wide variety of different solutions to achieve the objective. In an early phase it is not clear which technology or solution will receive most attention and will finally end up as the dominant solution direction. In this phase there is room for bottom-up experimentation which will lead to

multiple solution directions (Bergek et al., 2008). The solution space can also be either divergent or convergent. The development of a dominant solution will be dependent on the priority given to the solution direction. Per case, technological- and social solutions are explored.

The social agreements are initiated to apply a specific material in a more circular way. A possible solution to take into account is to refuse or substitute the specific material. An important note to make here, is that some of the actors who have signed the agreement have a (financial) interest in the continuation of the use of the material. Therefor it is important to have a critical look at the choices made by the actors.

Data collection

As described above, in this research three cases will be explored by performing three separate MIS-analyses. In every case, a smaller mission per material has been formulated to contribute to the overall mission in the infrastructure sector. The general mission for the infrastructure sector has already been mentioned in paragraph 1.2. First it is important to provide a clear overview of the formulated mission per case. The data collection starts with exploring grey-literature. The goals and the problems according to the actors affiliated with the social agreements, are documented in policy documents. In every case, many actors are involved. Various types of documents were consulted to get an understanding of the assumed problems and solutions. Reports from meetings, news articles and a selection of relevant policy documents are expected to give a good insight in the problems the actors in the agreements try to address. An overview of possible solutions per case can also be made, based on these documents. Studying grey-literature gives a good insight into the problems and solutions that have received attention.

3.2.2 Structural system analysis

After clearly mapping out the problem- and solution space, the structural components involved in the process to accomplish the mission are analyzed. This phase of the analysis provides an overview of the relevant actors and their steering power. A MIS does not operate in a vacuum, it involves actors, institutions, networks and materiality (Bergek, et al., 2015). It is important to identify which actors have steering power in the system. The mission arena contains the actors with steering power (Wesseling & Meijerhof, 2021). Actors, networks, institutions and materiality that affect the rate and direction of solutions to the mission, form the overall MIS. A mission arena is temporary, actor-dependent and has a contested or controversial nature (Jørgensen, 2012). The concept of mission arena is based on Loorbach's concept of transition arenas (Loorbach, 2009).

The overall MIS

The overall MIS consists of the mission arena and a much larger group of other actors, networks, institutions, and materiality that support the transition towards a circular infrastructure sector. These actors have less steering power compared to the actors inside the mission arena. Figure 3-2 shows how the mission arena tries to mobilize other existing innovation systems (national (NIS), regional (RIS), sectoral (SIS) and technological (TIS)) to complete the mission. MIS looks beyond the boundaries of other innovation systems. The more successful the mission arena becomes at mobilizing other innovation systems, the more structured the MIS becomes. In a better developed MIS, actors are more engaged, institutions are more institutionalized and solutions are better developed (Wesseling & Meijerhof, 2021).

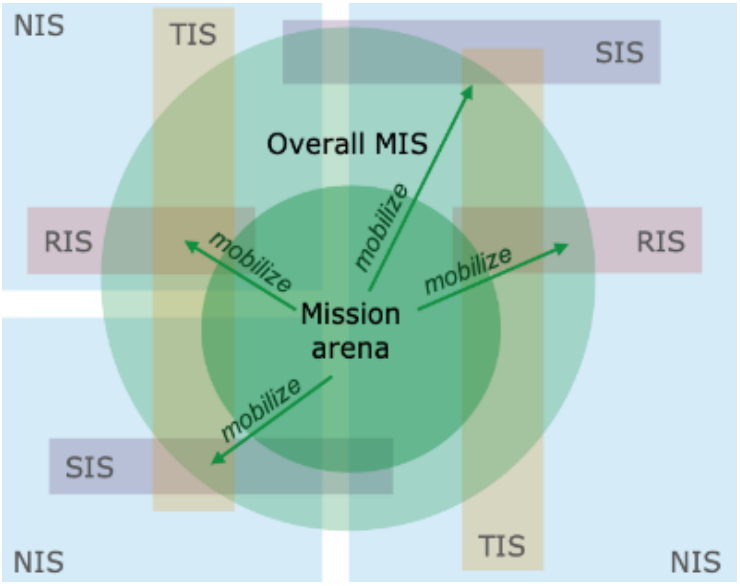


Figure 3-2: Overview of the Mission Arena trying to mobilize other innovation systems into a well-functioning overall MIS (Wesseling & Meijerhof, 2021)

Mission arena

Stakeholders in the mission arena have more steering power compared to the stakeholders outside of the mission arena. Influential stakeholders have acquired the power to set the direction of the solution. Studying mission arenas provides information about how actors can perform strategic interventions that support sustainable transitions (Jørgensen, 2012). Actors that take part in the mission arena have four tasks (Wesseling & Meijerhof, 2021).

1. Setting up the mission arena;
   Establishing the mission arena by determining which actors are inside the mission arena and which are outside.
2. Formulating the mission;
   Societal problems have to be prioritized and translated into executable missions, providing directionality to the overall MIS.
3. Mobilize MIS components via mission governance actions;
   This requires an action plan how the mission arena aims to mobilize the MIS components to improve the MIS performance.
4. Engaging reflexive mission governance;
   Progress of the mission has to be monitored and evaluated. If the MIS no longer captures the most relevant societal problems, it has to be reformulated and redirected.

Data collection

In this phase of the analysis the goal is to map out the relevant actors and other elements that clarify the structure of the case. In this part of the analysis is also room for other structural features that influence sector dynamics. Relevant actors fulfilling the four tasks in the mission

arena are identified by analyzing the actual agreement and other, closely related policy documents. Starting point was a list of actors who have joined the social agreement. The role of influential actors is elaborated on. These actors together form the Mission Arena.

After building up the Mission Arena, other relevant elements in the overall MIS were explored. The overall MIS consists of actors, networks, institutions and materiality if they/it contributes to the circular mission, formulated per case. A list of actors was made up based on information found in policy documents, website of the branch organizations, project descriptions and research articles. Actors are identified as a MIS actors if they contribute to the circular mission, formulated per case. These actors were categorized in different *actor types*, based on their characteristics.

3.2.3 Functional system analysis

In this phase, the performance of the innovation system is being assessed, based on system functions (SFs), mentioned in Table 2-4. These system functions are key processes to build up the innovation system. In a new transition, the innovation system has to be build up. Positive interaction between system functions, also referred to as *motors of innovation*, can help to speed up the development of an innovation system. Negative interactions on the other hand, can slow the process down. A well-functioning innovation system improves the chance to successfully achieve the mission. How the innovation system has developed over time, and what the role of the different functions was in this development, will be the outcome of this phase of the MIS-analysis. The result of the functional analysis will be presented as a narrative description (Hekkert, 2007). "*Activities in innovation systems are considered relevant when they influence the goals of the innovation system*" (Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007). These relevant activities are the functions of the innovation system.

Variance approach versus process approach in social science

In general there are two research methods, often applied in social science: the variance approach and the process approach. Both methods are elaborated on to follow the line of reasoning in the decision to apply the process approach for this research. The variance approach is a research method often used in social science. The variance approach is outcome-driven and gives an explanation of the input factors (independent variables) that statistically explains variation in some outcome criteria (dependent variables) (van der Ven, 2007). The qualitative aspects of a statistical approach can have the disadvantage of losing explanatory information about *how* the process develops over time (Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007). The variance approach is less suitable for this research because it neglects the order of events.

Arguments to support the decision to take the process approach for this research

The process approach, also known as sequence analysis, conceptualizes development and change processes as sequences of events. The outcome of a process approach presents a narrative explanation of the order and sequence of events (van der Ven, 2007). The process approach creates much more insight in the underlying mechanisms compared to the variance approach, because it also gives a narrative explanation. Events will be allocated to the nine system functions defined in the MIS framework. All events either have a positive- or a negative influence on the functioning of the innovation system. As this research method builds further on the coding of the event, it is important that the opinion of the researcher does not

influence the coding process. Validating the coding of the events makes the categorization into the nine system functions more objective. To validate the coding process, a researcher from Utrecht University with extensive experience in coding events, has randomly coded a number of events (appendix A). The differences in coding will be discussed and will help to improve the interpretation of the events.

Two steps of data collection for the functional analysis

In the final phase of the MIS-analysis, the goals is to collect event data for all three cases to create a database of historical events. The first step in the data collection is an extensive analysis of various documents. In order to complement the research from Utrecht University, the main focus for this research was on document analysis. The second step to collect data was to complement the document analysis with interview data. In this second step, a group session and some one-to-one interviews have been done. By performing these two steps successively, the researcher will not be biased by the opinion or view of the interviewees.

Desk research

For the first step, events are selected from documents. It is important to clearly determine which events resulted directly from the selected agreements. In some cases this is difficult to distinguish. Criteria have been formulated to indicate as accurately as possible the difference between events that do and do not arise from the social agreement. The criteria for events that contribute to the mission of the social agreements are either selected from:

- the agreement itself;
- (references on) the website of the agreement;
- the website of the branch associations;
- related research reports;
- news articles.

Most of these documents are written in Dutch. Because all three cases are focused on the Netherlands and the main language is Dutch, the event history analysis is in Dutch. By using these criteria for collecting data, the events that happened as a result of the existence of the agreement, are as accurately as possible distinguished from other circular activities. Circular initiatives initiated by parties from outside the agreement are not taken into account here. For every case, all sources mentioned are consulted to keep the process of data collection consistent. In this way you will get the best possible picture of the events that took place as a result of the social agreement.

An important note to make is the difference in how long the social agreements operate. All three agreements are established with roughly two years in between. Because CE is very topical at the moment, there are many developments and changes in a short period of time. By limiting the data collection to the term of the agreement, the amount of data that can be found per agreements is very different. All events are collected in a separate Excel sheet per case. Per event the following information (if available) has been included in the table:

- Serial number, year and date
- Event description
- Sub-sector
- R-strategy
- Involved partie(s)

- Public/private actor(s)
- System function
- Source

Group session and interviews

To complement and verify this extensive document analysis, experienced people in the field were consulted. This has been done by a group session and by personal interviews. All interviews were conducted in Dutch because this is the native language for all respondents. Conducting interviews in their native language can help people to express themselves better and it reduces the risk of misunderstandings. The group session was structured by going through the nine system functions step by step. For the one-to-one interviews, a semi-structured interview approach has been used. Qualitative research requires flexibility in the interview method. A semi-structured interview approach allows the interviewer to go into more detail on interesting topics that come up during the interview, in addition to the predefined questions. The interview guide with the predetermined questions can be found in appendix I. Based on the prior knowledge from the document analysis, specific questions were also formulated per sector or per actor type. Information that was lacking or unclear from the documents can be elaborated on. The scheduled time per interview was one hour. All interviews are fully transcripted. Quotes from the interview transcripts are used as examples to support the narrative description of the functional analysis. The interview summary and the quotes used in the final report are also checked with the interviewees before presenting the final report, to ensure reliability and integrity.

Participants for the interviews are selected by purposeful sampling. This sampling method is a non-probability sampling technique. The researcher selects the participants for the interviews in such a way that variation among the functions within the agreement are represented in the research. In the selected agreements, many parties are involved. The focus of this sampling method is on selecting information-rich participants (Patton, 1990). Maximum variation sampling is one of the strategies for purposeful sampling and it can be used to construct a holistic understanding of the selected social agreement (Suri, 2011). In this method, central themes are identified to find categories that vary the most. For this research, the themes are divided into the client- and the contractors side. A short description of the categories is presented in Table 3-2. Within each of the three social agreements, all actors who signed the agreement can be grouped in one of the categories.

Actor type	Description
Chairman	A person in charge over a meeting or organization[2]
Public client	The public organization for whom a structure is constructed, or alternatively the public organization that took the initiative of the construction[1]
Contractor	A person or firm that undertakes a contract to provide materials or labor to perform a service or do a job[2]

Table 3-2: Description of the sampling categories

[1] http://stats.oecd.org/glossary/
[2] https://languages.oup.com

The interview can be either a semi-structured interview or a group-session. From every category, for each case was at least one the above mentioned methods has been used. Table 3-3 indicates the type of interview per category per case. The total number of participants in the group-session was 19. A list of organization categories that attended the group session can be found in Appendix C. In the group-session, all three cases have been discussed with contractors and clients. Case I and III formally have assigned a chairman, unlike the second case. This is why the box of the chairman for the second case is grey.

	Case I	Case II	Case III
Chairman	Semi-structured interview (#1)		Semi-structured interview (#1)
Public client	Group-session & semi-structured interview (#2)	Group-session	Group-session & semi-structured interview (#2)
Contractor	Group-session & semi-structured interview (#3)	Group-session	Group-session

Table 3-3: Indication of consulted experts

The deliverable of this final part of the MIS-analysis is a narrative description of the level of fulfillment of the individual system functions. The score of the function is evaluated more in-depth. If structural components are unable to support the system functions, there are systemic barriers. This hampers the functioning of the system (Wieczorek & Hekkert, 2012). Interrelated barriers could also be linked to a potential lock-in of the system (Wesseling & Van der Vooren, 2017). The narrative description provides the opportunity to discuss the "*why*" behind the weak or strong fulfillment of the individual functions. The level of fulfillment of the system function is supported with arguments and quotes from the interviews and examples from news articles and other documents.

3.3 Data analysis

Coding the events

After collecting all the events from the above mentioned sources, a long list of events has been created. An important note to keep in mind while coding the events using the MIS functions is the difference between first and second order effect. The first order comes directly from the event, while the second order effect is the result on other system processes. The first order effect should be coded, but the second order effect should not be coded. The second order effect is mostly an assumption. For example, actors forming a coalition would be coded as SF8: coordination. The assumption that this coalition creates legitimacy (SF7) is the second order effect and should thus not be coded accordingly. Nevertheless, there can be more first order effects in one event. It is allowed to code an event as more than one system function. Therefor the number of events is not equal to the number of nodes (codes on the system functions).

From results to conclusion

To analyze the results from all steps in the MIS analysis, the cases are compared. Per case an overview table with all the highlights from the event analysis is presented. Based on these key events, a dynamic model per case is presented to visualize the results. In the dynamic model, the interaction between the system function become clear. To get from results to conclusions,

the three analyzed cases are categorized in two wider applicable categories. The dynamic models for these two cases are based on the previous dynamic models. Positive interactions between system functions show the processes which are working well and speeding up the transition process. The negative interactions or feedback loops in the dynamic model are slowing the transition process down at the moment and therefore require attention.

3.4 Reliability and validity

To assess the quality of research, reliability and validity are important criteria. According to Bryman (2016), reliability and validity both consist of an internal and an external factor. All four categories are discussed below.

External reliability

The external reliability refers to the extent to which a study can be replicated. The external reliability is a difficult criterion to meet in qualitative research. The exact social setting and circumstances from this research cannot be retrieved later which makes it impossible to replicate the research. However, by indicating the exact time frame for collecting events and the search strings and the used sources, the external reliability is guaranteed as much as possible.

Internal reliability

The internal reliability is determined by the judgement of other researchers. Internal reliability assesses the consistency of the scores on the system functions across the events within the event analysis (Bryman, 2016). An experienced researcher in MIS analysis randomly reviewed 17 events to check the internal reliability. In total there were 33 nodes observed. As it can be seen in appendix A, the number of difference observed in coding is 6 out of 33.

Internal validity

According to Bryman (2016), internal validity indicates whether there is a good match between the observations of the research and the developed theoretical ideas. To assure internal coherence, the results have been cross-checked (Riege, 2003).

External validity

External validity concerns the degree to which the findings can be generalized across social settings. In this MIS analysis, only three specific cases in the Dutch infrastructure sector have been analyzed. Generalizing the results across social settings, for example other countries or other sectors, is complex as every mission is unique (Wesseling & Meijerhof, 2021). Nevertheless, in the discussion (chapter 5), the cases have been generalized into two main categories. This has been further elaborated in the discussion chapter.

3.5 Conclusion to the second sub-question

The second sub-question refers to the methodology. In order to understand the transition to a circular Dutch infrastructure sector it is important to know how this can be mapped and analyzed by employing the MIS approach.

How to map and analyze the circular transition process of the three recent social agreements in the Dutch infrastructure sector by employing the Mission-oriented Innovation Systems approach?

The figure below (3-3) gives a visual representation of the methodology.

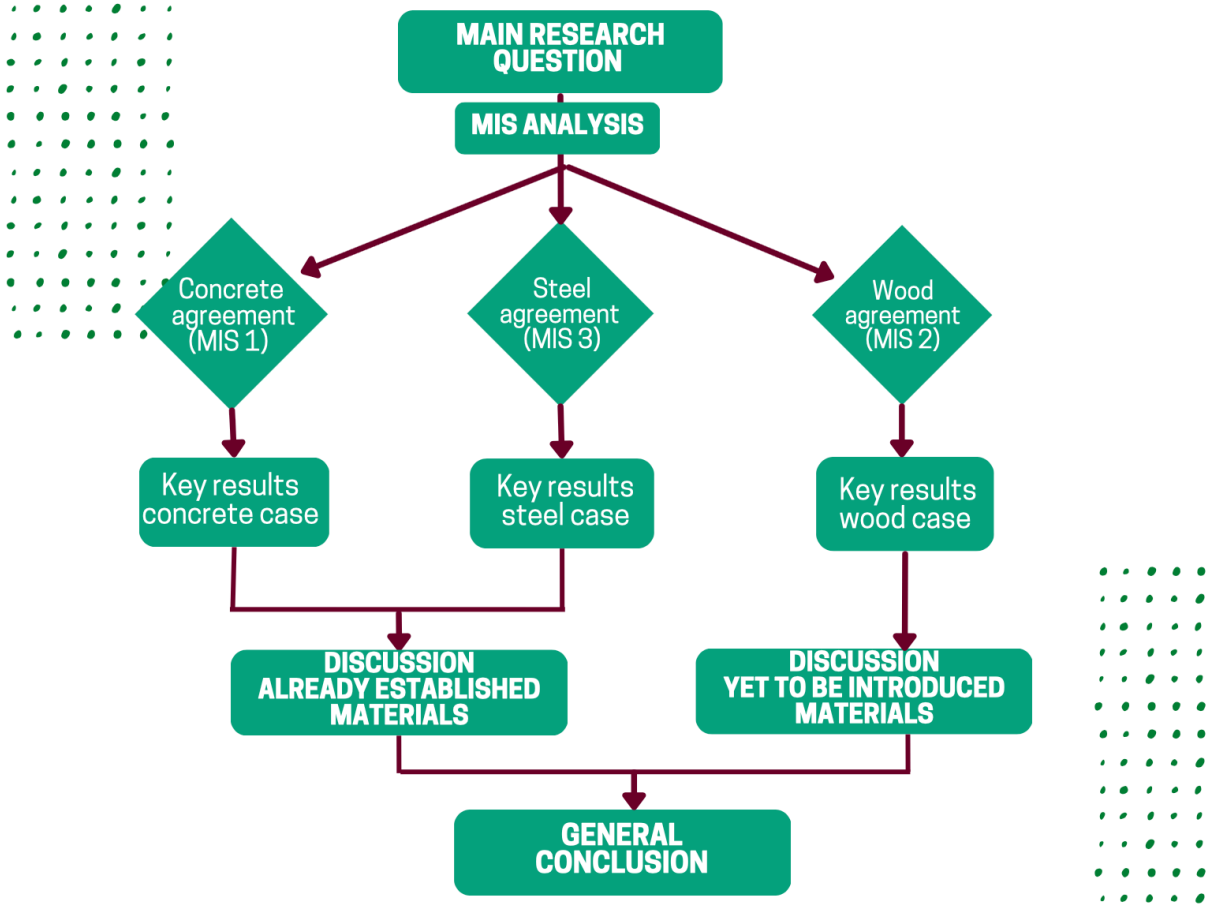


Figure 3-3: Conclusion on second sub-question

4. Results

In this chapter, the results are presented. In the past years, many agreements were founded with the aim to make a specific sector fully circular in 2050. In the "Resource-agreement" ("Grondstoffenakkoord", in Dutch; translation by the author), partners of this agreement draw up five Transition Agendas (TA). One of the TAs concerns the construction sector. The transition team describes the strategy to realize the intended goal of a complete circular Dutch economy in 2050. To implement the tasks from the TAs and the national plan "*Nederland circulair in 2050*" (The Netherlands circular in 2050), several chains of specific materials in the construction sector took the initiative to make agreements to achieve this goal. For this research, three recent agreements were analyzed. In this chapter, the results of the analysis per case are presented. Every case starts with a general introduction to the agreement, followed by the results of the three steps of the MIS analysis.

4.1 First case: Concrete Agreement

This first case is about the social agreement regarding the concrete sector. Worldwide, the Netherlands is one of the frontrunners in reducing CO_2 emissions and is internationally seen as testing ground. "*Leading in the development of high-quality reuse, recycling and CO_2 reduction is the Concrete Agreement*" (Rijkswaterstaat, 2022).

Reasons to adapt the use of concrete in the construction sector

Concrete is one of the most common used building materials in the construction sector because of its strength and resilience. The fact that it is also relatively cheap and simple to produce, also makes it popular. Both the building and utility and the infrastructure sector rely highly on concrete. The high level of CO_2 emission in this production process is what makes it problematic. Cement is the material in concrete which makes it as strong as it is. The main component in cement is clinker. As a part of the process to produce clinker, fossil fuels are burned in a kiln to heat limestone and clay to more than 1,400 degrees Centigrade. The chemical reaction to break down the limestone, is what releases the bulk of the CO_2. This makes the cement industry the third-biggest carbon dioxide producer, accounting for 8% of the global emissions. But because this is a fundamental part of cement production, there is no obvious technology to eliminate the emissions from the concrete.

Process of establishing the Concrete Agreement

The figure below shows a timeline of the notable moments in formulating the concrete agreement. The Green Deal Sustainability on the concrete chain, resulted in a clear definition of sustainable concrete. In 2016, the concrete sector made an effort to draft a sustainability roadmap. Due to the lack of targets and timelines and the fact that actions were too noncommittal, this attempt failed (Cramer, 2020). The Concrete Agreement continues on this notion and links objectives to this definition of sustainable concrete. At the last minute, the Concrete Agreement almost seemed to be canceled. The concrete and cement industry was not willing to commit themselves to the content of the agreement without additional principles. There was a lack of trust, support, consistent policy and incentive from the government. The principles mentioned in the side-letter from the parties represented by the knowledge platform "*het Betonhuis*" will be included in the next phase. After achieving consensus, the parties officially signed the Concrete Agreement in July 2018. The four main targets formulated in the Concrete Agreement for 2030 are:

1. At least 30% CO_2 reduction though with an intended 55% compared to 1990, which is in line with the climate targets of the Dutch government;
2. 100% reuse of concrete residual streams and circular design, which is in line with the Circular Construction Economy transition agenda;
3. A net positive value of natural capital, meaning that after extraction of sand and gravel, the natural environment is left with higher biodiversity than before;
4. Increase of social capital by improving and sharing knowledge, innovation and education.

Table 4-1: targets Concrete Agreement

2016 Finalization of the Green Deal	2018 Signing of the Concrete Agreement	2021 Start of scaling up phase
•Goal is to give a clear definition of sustainable concrete; •With the objective to come to a widely supported and indepent definition of sustainable concrete.	•The Concrete Agreement continues where the Green Deal left off; •Gives concrete details to this definition for the concrete chain partners -> formulation of roadmaps.	•Clients will request sustainable solutions and make room for innovations in projects; •Market parties have to comply with stricter contract requirements and purchasing criteria and are challenged to perform even better.

Demarcation of the Concrete Agreement

The focus in this agreement is on the transition from a linear to a circular economy and also from a high CO_2-emission to a low CO_2-emission economy. Circularity is included as a separate article in the agreement. The goal is value retention at the level of raw materials, components and objects with the focus on circular design, life extension and reuse.

4.1.1 Problem-Solution diagnosis

Problems

As the chairman of the concrete agreement said: "*The concrete sector is highly regulated, which makes it hard to develop and implement innovations*" (Cramer, 2020). Due to the long existence of methods for producing concrete, the production process has already gone through a learning curve. This gives concrete a huge financial advantage over other less optimized production processes or other materials. The fact that the margins are low in the concrete sector and the sunk cost are high makes it even harder to innovate in the sector. This is one of the main problems with concrete in the transition to a circular construction sector. One of the interviewees also mentioned there are many contracts and rules in the construction sector which makes it difficult to innovate. The concrete market is a global market, which makes action must be taken on a larger scale. At the moment, most secondary concrete is used as foundation material under the road (Rijkswaterstaat, 2022). The demand for new concrete is substantially higher than the supply of secondary material (EIB, 2016).

At the beginning of the Concrete Agreement, mid 2016, the attitude towards sustainability was different from today. Circular economy was not a topic that received much attention. This

also became clear during one of the interviews. At the start of the concrete agreement, there were parties that joined, but wondered if this was really that urgent (interview C2). In 2018 the urgency was not felt among all of the actors and the intrinsic motivation was low, which resulted in a wait-and-see attitude. The chairman of the Concrete Agreement rated the urgency as medium and made the following statement about it:

> *-"Some actors had clear, ambitious goals, others had a wait-and-see attitude or acted as watchdogs. However, all actors felt societal pressure to improve their environmental performance and meet national CO_2 targets and the government's circular ambitions. This triggered the needed shared sense of urgency, resulting in a Concrete Agreement with ambitious targets for CO_2 reduction, circularity and biodiversity in 2030."- (Cramer, 2020)*

Another problem is the measurability of circularity. Reduction in CO_2 emissions is measurable and clear goals can be set. This makes it easier and safer to go for CO_2 reductions.

Solutions

In the progress report published in February 2021, the following ideas are mentioned as solutions.

- Concrete with a low CO_2 profile
- Reduce CO_2 emissions in constructions
- Less concrete in constructions
- Reuse of concrete
- Low CO_2 binder in concrete
- Geopolymer concrete
- Electric construction equipment
- 3D printed (cycle-)bridges
- Circular demolition

A list of action perspectives is presented on the website of the Concrete Agreement. In figure 4-1 can be seen that most of these actions are related to the R-strategy reduce.

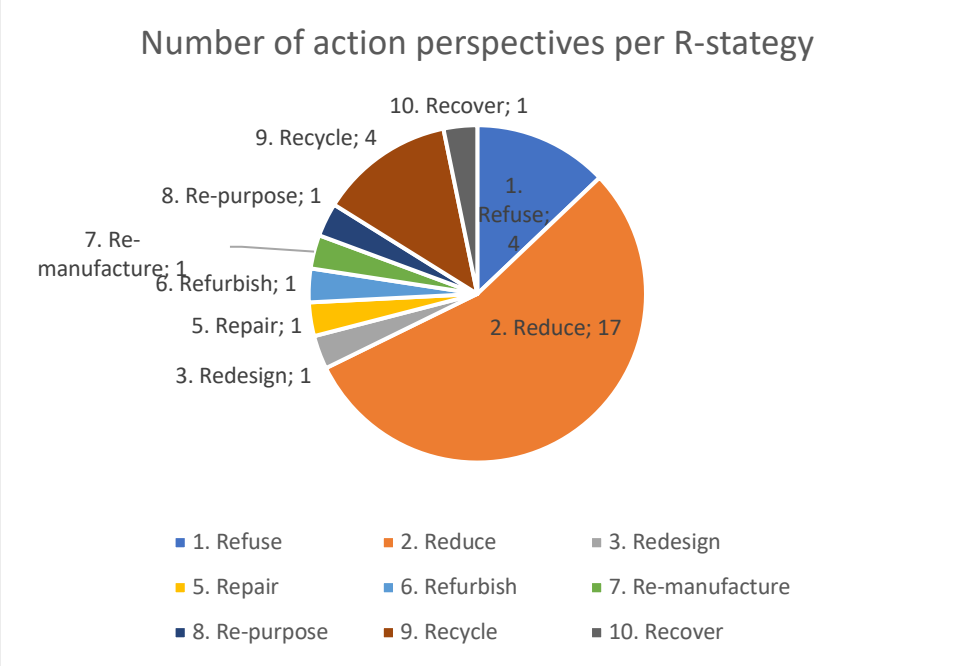


Figure 4-1: Number of action perspectives per R-strategy, adapted from https://www.betonakkoord.nl/publish/pages/166796/handelingsperspectieven_betonakkoord.pdf

4.1.2 Structural system analysis

The concrete agreement was initiated by a relatively small group of actors who wanted to expand to the entire sector. Actors in the concrete chain felt that more result could be achieved and took the initiative to make clear and transparent arrangements in the Concrete Agreement. Cooperation and transparency are important values in the Concrete Agreement. It is a contract between three different categories of organizations: clients, suppliers, construction companies. Table 4-2 shows the number of signatories at the start and at July 2022. The agreement emphasizes the joint effort of public and private parties to innovate. The government participates as a supporting and following actor in the agreement (actors like Rijkswaterstaat and several ministries), the center of gravity lies with the other parties. The group of sympathizers contains parties like trade associations and universities for example. These parties actively support the goals of the Concrete Agreement and are valuable for achieving the objectives, but they do not have an executive role. Because of this, the sympathizers did not officially sign the Concrete Agreement.

	Number of parties at incorporation (July 2018)	**Number of parties in total (July 2022)**
Clients	7	11
Suppliers	20	43
Construction companies	8	13
Sympathizers	2	10

Table 4-2: Overview of the number of participating parties in the Concrete Agreement

Benefits for actors to participate in the Concrete Agreement are improving their competitiveness and getting access to concrete related innovations, knowledge and experiences.

	Concrete case
Mission arena actors	Concrete sector, commissioning parties, recyclers and builders
MIS actors	Government and researchers
Supportive actors	Branch organizations of concrete sector, recycling industry and building sector and organizations representing commissioning parties

Table 4-3: Actors involved in concrete chain (Cramer, 2020, p. 147)

Table 4-3 shows the role of the different actor categories in the Concrete Agreement. Arena actors are actors who can steer the transformational change process into the necessary direction of scaling up and mainstreaming. Arena actors are in the mission arena. The supportive actors are in the overall MIS.

Collaboration between the entire concrete chain is key. Every participant is expected to contribute to the substantive elaboration of the compromises made in the Concrete Agreement. The elaboration of the compromises is the responsibility of the execution teams and the director. The compromises are clustered in seven themes (Appendix A). The first four

teams are more content-related where the other three are more supportive. Per theme there is an execution team and a director. Every theme is self-steering and responsible for the execution and further details of the agreements. The progress committee will monitor and evaluate the strategy the teams present with which they think they can achieve the goals. The progress committee also advises the teams on feasibility and effectiveness. The steering committee is ultimately responsible for achieving the agreed goals and fulfilling the agreements made. Figure 4-2 gives a visual representation of the organization structure.

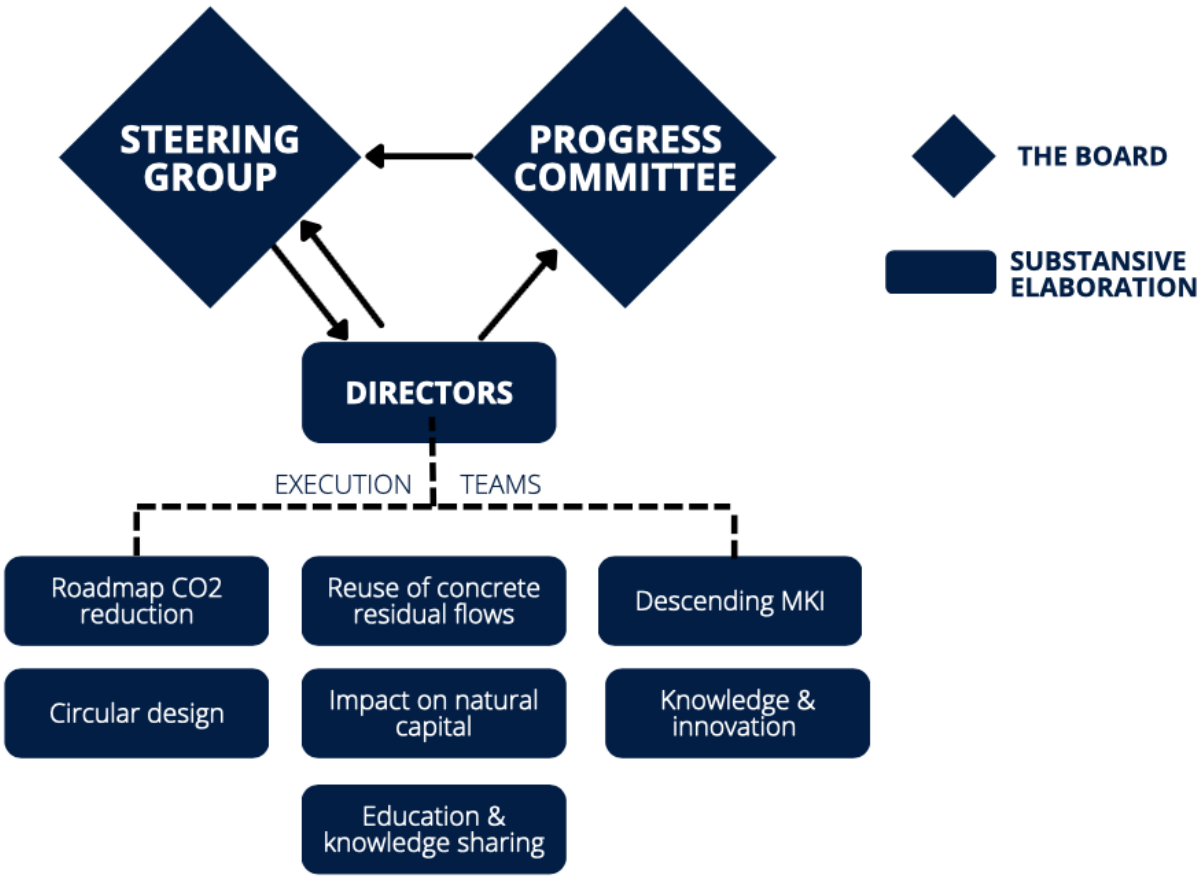


Figure 4-2: Organizational structure of the Concrete Agreement, own image, adapted from: https://www.betonakkoord.nl/organisatie/

Formally, participating in the Concrete Agreement does not obligate the parties to anything. In the contract is stated that compliance with compromises in the Concrete Agreement is *not* legally enforceable. The ambitions in the agreement are primarily intended to encourage the parties to take action.

Market power of concrete suppliers

The number of concrete suppliers, nationally, but also globally, is limited. As a result, the suppliers have substantial market power, which allows them to set higher prices. But this also results in a lower price volatility (ING, 2021). Because of the low level of competition, price reduction for raw materials or energy costs do not have to pass on directly to the consumer. However, price increases cannot be passed on directly either. This is one of the reasons why the price of concrete has risen less rapidly compared to other materials, for example wood.

This is despite the high energy prices, which are an important part of the cost price of concrete and cement.

4.1.3 Functional system analysis

As foundation for the functional system analysis, an event analysis was made in a separate Excel sheet. In this paragraph a narrative description of the event analysis is presented. The level of fulfillment of the nine system functions is elaborated on, illustrated with examples from the event analysis and the interviews.

SF1.Entrepreneurial activities

This category concerns activities of entrepreneurs directed towards achieving the mission. Activities can be aimed at stimulating the circular system as well as at breaking down the current system. The impact on this function can be either positive or negative.

According to a research of the Economic Institute of Construction (EIB), pilots must take initiatives to a higher level. From the event analysis can be seen that many events have a positive influence on the fulfillment of entrepreneurial activities in this MIS. Many pilot projects are initiated from the Concrete Agreement.

The action plan of the implementation team knowledge & innovation distinguishes three types of innovations, based on technology readiness level (TRL). According to the Concrete Agreement, the biggest challenge at the moment lies with innovations with TRL 4 to 6. These innovations are in the development phase.

> *"There appear to be many interesting developments, but they are only used to a very limited extent in practice" - (uitvoeringteam kennis & innovatie – stappenplan opdrachtgevers).*

In order to realize the ambitions in the Concrete Agreement, the needs of the market party to apply their innovative solutions with those of the government, need to be connected. More high-value recycling and reuse is possible, but not yet commonly applied (Cramer, 2020). The implementation team on knowledge & innovation presented a ten-step, step-by-step plan to guide clients to effectively integrate innovation in their tenders. If the pilot appears successful, this plan also guides the client to apply it in standard practice (event 46).

Despite the promising number of pilot projects and the guideline of the knowledge & innovation team, it seems difficult to scale innovations up to standard practice. A successful pilot project can demonstrate whether the chosen solution actually solves the problem and what the impact of the solution is. However, this is only the start of an innovation trajectory. It is important to keep the next phase in mind. After executing a pilot project it stops most of the time, this is also confirmed in the interview with the public client.

An explanation for the fact that pilot projects often stop at implementation is because only a few aspects of the entire asset management cycle are taken into account. Certain aspects of the asset management cycle are innovative, but the overview of the entire system is not enough taken into account. For example, research or experimentation shows a project is technically feasible, but other aspects have not been sufficiently researched. The awareness

that projects have to be seen as a transition where the entire playing field has to be taken into account is a first step in enabling upscaling.

SF2. Knowledge development

In the action plan of the implementation team knowledge & innovation distinguishes three types of innovations, based on technology readiness level (TRL-level). Category C is the category with the lowest TRL level (1 to 4), which means the innovations are still in the discovery phase. As the action plan states: "*where appropriate, contributions from knowledge institutions will be included in the developed products*".

Figure 4-3 shows the distribution of studies over the different R-strategies.

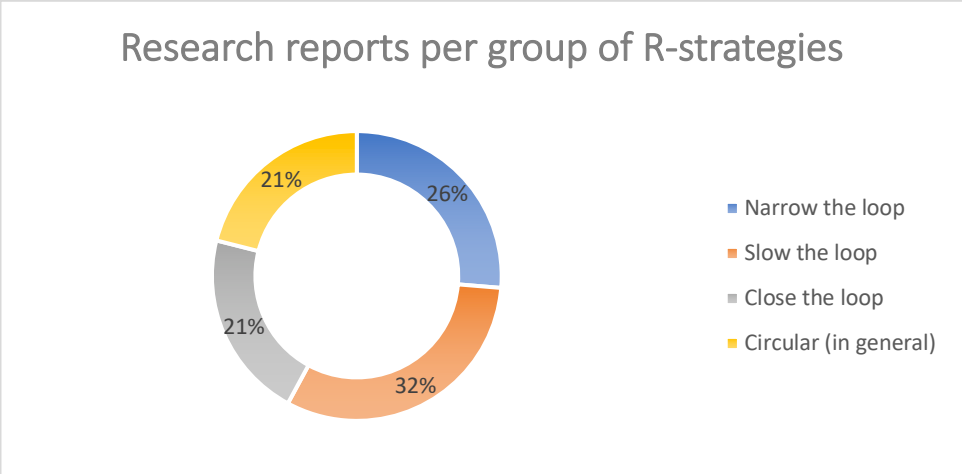


Figure 4-3: Research projects categorized per group of R-strategies, based on event analysis

The need for more fundamental research

From the event analysis it became clear that there are quite a lot research reports and projects focused on the development of new knowledge. To reach the targets formulated in the roadmaps of the Concrete Agreement, innovation was essential. A distinction between short run and long run application has been made. Projects that could be implemented in about one to five year were the most appealing because they could be rolled out to achieve the interim goals for 2030. For the long run applications, more fundamental research was needed. Despite the need for more fundamental research, the chairman indicated in the interview that the transition is not being held back by the current level of knowledge.

More attention for learning from pilot projects

Pilot projects are aimed at the development of new knowledge. The number of pilot projects is promising, nevertheless more knowledge can be gained if companies internalize learning from these projects. The results show the challenge with implementing the lessons learned from previous projects in future projects.

SF3. Knowledge diffusion

Diffusion of knowledge in the educational system

Collaboration is one of the key goals of the Concrete Agreement. Diffusion of knowledge is an important part of collaborating. Two implementation teams have been established. The teams "knowledge & innovation" and "education & knowledge sharing" are established to meet the

objectives of this function. Examples of actions of the implementation teams are the preparation of a concrete game and the development of an introductory lesson about sustainable concrete. One of the objectives of this team is also to make an inventory on the knowledge needs in the concrete chain. Knowledge diffusion starts with teaching students, the employees of the future, about circular economy. Implementing circular practices requires another way of thinking. To teach future employees this way of working and thinking, it must be embedded in the educational system.

Knowledge diffusion by different layers of clients

Next to implementing the new way of circular thinking in the current educational system, innovative knowledge can also be shared in projects. On a higher strategical level the diffusion of knowledge goes well. Knowledge of clients is shared in for example "*het Moederbestek".* The "*moederbestek*" helps clients for formulate circular requests with minimal requirements in projects. For example how the apply the MKI requirements in projects. Despite the fact that this knowledge is freely available to use, it is still difficult to reach lower governments like smaller municipalities.

Knowledge diffusion by contractors is complicated

The diffusion of technical knowledge is something which is more difficult. Technical knowledge is hardly shared. Construction companies are spending money on innovative ideas. If they share this technical knowledge, they lose their lead. The industry has too big of an interest to share this. One of the key take-aways from the first years of the Concrete Agreement is: "*do not make it a competition, keep connecting*". An attempt, initiated and funded by Rijkswaterstaat, to openly share knowledge amongst parties was the Strategic Business Innovation Research (SBIR). When the consortia of parties choose to offer their innovative knowledge open source, they are being higher rewarded in one of the phases. This results in wider application of knowledge. As stated in the action plan: "*knowledge must be made available in the right place, with parties that can do something with it*".

SF4a: Creation of problem directionality

The intrinsic awareness of parties and society

The effects of climate change are starting to show. This makes people realize climate change and other environmental problems are becoming reality. When the concrete agreement was established, the urgency to fight climate change did not have a priority to many parties yet. As a contractor mentioned in an interview: parties joined the concrete agreement because they felt they had to, but they thought that mostly there was a lot of talking. Currently, the mission is more urgent and tangible compared to a few years ago. There is awareness in the society for this problem. Radical changes can only be realized when it is broadly supported. In the building up phase of the Concrete Agreement, problems are clearly formulated. Nevertheless, not many people know them. The terms sustainability and circularity are used interchangeably by many people.

Different set of requirements for tenders from different public clients

From both the document analysis as the interviews, the topic of certainty in the tendering process is an important issue here. Construction companies are willing to innovate, but the set of requirements in every tender is different. Another problem is the variety of public clients on different levels. The public client can be either from a national level or from a more

local level, like the municipality. National public clients, like Rijkswaterstaat, operate on a larger scale, which gives them more opportunities to think of a better and more structured set of requirements. The analysis shows that the set of requirements is unpredictable in tenders from local clients. This makes it nearly impossible for construction companies to make the right investment choices to meet the requirements in future tenders.

SF4b: Creation of solution directionality

Formulation of ambitions rather than goals

What also made a major difference was the formulation of the goals. At first the goal was to deliver a reduction of 30% of the CO_2 emissions with respect to the year 1990. The client noticed that with the current practices, more reduction is possible. By formulating the goals as "goals", this felt like something that has to be achieved, otherwise you will be punished for failing to achieve this goal. Because of the nonbinding nature of the agreement, parties cannot be punished if they fail to meet the goals. Nevertheless, by changing the word *goals* in *ambitions*, a much higher CO_2 reduction was agreed upon. By using the word ambitions, parties were stimulated to be more ambitious and to aim high. It sounds like something that you want to achieve rather than being punished by failing to achieve a goal.

Lack of directionality in radical, destructive innovations

Actors start to realize that only incremental innovations are not sufficient to meet the goals. Incremental innovations are marginal improvements on an already existing product. The possibilities for optimizing current concrete compositions are not unlimited and will not be sufficient. To become 100% circular, the path of radical innovations has to be explored and rolled out. Radical or destructive innovations are usually a completely new product or service, which makes a big difference with the existing product. The lack of solution directionality became also clear from the interviews. There are still too many different directions by different actors in the steps that are required in five to ten years. Radical innovations are also associated with higher costs. Due to the lack of prospects for a specific solution direction, investors do not dare to invest on a large scale and banks are not willing to provide financing. Before financing, banks want certainty that this development will be requested in future tenders. There is a proposal for financing from the National Growth Fund (Nationaal Groeifonds, in Dutch), but the lack of solution directionality makes it harder to obtain financing. As one of the interviewees mentioned, the path towards 2030 needs to be tightened.

Attention for solutions higher on the R-ladder

A circular strategy is the construction value model ("*bouwwaardemodel"*). To aim of this model is to shift the focus from strategies lower on the R-ladder also to strategies higher on the R-ladder. The most important circular ambitions of the construction value model are: extending the lifespan, reusability and high-quality recycling.

Both technical and process-related types of solutions

It became clear from the analysis that both technical and process-related solutions are provided. An example of one specific technical solution is the introduction of 3D printing in concrete constructions. A process-related solution is the adaptation of the NEN206 norm to make it easier for new entrants to get their product approved under current standards. While cement is the most environmentally harmful element in concrete, this standard states that

there must be at least 20% cement in concrete. Due to this, innovations could not be assessed fairly. To remove this bottleneck, a guideline “concrete on performance” is being drawn up parallel to the NEN standard to assess the quality of new products.

SF5. Market formation and destabilization

Create uniformity and certainty in tenders among clients

One of the important characteristics of the construction sector is its strongly public-oriented nature, as already came forward in the structural analysis. In the roadmap reuse of concrete residual streams the following quote also supports this statement: “c*lients are an important steering link that can accelerate the transition to a circular economy*”. The Buyer Group low carbon concrete is an initiative to create a market vision and a purchasing strategy for the structural sustainable procurement of concrete in infrastructural projects. They have set specific goals for public clients. Public clients from different levels (Rijkswaterstaat, ProRail, provinces and municipalities) are involved with the aim of achieving a consistent procurement of sustainable concrete. A consistent and realistic, but challenging set of requirements from public and private clients is required. This ensures that continuity is provided and renewal and innovation are stimulated. Construction companies are willing to take steps, but on the condition that the market is given certainty about tightening the requirements over time. In 2020 and 2021 the first results have been delivered. Until tenders from clients are not yet harmonized and enforced in any way by law, investors do not dare to make big financial decisions. For example, a major financial decision could be to invest in a large factory that serves half the Dutch market. This is risky because it is not known whether the product will be purchased. Therefor a consistent and generic set of requirements is important.

Making sustainable concrete mandatory by law in tenders

A recent example of a positive effect on market forming activity derived from signatories of the Concrete Agreement, is making sustainable concrete mandatory by law in tenders from 2023. This is remarkable, given the fact that for a long time, the sector was against regulations that restrict aspects of building materials by law. Already back in the nineties the government wanted to introduce standards to encourage using old concrete in new concrete. All parties in the Concrete Agreement agreed that making the concrete sector more sustainable, will only succeed if it will be made mandatory by law. Every two year the requirements will be further tightened.

Scaling up of contract requirements as a tool to form a market

In the entrepreneurial system function can be seen that upscaling of innovations is not yet very successful in many cases. Scaling up of contract requirements does work (interview AM). Examples of contract requirements that have been scaled up are stricter MKI requirements and the percentage of recycled material in new concrete. One of the key take-aways from the first few years of the Concrete Agreement was that technicians needed measurable requirements, like MKI. Important in the scaling up phase is harmonization and legal regulations. At the moment, procurement requirements are not yet legally established. Although it is laid down by law, the requirements as agreed in the Concrete Agreement are used in most public procurements from municipalities. Many municipalities use the “*Moederbestek*” of Bouwcirculair or the “*Sustainable public procurement tool*” of Pianoo. Both are procurements tools with a premade set of requirements what sustainable products must meet. Both parties are affiliated with the Concrete Agreement. In this way the procurement

requirements are indirectly steered for those who are not joining the Concrete Agreement. However, it is not compulsory for clients to use those procurement tools. Scaling this up can be done by making the procurement requirements legally enforceable.

SF6. Resource (re)allocation

Financial resources

The Concrete Agreement itself does not have any financial resources. Money has to be arranged for every project. From public clients, approximately 8 million euros is made available. Half of it is available via the innovation budget of Rijkswaterstaat and ProRail and the other half of the budget is available in ongoing projects of various public clients. The fact that money is not directly available has the benefit that it puts the responsibility on the right place. The downside of this is that it sometimes withholds parties from participating in an innovation project. As the chairman states: "*it remains to be seen whether sufficient funding can be raised to test and prove the necessary innovations*". Financial sources are available, but the project must fit within the precondition of the money source. Financing cannot be promised in advance which makes it uncertain for parties to participate in these types of projects.

Human resources

Especially the need for human resources seems high. Expertise is lost because people with a lot of experience retire. The attention for circularity is often not embedded in everyone in the organization. The problem starts by the education of these people. The older generation was educated with the idea that the production of concrete is cheap and easy and there was little attention for resource scarcity. To make the shift from thinking in this (partly) linear approach to a more circular approach is not easy. This change in way of thinking has to start in education. Activities from the implementation teams should lead to professionalization of employees in the concrete chain.

The lack of human resources also means that organizations pay little or no attention to circular economy. Knowledge on circular tenders with minimal requirements in projects is freely available (SF3). Especially for smaller municipalities it is challenging to implement circularity in their way of working. Staff is limited so they have to prioritize and make decisions where they want to spend time on. Because of the lack of knowledge and the lack of staff, circularity is often something that receives less attention.

SF7. Creation of a supportive socio-technical environment

The "*socio*" part of a social innovation is very important. As can be read in the fulfillment of the previous functions (especially SF1, SF2 and SF3), the level of technological knowledge does not seem to be the main problem in the development of the innovation system. In the field of knowledge development (SF2), the national concrete chain does not fall short. Focus should be on system change. The opinion towards the concrete sector should change. As the director of a prefab concrete factory mentioned at the opening of the 62th concrete day:

> *-"flying shame is the buzzword, but I fear that it will soon be replaced by concrete shame"-.*

For a long time the sector was not supporting legal enforcement of requirements for concrete.

During the scaling up phase, the focus is also on communication with the parties that have not signed the agreement.

Broadening the scope to explore changes in the socio-technical environment

Participants in the Concrete Agreement explored promising innovations. With the first list of innovative ideas it was not possible to achieve the goals, particularly not for the reduction of CO_2. As the ideas were explored by the parties in the concrete sector, most options were related to CO_2 reduction in the materials used which is the main expertise of the sector. To explore ideas higher on the R-ladder, experts were asked to broaden the scope. These ideas ultimately added up to a reduction of at least 60%. These options must be implemented by other actors, such as commissioning parties and the building sector (Cramer, 2020). The first ideas were only related to incremental innovations which did not add up to meeting the goals for 2030. This shows the need for a cultural change. To come up with ideas higher on the R-ladder it requires a change in the socio-technical environment. To initiate this change is difficult. From the event analysis and the statements made in the interviews, the awareness for this difficulty became clear. It starts with embedding the new way of thinking in education for future employees (interview AM).

Corporate Social Responsibility (CSR) is an important criteria for employees to determine whether they are willing to work for the company. Companies in the concrete sector have to keep up with current developments and demonstrate their social responsibility to employees.

SF8. Coordination

34 of the events are related to coordinating activities. To align activities between different actors in the innovation system, the agreement set up seven different execution teams. In these teams, the signatories are working together to accelerate the concrete implementation of the goals and ambitions of the concrete chain. Monitoring and control are essential in the Concrete Agreement. They are important instruments for realizing the goals and ambitions and to motivate each other positively.

One of the most important goals of the Concrete Agreement in the transition to a circular economy in the concrete sector is to get everyone on the same page.

Monitoring progress

As a result, all the teams created a roadmap, presenting the next steps to accelerate the process of reaching the goals. Monitoring, evaluating the mission and subsequently taking appropriate measures is another important part of the coordination function. Monitoring can be seen in several projects in the event analysis. The execution teams developed methods and instruments to measure the progress. On May 20th 2020, all teams presented their progress and planning. In the scaling up phase, the roadmaps are being implemented. Also clients, construction companies and suppliers start to monitor projects.

4.1.4 Main results for concrete per system function

To wrap up all the information from the previous paragraph, the main results per system function are presented in table 4-4.

Function	Description
F1: Entrepreneurial activities	• Many pilot projects initiated which has a positive influence on F1. • Despite this, it seems difficult to scale innovations up to standard practice. • Important to take all the steps in the asset management cycle into account.
F2: Knowledge development	• The need for more fundamental research, especially for the long run applications. Despite, the transition is not blocked by the current level of knowledge. • More attention for learning from pilot projects. Valuable knowledge gets lost here.
F3: Knowledge diffusion	• Circular knowledge has to be included in the educational system • All clients have access to knowledge about the formulation of circular requests with minimal requirements in a project. Despite this free available knowledge, especially smaller municipalities are hard to reach. • Contractors do not share technical knowledge. In the SBIR, sharing innovative knowledge open source is rewarded higher which gives an incentive to share this information.
F4a: Problem directionality	• The mission has become more urgent and tangible to actors. The problem is clearly formulated in the Concrete Agreement. Nevertheless, not many participants clearly know this, which indicates a lack of directionality. • Contractors feel a lack of directionality in tenders from different clients and even in different projects from the same client.
F4b: Solution directionality	• A lack of directionality in the solution space, especially for radical innovations, is observed. • Formulating goals in a positive and supportive way has proven to be helpful. Formulating an ambition rather than a goal made the actors aim higher and actually achieve higher goals. • Process-related solutions, like adapting NEN norms in order to enable innovative products to get approved under current Dutch standards.
F5: Market formulation and destabilization	• Contractors request for tighter requirements over time before they are willing to make big financial investments. • Sustainable Concrete is mandatory by law in tenders. At first all actors were against regulations, now they agreed that these things will only succeed if it will be made mandatory by law. • Scaling up contract requirements works, for example make procurement requirements legally enforceable.
F6: Resource (re)allocation	• Lack of human resources. Expertise gets lost when people retire. • Financial resources are available, the project must fit within the preconditions of the money source, which results in uncertain situations for parties to participate in these types of projects. • Because of the lack of knowledge and the lack of staff, circularity is often a topic that receives little attention.
F7: Creation and withdrawal of legitimacy	• Change in culture is required. At first parties only came up with ideas low on the R-ladder because thinking in incremental innovations is in their nature. Higher ideas on the R-ladder require a change in the socio-technical environment.
F8: Coordination	• Different teams have been developed to align activities between actors. • Creation of roadmaps. • Methods have been developed to measure progress.

Table 4-4: Overview of results for the concrete case

4.1.5 Concluding remarks Concrete Agreement

In the previous paragraph, the analysis of the Concrete Agreement has been described in detail. Overall one should take into account that the goal of the Concrete Agreement is to bring actors in the entire concrete chain together and work towards a common goal. The transition from a (partly) linear to a circular economy and the reduction of CO_2 emissions are important. The transition to a circular economy is not the only goal in the Concrete Agreement. Key takeaways from this analysis are:

- The main focus is still on reduction of carbon emissions. As the Agreement was not established with the main goal to make the transition towards a circular economy. Circularity is included as one of the articles in the Agreement. The awareness that, next to incremental innovations, also bigger steps should be made is increasing over time. At the start of the Concrete Agreement, the awareness and willingness to join was not completely clear for many parties. Over time everyone has been feeling the urgency to do something and to take bigger steps here.

- Many actors have an interest in the continued existence of concrete as a building material. "*The concrete sector is highly regulated, which makes it hard to develop and implement innovations*" (Cramer, 2020). Especially in market formation (SF5), the concrete sector is stiff. It is easier to steer in a clear and measurable direction, like the environmental costs indicator (MKI). Circularity is hard to measure which makes it more difficult to implement and steer. This is an obstacle in the transition to a circular economy.

- The R-ladder is a useful tool to implement the circular way of thinking. The higher the strategy is on the R-ladder, the more circular the strategy is. It requires a systematical change in mindset to also take higher R-strategies into account in projects. High R-strategies, like refuse or rethink, have to be thought of early in the process. To change the current culture, it is important make the right knowledge available already in education and passing this on to the employees of the future from the start of their career. The construction value model (*bouwwaardemodel*) is created to focus on higher R-strategies. The concrete association will give courses on this model. This are two ways to shift the focus to higher R-strategies, but this is something which still requires attention. Without the implementation of higher R-strategies, the goals and ambitions cannot be achieved.

- The number of pilots from the concrete agreement and in the concrete sector are promising. Although at the moment it does not lead to the desired results. Flexibility in regulation together with keeping the entire system in mind while performing pilots can help to scale up pilot projects. This requires attention.

- More fundamental research is required. However, at this moment the transition is not hindered by the lack of knowledge.

    - Lack of long term solution directionality which makes it also difficult for researchers which direction has to be explored.

- Knowledge can be shared among clients and contractors. Contractors hardly share knowledge because knowledge is one of their main assets. Clients do share knowledge. Despite the fact that knowledge is freely available to use, it seems difficult to engage some smaller parties.

4.2 Second case: Wood chain trajectory

The second case in this research is about the agreement on wood as building material. The ambition of the Dutch government is to reduce the use of raw materials with 50% by 2030. This ambition can be realized in various ways. One obvious way to reduce the use of raw materials is by using more secondary materials. However, the realization is beginning to emerge that the available secondary raw materials in the construction sector will not be available in sufficient quantities to realize the national ambitions.

Reasons to explore the application of wood in the construction sector in a chain agreement

Given its renewable character, the application of wood in the infrastructure sector can make a significant contribution in the transition to a circular economy. The production of wood leads to the absorption of CO_2, which is converted into oxygen by trees. When wood also replaces other materials, a lot of the CO_2 emission can be prevented. Because of this, in 1994 a national program was launched to realize 20% more wood in the construction sector. In 2018 an exploration, initiated by Rijkswaterstaat, has inventoried the opportunities and obstacles to stimulate the use of wood in the infrastructure sector. A community, with actors in the entire chain, was created and they committed themselves to collaborate on the field of research, innovation and communication. The cooperation agreement “wood in the infrastructure sector” was signed by the chain parties. This agreement is part of the replacement and renovation task, to develop an innovative approach to realize this in a sustainable and affordable way, with as little disruptions as possible.

The development of the use of wood in the construction sector over the past years

Until the end of the Middle Ages, almost everything in the Netherlands was built by wood. Figure 4-4 shows the use of wood as building material in North- and Middle Europe as percentage of all building materials. Over the years, wood was used less often, among other things because it could not withstand moist very well. Wood used to be a common building material. Nowadays wood as building material can be used smarter and has many popular properties other than only being sustainable. In addition, wood fits perfectly within the circular economy philosophy. Especially larger pieces of wood can be reused and after a few times it can be processed into other wood applications. Finally, it can be burned as biomass.

Percentage wood used as building material in the construction sector over the years

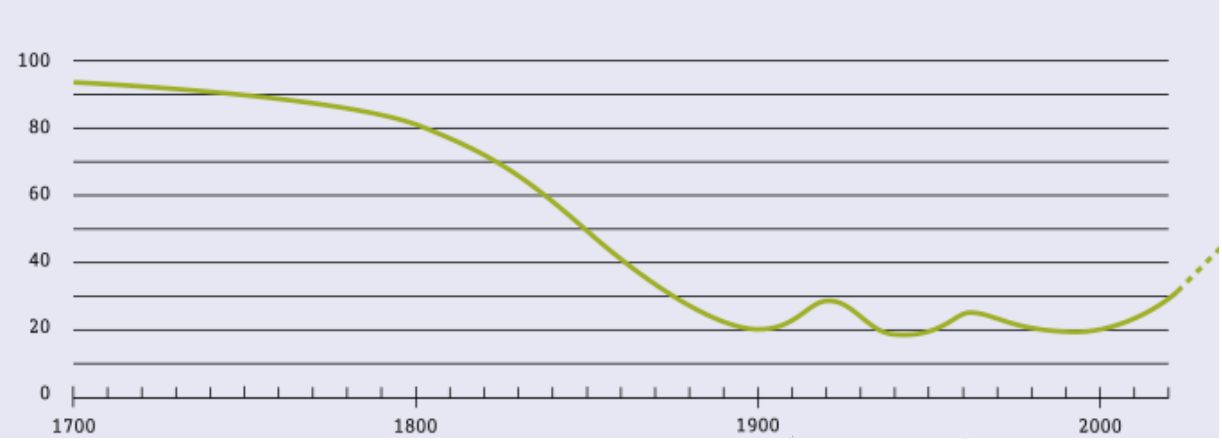


Figure 4-4: Use of wood as construction material in North- and Middle- Europe, as a percentage of all construction materials. Source: https://www.ams-institute.org/documents/64/AMS_Institute_Houtbouwmythes_ontkracht.pdf

Delineation of the agreement

This chain cooperation is solely focused on the infrastructure sector. Specifically, the focus is on wooden bicycle- and pedestrian bridges. The goal of a chain cooperation is to achieve mutual gains in a long-term cooperation (Elstgeest & Willemsen, 2022). Every actor contributes by providing their own, unique expertise to other actors in the chain cooperation. This exchange of knowledge and expertise in the entire chain has a high probability on the development of innovations. Actors in the cooperation are more likely to share their assets.

2018

- Exploration into wood in the infrastructure sector
- Invetory of opportunities and possibilities to stimulate the use of wood

February 2020

- Chain parties signed the agreement and commited themselves to work towards a biobased and circular economy

4.2.1 Problem-Solution diagnosis

Problem with deforestation worldwide

Yearly we are losing forest at a rate of 10 million hectares (WNF, n.d.). The World Wide Fund for Nature (WWF) wants to protect the forest. With better management, the demand for wood products can be met, without damaging the local environment. WWF believes that sustainably managed forests are necessary for the management of biodiversity and ecosystem services. When the forest is managed in this way, it generates a commercial profit, which ensures that the forest is preserved. The two most well-known quality marks are FSC and PEFC. These marks indicate that the wood comes from a sustainably managed forest.

Image problem of wood as construction material

One of the main problems with wood as construction material is the image of it. Wood has to be acknowledged as a sustainable product with a positive contribution to the climate and the

prevention of deforestation. Due to the rise of other cheap and strong materials, wood has been used less often in the past decades. Due to the decline in its use, the level of knowledge has declined as well and people have several persistent misconceptions about the application of wood in the construction sector. *Wood is highly flammable, there is not enough supply, it is not strong enough and wood rot will cause serious problems.* These are some of the most common misconceptions about wood. Large scale adoption of wood as construction material goes slow because of the general image of the material. The image of wood has to change before it will be widely applied.

Problem with the price of wood

Another problem is the price volatility of wood. The world wood market is very competitive which means that changing purchase prices are passed on to the customer within one or two months. The higher the price volatility, the greater the risk. This makes it unpredictable and risky to plan ahead.

Other than the price volatility, the overall costs are (still) higher. On the one hand the costs are higher because new investments are required, both in knowledge as in production processes. On the other hand the costs are higher because the lack of economies of scale. ING makes an estimate that the cost of a wooden building will be approximately 5-10% more expensive compared to a concrete building (ING, 2022). When wood is used on a bigger scale it will become cheaper because of the economies of scale. Also the production of other energy intensive construction materials will become more expensive because of the CO2 taxes, which makes wood relatively cheaper compared to these other materials.

4.2.2 Structural system analysis

The arena actors in the wood chain trajectory are the wood sector itself, commissioning parties and recyclers.

	Wood case
Arena actors	Wood sector (builders, contractors, processors, maintenance), commissioning parties, recyclers
MIS actors	Government and researchers, knowledge parties (advisory)
Supportive actors	Centrum Hout and VVNH (branch associations), certification organizations.

Table 4-5: Actors involved in wood chain

This chain trajectory was initiated by Rijkswaterstaat in 2018. This was followed up by de Bouwcampus in 2020. Bouwcampus is a non-profit network organization that connects people in the construction sector and drives transitions. For this specific case, the platform will bring chain cooperation to a higher level and provide acceleration and broadening. During the kick-off meeting, actors were asked to attend and actively participate in the upcoming sessions. This directly shows the struggle with the non-binding nature of the agreement. Participation is formally without obligation, but active participation is highly appreciated.

The demand for wood has increased. ING bank highlights the unexpected demand for wood in their publication about the construction sector (ING, 2021). The wood market is highly competitive. 60% of the total use of wood in the Netherlands has direct or indirectly to do with the construction sector. Most of this 60% ends up in the residential building and utility sector. Currently only 5% of the total use of wood is used in the infrastructure sector (ING, 2022).

4.2.3 Functional system analysis

As foundation for the functional system analysis, an event analysis was made in a separate Excel sheet. In this paragraph a narrative description of the event analysis is presented. The degree of fulfillment of the nine system functions is elaborated, illustrated with examples.

SF1.Entrepreneurial activities

Pilot projects to improve the image of wood

Before large-scale adoption of wood as a construction material, clients, financiers and contractors need to get confidence in this currently relatively unknown material. Therefore, small scale pilot projects are aimed at increasing the level of confidence in wood as construction material. The aim of the pilot project is to continue building infrastructure in the Netherlands in a sustainable way. Communication about the process and the results of the pilot project is an important step in improving the confidence level of wood in the construction sector. In this chain trajectory they choose to focus on wooden bicycle and pedestrian bridges first. The event analysis shows many pilot projects.

Pilot project for testing and taking away uncertainties

Pilot project are used as showcase to widely present what is possible with wood at the moment. On the other hand pilot projects are also useful to test certain characteristics and eliminate uncertainties. When contractors get the opportunity to perform a pilot project, they will be able to test their solutions or product under real world conditions. For example in a project of an old pedestrian bridge over the highway A27 at Vianen, the contractor decided to demolish and reuse the wood from the old bridge in a new bridge. The wooden beams are considerably over dimensioned. If necessary, maintenance can be done so that it can last for another decade. “Whether this also works for the wooden deck remains to be seen”. This shows the experimental nature of the project.

Scaling up of pilot projects

Ultimately, the goal is to scale up successful pilot projects and roll them out more widely. By choosing wooden pedestrian and bicycle bridges as delimitation of this Agreement, the scale remains relatively small. Scaling up within the boundaries of this delimitation can happen by a serial tender in which multiple bridges are tendered as a package of projects.

SF2. Knowledge development

Development of knowledge by the client

The (re)introduction of a relatively unknown material requires new knowledge in many areas. First of all, the general level of knowledge on the possibilities and limits to apply wood has to be improved. Because there are not many examples yet, confidence in wood is one of the main issues for clients. Supportive knowledge has to be developed to address these issues. By improving the general level of knowledge, the confidence will grow too. In the Agreement,

the chain parties commit to make knowledge available to help clients a step further (Rijkswaterstaat, 2022). Also knowledge on how to arrange the commissioning process in order to give wooden solutions a fair chance needs to be developed.

Development of knowledge by the contractor

The contractors side on the other hand also indicates the need for improving the level of knowledge. Experiments and small scale projects are executed with the aim to test and prove properties with the application of wood. Research reports are published about among other things, the lifespan of wood applications in infrastructure, reuse of wood and research into the sustainability score of wooden bridges. From an exploratory report it became clear that one of the main obstacles of using wood has to do with the lack of knowledge about it.

SF3. Knowledge diffusion

Knowledge diffusion by clients

By signing the agreement, the chain partners agreed to make their knowledge available to help clients a step further. One of the goals of the chain cooperation is to learn from each other. Together with (public) clients they will collect lessons and share concrete tips and inspiring stories.

Open source projects for knowledge diffusion among contractors

Knowledge is one of the important assets of a contractor. There is no incentive for contractors to share knowledge with each other. In an ideal world, knowledge is a common good and everyone has access to it. Another way to diffuse knowledge, is via Small Business Innovation Research (SBIR) (PIANOo, n.d.). This is an approach by the government to challenge entrepreneurs to develop innovative products or services in competition with each other. The advantage for the government is that they will receive multiple possible solutions to the challenge or problem by starting an SBIR competition. SBIR is a form of innovation-oriented procurement by the government. It gives small, innovative entrepreneurs (including startups) the opportunity to take the R&D of their company further. SBIR is a government contract and the costs are fully reimbursed in accordance with the offer. Sharing knowledge of the project and working open source is valued. In the circular viaduct SBIR, a consortium of Heijmans, Arup and Schaffitzel which is called Bridges of Laminated Timber (BoLT), applied. Their circular viaduct design is completely made of wood. After completing all tests, their design will be released as an open-source document to be further developed by anyone. Usually, this type of knowledge will not be shared because of the competition between the contractors.

Importance of improving the confidence in wood by sharing knowledge

In addition to developing relevant knowledge on wood as building material, it is also important to share this knowledge with other parties. The confidence in wood as building material, is one of the main reasons why wood is not widely accepted at the moment. As mentioned in a research report, personally convincing clients of the benefits of wood through knowledge sharing and dissemination, is the most effective means of ensuring more wood in civil engineering. Besides having confidence in wood, it is especially important in some cases to see the advantages of wood compared to other building materials. When (public) clients have confidence in wood as building material for infrastructural assets, they will be positive about it or consider to put it as request in their tender. Banks and other financiers on the other hand,

also ask for assurance. Before these type of actors are willing to finance infrastructural assets using this "*unknown*" building material, they want to be assured of the quality.

Public in-depth sessions

Several free and public, in-depth sessions have arisen from this agreement. Many participants (between 40 to 95 for most sessions), mainly from the government, province and regional water authorities, joined these sessions. After the in-depth sessions, the next step was to concretize in smaller coalitions by means of a tender. The deceasing interest and enthusiasm for this follow-up learning trajectory was striking. Many participants did not feel like they got the space and time by their manager to get started with this.

SF4a+b: Creation of directionality

Creation of directionality by limiting the scope of the task

In this agreement, the decision was made to limit the scope of the problem and focus only on bicycle and pedestrian bridges first. This ensures a manageable scope of the problem and the solutions. Because of the magnitude of the replacement task of these bridges, the environmental impact is high. Given the mandate to introduce wood as a reliable building material, the approach of starting with a relatively small and manageable scope of the problem seems to make sense. In the field of wooden bridges, the Netherlands has yet gained little experience.

Creation of directionality in the solution space

The Agreement on wood started from an exploration, initiated by Rijkswaterstaat into the chances, possibilities, barriers and actions to stimulate wood as construction material. Solutions in multiple directions have been explored. This indicates the early phase of exploration the case is in. From the event analysis it also became clear clients ask too many innovations. The solution space is too wide. The great variety of explored solution directions has to be limited to a few promising directions. This enables contractors to invest time, money and other resources to come up with a good idea.

SF5. Market formation and destabilization

The importance of the role of the client in market formation

The construction sector is highly influenced by the client. The client is the one who issues a tender and comes with the set of requirements. It appears difficult to formulate the functional- and technical requirements which does not affect the environmental impact. A normal requirement for the one material, might be a heavy requirement for the other material. As concrete and steel are more established materials in the construction sector, they benefit from this. A point of attention is that it is difficult to go to truly technical "material-free" specifications.

Alternative (biobased) materials in a conventional tender

The next example is in line with the previous statement. A wooden construction must often be explicitly requested in a tender. It is not common to get wooden solutions in a normal tender. The requirements in a tender are formulated, taking into account the properties of the most commonly used building materials. In the project "de Blauwe Loper", mentioned in the event analysis, a wooden bridge has won the tender because sustainability was an important element in the tender criteria.

SF6. Resource (re)allocation

Raw material resources

Wood is one of the few renewable materials used in civil engineering. A sustainably managed forest, ensures the existing forest area to continues to exist. To guarantee the consumer that the wood actually comes from a sustainably managed forest it has a certificate or quality mark. Also the availability at the required location has to be taken into account. The problem with the Netherlands is that we have very little forest. This means wood has to be imported from other countries. When importing the construction material, also the impact of transport has to be taken into account.

Financial resources

It takes financial resources to introduce a relatively unknown material in a market with materials which are known and optimized for the application, in this case bridges and other infrastructural assets. From the event analysis it became clear that contractors are willing to make financial resources available to explore the possibilities of wood. However, contractors cannot be expected to cover for all the expenses of the development of new and innovative knowledge. The client requests too many innovations which cannot all be explored without financial support. Banks also see an increase in the number of financing requests. The banks say that they are open to share their knowledge and network and take care of financing options.

Human resources

A very important category of resources is human resources. Finding people with the right knowledge and motivation is challenging. Most of the projects seem to be initiated and continued by a small group of highly motivated people. In innovative projects or other pilot projects there is usually not enough time and budget available for the project. Most people do these kind of projects a few hours next to their fulltime job. Projects get cancelled or discontinued due to the lack of human resources. One of the recommendations of a collaboration between Heijmans and Staatsbosbeheer on sustainable timber constructions and making urban areas greener, was to continue the project, but with a larger budget.

SF7. Creation of a supportive socio-technical environment

On the dashboard of “de Bouwcampus”, experiences about the use of wood and other biobased materials in bicycle and pedestrian bridges can be found. Communication and telling the right story is important to strengthen the image of wood as construction material.

High expectations of the use of wood to close the loop

The application of wood in the infrastructure sector has high expectations. Due to the renewable nature of wood, its application is one of the most promising approaches to close the loop.

Need for a socio-technical environment in which wood is seen as a full-fledged building material

Creating a supportive socio-technical environment is very important to gain trust from all partners in the chain. The legitimacy of wood in the infrastructure sector is low due to the overall negative image most parties have at the moment. While creating a new and supportive socio-technical environment it is important to remain open and transparent in

communication. It is important to be open and transparent from the design phase of the project on, about the properties of the material and the risks and possibilities.

Positive effect of quality marks for wood

Awarding a quality mark to wood, makes it easier to justify the use of it.

Creation of a guideline with the aim to inspire parties

In the first session organized from the agreement, all participants were asked to help create a guideline to inspire others. By informing parties about the possibilities in the field of wooden bridges the parties from the agreement want to create a supportive socio-technical environment.

SF8. Coordination

In the chain cooperation they strive for optimal cooperation such that knowledge is available to all parties and there are no longer erroneous assumptions about wood.

Coordination by the branch organization has to be broadened over more sectors

Branch organizations are coordination mechanisms.

4.2.4 Main results for wood per system function

To wrap up the elaborate results from the functional analysis, the main results are presented in table 4-6.

Function	Description
F1: Entrepreneurial activities	• One of the main goals of pilot projects is to improve the image of wood. • Pilot projects are executed on a small scale to eliminate uncertainties. • Options for scaling up within the delineation of the agreement is a serial tender with multiple bridges as a package of projects.
F2: Knowledge development	• Reliability is one of the main aspects for the client. This type of knowledge is highly requested. • Need for new ideas to give wood a fair chance in current commissioning processes. • Main obstacle for contractors to use wood is the lack of knowledge.
F3: Knowledge diffusion	• SBIR project to share knowledge among contractors • Knowledge to increase the reliability to apply wood in civil engineering should also be shared among clients and banks. These actors want to be assured of the specifications and quality. • Free and public in-depth sessions were organized from the agreement.
F4: Problem + solution directionality	• Directionality has been created by limiting the scope of the task as the focus is only on bicycle and pedestrian bridges first. • Clients request too many innovations which indicates a lack of directionality in the solution space.
F5: Market formulation and destabilization	• Role of the client in market formation to create material-free specifications. Concrete and steel have benefits over wooden constructions in the current functional- and technical requirements. • Has to be thought of the introduction of an alternative material in conventional tenders. Currently a wooden construction has to be explicitly requested in a tender.
F6: Resource (re)allocation	• Contractors are willing to make financial resources available. However they will not cover for all the expenses, especially due to the wide variety of innovations requested by the client.

	• Very little forest in the Netherlands, wood has to be imported. • Projects get cancelled or discontinued due to the lack of human resources.
F7: Creation and withdrawal of legitimacy	• The application of wood is one of the most promising approaches to close the loop. • The socio-technical environment has to change to see wood as a full-fledged building material.
F8: Coordination	• Branch organizations have a coordinating role.

Table 4-6: Overview of results for the wood case

4.2.5 Concluding remarks on the wood chain trajectory

In the previous paragraph, the chain cooperation on wood was described in detail. This agreement is specifically focused on the infrastructure sector. Wood has already been applied in the residential building and utility sector. Therefore this is an exploration on the possibilities to apply wood in the infrastructure sector as well.

Key takeaways from this analysis on wood in the construction sector are:

- The outcomes of this research also have suggested that the use of wood is not that common yet because of the higher costs, the unknown properties and the negative attitude towards the use of it. The investments on new knowledge and productions processes are high and it takes time before economies of scale can be achieved. The focus of the pilot projects is on testing certain characteristics and eliminating uncertainties to improve the image.
- In this trajectory people are more open to explore options with a combination of materials, unlike the Concrete Agreement for example. Multiple events show a combination of wood and concrete solutions.
- When it comes to applying wood in the construction sector, most attention goes to the residential building and utility sector.
- Participants were specifically asked to attend every session with at least one person from their organization. This made it possible to continue building on previous sessions.
- Participating parties in the deepening sessions by “Bouwcampus” indicated their challenge to get from policy to actual implementation.
- The market requires too many innovations which cannot be examined without any financial support. The directionality is lacking.

4.3 Third case: Construction Agreement Steel

Introduction to the agreement

The subtitle of the construction agreement steel is as follows: *chain-wide agreements towards a circular economy*. This title indicates the ambition of the steel sector to participate in the mission to fulfill the transition to a circular construction sector. In the Construction agreement Steel, the focus is on both the residential building and utility sector and the infrastructure sector. According to the coalition agreement of the cabinet Rutte IV, all construction materials, including steel, must become more sustainable. The benefits of steel as a building material are that it is strong, cheap and versatile. The partners who signed the construction

agreement steel realize that making steel more sustainable in the construction sector makes a significant positive contribution to reducing environmental problems.

Internal motive to improve the sector

A combination of the realization that raw materials are not unlimited available and the policy imposed by the government to get to a 100% circular economy in 2050, makes the steel sector realize they should also take steps. As stated in the formal text of the agreement do the parties acknowledge that further sustainability of steel have a positive contribution on solving environmental problems. The awareness that something had to change came from the sector itself. The parties itself felt the urgency and collaboratively took the initiative to take control over the future of "*their*" steel sector. Later in the process, Rijkswaterstaat was approached by chain parties to participate in the construction agreement steel.

Magnitude of the problem with steel in the Dutch construction sector

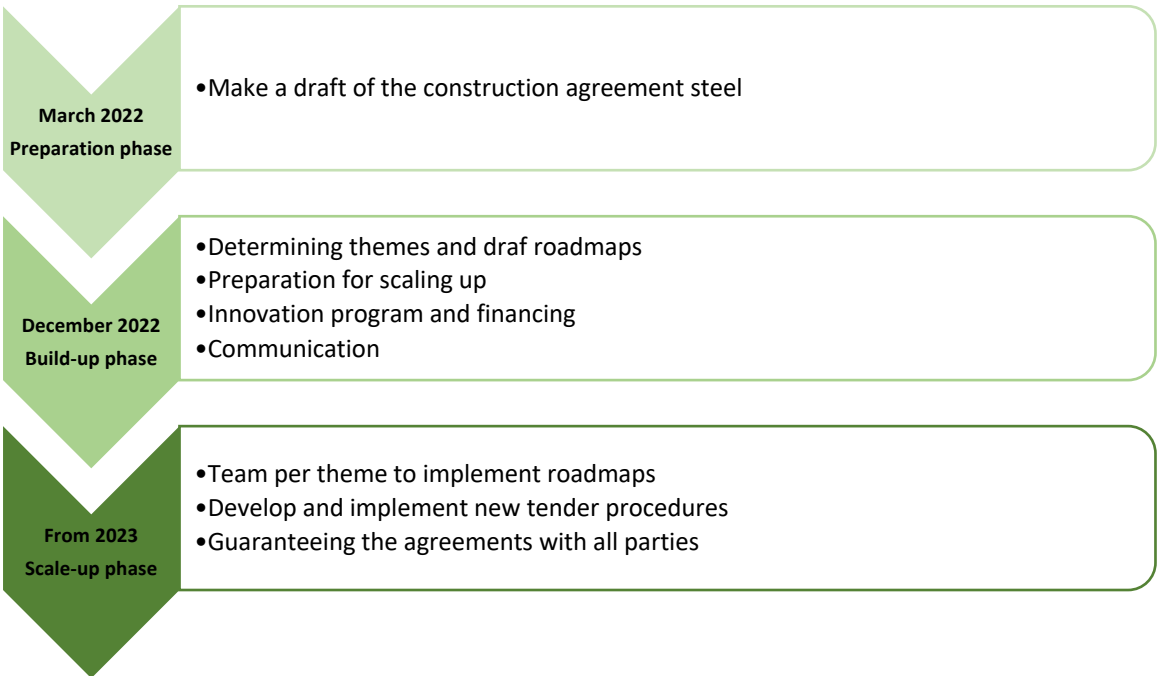
The volume of steel, used in the Dutch construction sector, is less than concrete. Expressed in mass, steel is not a big material stream. Although, the CO_2 emission of steel is comparable to concrete. At the moment, steel is mostly recycled on material level, this process takes a lot of energy. The focus should shift from this type of recycling to reuse on product- of element level (Rijkswaterstaat, 2022). Also the demand for secondary steel is higher than the supply at the moment.

Pioneering approach ("koplopersaanpak")

From the beginning of the steel construction agreement, the pioneering approach was introduced. The pioneering approach is applied to stimulate innovation and provide the market with a foothold. Pioneers indicate what is already possible in the market on the field of innovation. In this approach, pioneers are partners in the chain who can meet stricter environmental requirements with proven innovations. The pioneers set the example with what they have already achieved and the peloton should be able to meet the current level of the pioneers within a few years. In this way, clients can gradually achieve greater environmental benefits and continue to set higher requirements in tenders.

Lessons learned from previous Agreements

Compared to the previous two agreements regarding concrete and wood, the construction agreement steel is the most recent one. The chairman of the construction agreement steel is also the chairman of the concrete agreement. Her strategy is to learn from previous experience and not to reinvent the wheel. By applying the lessons learned from the Concrete Agreement to the steel sector, the steel construction agreement is given a head start. In the preparation phase of the construction agreement steel there was a kick-off meeting with one of the slides named "*learning from the Concrete Agreement*". The following timeline was presented during the kick-off meeting (Schepers, 2021).



4.3.1 Problem-Solution diagnosis

The mission as formulated in the Agreement is:

> *-"The aim of the Steel Construction Agreement is for parties to jointly implement a steel construction sector and chain-wide commitment to significantly improve the sustainability of their activities by 2030."-*

A problem with steel in the construction sector is the supply of secondary steel. Currently two thirds is sent abroad as scrap (interview JC). The used steel must be returned to the cycle. At the moment the supply of secondary steel is not sufficient. That means there is still a demand for primary steel (Rijkswaterstaat, 2022). Primary steel often comes from outside of Europe. The environmental effects of the production energy and the large transport distance is insufficiently included in the assessment of the environmental impact.

Another problem is the required energy for the production in the steel industry. The steel industry is fueled with fossil fuels. Recently, the first hydrogen fueled steel production factory was opened in Sweden. Sustainably produced hydrogen is used for the production of steel. But this "green steel" is 20-30% more expensive compared to normal steel. Sustainability should be chosen over efficiency, and less for better should be chosen over cheap and a lot. Hydrogen and recycling are likely to play a central role in reducing emissions from steel production (interview JC).

It is still possible to improve the development of steel processing. Other elements (like silicon or chromium) are added to give the product more properties like stronger, stainless or stretchable. In this way a steel alloy is created and the properties are difficult to predict when melted for recycling. Because of the unpredictable properties of this secondary steel, it can only be used in low-grade applications, for example as reinforcement of concrete. Welding is another problem when you want to recycle. Because steel structures are often welded, the detachability of steel elements is low (Rijkswaterstaat, 2022). Promising strategies for the

steel sector are reuse and modular construction. The more steel is reused as a product or component or is recycled, the less new steel needs the be used in construction. Problem here is the lack of facilities and infrastructure to make steel products out of 100% recycled steel.

4.3.2 Structural system analysis

The actors involved in the Construction Agreement Steel played a very important role in the founding of the agreement. They felt the urgency to do something and to keep control over their sector so they took initiative to take action. The steel sector itself are arena actors. Because of the way the construction sector is organized, commissioning parties also play an important role. Control in construction mainly comes from those who give the order.

	Steel case
Arena actors	Steel sector (industry, steel trade, steel builders), commissioning parties (public/private)
MIS actors	Government, researchers and consultancy firms
Supportive actors	"Bouwen met Staal" branch organizations of concrete sector, recycling industry and building sector and organizations representing commissioning parties

Table 4-7: Actors involved in steel chain

During the building-up phase, six multidisciplinary teams have been established. Until 2024 they work on roadmaps, action perspectives and other tools to continue to be sustainable and to translate this into projects.

Baseline. Examines a suitable method for measuring the improvement of environmental performances towards 2030
Design
Steel construction
Conserve
Recycling/reuse
Demolition, disassembly and harvesting

Table 4-8: The six multidisciplinary teams in the steel agreement

As mentioned in the introduction to the Construction Agreement Steel, the pioneering approach is applied from the beginning. Pioneers participate in a team where their specific insights and expertise are most useful.

In the Construction Agreement Steel is states that none of the actors are obliged to anything. Despite this, the chairman wants to get rid of the non-committal nature of the agreement. The focus of the parties should be on participating rather than only joining. The goal is not to present a completely prescribed plan with prespecified objectives with steps how to achieve a sustainable steel sector, this is also yet unknown. The ambitions in the agreement are primarily intended to encourage action from actors.

The price of steel is quite sensitive to changes in the market, just like wood (ING, 2021). In the beginning of 2022 the demand for steel has increased considerably. Because of the competitive market, changes in the purchase price are quickly charged to the consumer.

4.3.3 Functional system analysis

As foundation for the functional system analysis, an event analysis was made in a separate Excel sheet. In this paragraph a narrative description of the event analysis is presented. The level of fulfillment of the nine system functions is elaborated on, illustrated with examples from the event analysis and the interviews.

SF1. Entrepreneurial activities

The R-strategy which is applied the most in pilot projects with steel is reuse. Modular constructions are also explored in different pilot projects. In the interview, the chairman of the agreement also indicated that reuse and modular constructions are the two best strategies when it comes to steel.

Although there are not yet many circular pilots with steel, the awareness that scaling up is difficult but highly important, is there. This can be seen from a quote from the chairman of the steel agreement:

> *-"We in the Netherlands are good at pilots. And then it stops. We do not aim for scaling up, so that pilots become commonplace. This approach is insufficient."- J. Cramer*

The willingness and urgency from the sector itself

In this case, a great sense of urgency and willingness from the sector was palpable.

Development of new supply chains which include circular deconstruction

New supply chains have to be developed that include circular deconstruction. Ideally circular deconstruction is taken into account from the beginning. Pilot projects are not only focused on circular building, also on circular deconstruction. Pilot projects can be used to showcase the possibilities and benefits of circular deconstruction.

SF2. Knowledge development

To develop knowledge, the branch association ("*Bouwen met Staal*") has organized an annual competition among recently graduated students in the field of architecture and civil engineering. In the competition there is also attention for sustainability aspects. This is a smart way to make students enthusiast about sustainable or circular ideas and on the other hand helps to develop knowledge on this topic. In recent years, the number of submissions with a circular element in it has increased. From the circular submissions for the competition in 2021, all had something to do with reuse as R-strategy. In previous years also modular constructions got attention in the submissions.

Although the competition is open for students in the field of architecture and civil engineering, all submissions with a circular element in it from 2021 had to do with the residential building and utility sector. The specific attention for the infrastructure sector is lacking here.

Integrate and improve every step in the process

Steel is an already established material in the construction and infrastructure sector. Processes are highly optimized but little attention was given to circularity in the past. Integrating circularity in the process has to be included from the start. Making a design and taking into account circularity is something which requires new knowledge. Thinking about demolition already in the design phase of a project enables circularity.

SF3. Knowledge diffusion

The diffusion of knowledge on the possibilities of circular steel constructions is important. One of the events which had knowledge diffusion as a goal was the steel construction day ("*Staalbouwdag*"), where examples were presented that show what is already possible.

Actors are protective when it comes to sharing their knowledge. Collectivity in learning is something that has hardly be noticed.

SF4a+b: Creation of directionality

When contractors know beforehand what they can expect from the client, they can prepare and invest in innovative solutions. They can make a roadmap.

SF5. Market formation and destabilization

As described in the previous cases as well as in the structural analysis of this case, the (steel) construction sector is highly influenced by the client. Technical, material-free specifications are difficult to formulate.

Limited demand

The public and private client are the ones who indicate what the market has to deliver. Also here the problem is the divergent character of the set of requirements and criteria. Because of this, contractors do not have certainty what to expect in (near) future projects.

Destabilization of the current market

In the current market, the way of using steel is highly optimized. This gives the traditional way of working a huge benefit over the introduction of the new and circular way of working. To make place for CE in a highly optimized steel sector, the current market has to be destabilized. Destabilization of the current market gives room for innovative ideas. No events were found in the event analysis related to the destabilization of the current market.

SF6. Resource (re)allocation

Financial resources

The same as the previous two agreements holds for the construction agreement steel. The Agreement itself does not have any financial resources available. When there is an application for funding, the public client can make money available from the innovation budget or other ongoing projects. Remarkable in this case is the fact that Rijkswaterstaat does not have received any application for funding yet from within the steel sector. Parties will arrange this among themselves. This indicates the urgency from the sector itself. Not only as an actor in the steel construction chain, but also as a citizen, the urgency to do something is growing, which is clearly noticeable in this case.

Because of the limited demand, banks are reluctant to invest in upscaling. Before banks are willing to provide financing for innovative projects, they want some certainty.

Human resources

The lack of skilled people to initiate and continue the transition is a problem. The lack of skilled people is a problem in general, and the chairman of the steel construction agreement also agrees with this statement.

SF7. Creation of a supportive socio-technical environment

By creating an open, not legally binding agreement, they hope to find the required proactive stance, rather than a defensive stance, which often occurs when the contract is legally binding.

The change in the socio-technical environment enforced by the younger generation

From the new generation of employees there is also a pressure for companies to join the steel construction agreement. Companies notice that the younger generation highly values a company that considers sustainability to be of paramount importance. So there is also an incentive from the employees for the company to join the agreement and have sustainable and circular goals. A good reputation is important for the company if they want to attract staff. This change in the socio-technical environment is something that has especially been seen in recent years.

General awareness of the urgency of environmental problems

The moment of the conclusion of the steel construction agreement was favorable in creating a supportive socio-technical environment. As mentioned before, the Agreement has been concluded in the year 2022. By that time, communication to create awareness began to change the general attitude towards continuing the way the industry has always worked. Awareness started to emerge from all parties and they realized that action needed to be taken to keep their firm relevant during the transition to CE.

SF8. Coordination

To speed up the process of creating another covenant in the construction sector, coordination with corresponding covenants (such as on concrete and wood) is made where possible and necessary. The agreement is concluded to bring actors from the entire chain together.

4.3.4 Main results for steel per system function

In table 4-9, the main results of the elaborate functional analysis are summarized.

Function	Description
F1: Entrepreneurial activities	• Focus on the reuse strategy. Modular constructions and reuse are the most promising strategies when it comes to steel. • Pilot projects on the development of new supply chains which includes circular deconstruction.
F2: Knowledge development	• To invite recently graduated students to help with the development of new knowledge, the branch organization of steel organized an annual competition. The number of submissions with a circular element in the report has been growing over time. • Integrate circular knowledge in every step of the project, from design to demolition.
F3: Knowledge diffusion	• Organization of an event ("*Staalbouwdag*") to present what is already possible with circular steel. • Collectivity in learning is hardly noticed.
F4: Problem + Solution directionality	• Need for a roadmap for contractors to know the future solution directionality.
F5: Market formulation and destabilization	• Current market is highly optimized which gives the traditional way of working a huge benefit. Destabilization of the current market is very important here.
F6: Resource (re)allocation	• Lack of human resources to initiate and continue the transition. • Limited demand in circular steel constructions, so the banks are reluctant to invest in upscaling.
F7: Creation and withdrawal of legitimacy	• General awareness of the urgency of environmental problems have clearly been noticed. The moment of the conclusion of the steel construction agreement was favorable in creating a supportive socio-technical environment. • Pressure from the new generation of young engineers to consider sustainability to be of paramount importance. A good reputation on this field is important if the company wants to attract staff.
F8: Coordination	• Coordinating role of the agreement to bring actors from the entire chain together. • Where possible and necessary, coordination from other social agreements has been utilized.

Table 4-9: Overview of results for the steel case

4.3.5 Concluding remarks on the Construction Agreement Steel

In the previous paragraph, the Construction Agreement Steel was described in detail. First an introduction of the creation of the agreement. Next the problem-solution diagnosis and the structural analysis with the involved actors. Finally, a narrative description of the level of fulfillment of the system functions of the MIS framework. To wrap the analysis on the case on steel up, the key findings are listed below.

- The Construction Agreement Steel is the most recent agreement of the three cases described in this research. Learning elements from previous agreements, especially from the Concrete Agreement, can be seen. By applying these lessons learned, the build-up phase is clearly shorter and action can be taken more quickly.

- What also helps to speed up the process of the Construction Agreement Steel, is the overall change in the way of thinking about sustainability and circularity. The discussions for sustainable concrete (Green deal/Concrete Agreement) started years before the plan to draw up an actual agreement on sustainable steel. Where the urgency was not felt by all actors joining the Concrete Agreement, the actors who initiated the Construction Agreement Steel did feel the urgency. The general awareness on environmental problems has been rising over the years. This creates another context and starting point for the founding of the Construction Agreement Steel.

4.4 Comparison between the agreements

Especially in the most recent agreement (steel), a learning element can be seen. Where possible and necessary, coordination has also been made with corresponding sectoral covenants in the construction industry.

Created awareness for climate change

The Construction Agreement Steel is the most recent agreement analyzed for this study. Similar to concrete, steel is an established material with the advantage that it is strong, cheap and versatile. The initiative to make the construction sector circular by formulating the Green Deal sustainability on the concrete sector and later the Concrete Agreement, raised awareness throughout the entire construction sector. In the steel agreement, the sector itself realized they needed to take action to keep their sector alive and competitive with other materials. The knowledge about CE and the situation of our planet is different from the other two agreements at the time of signing the Construction Agreement Steel. This accelerated the process of taking the first steps.

The important role of the client in the construction sector

In all three social agreements, the importance of the role of the client became visible. Control in the construction sector mainly comes from the ones who initiates to build. A strong instrument to steer the construction sector is the procurement process (SF5). The public client can come up with a set of requirements and the market has to comply to it. Public clients are there at different levels like national, provincial and municipal level. There are many differences, especially on a municipal level, when it comes to steering and stimulating circularity through the procurement process. In all the studied agreements they are aware of the strong position of the client in the transition. In the chain cooperation on wood, two trajectories are created to facilitate clients in the step from policy to implementation. In the concrete and steel agreements, the focus is also on the client and the procurement process.

Restrained attitude towards circular economy

The awareness for circularity is growing, but applying circular ideas is not yet common practice. Many times, circular initiatives are initiated by one single enthusiastic person within the organization. Thinking and acting in a circular way is not yet widely embedded among employees (SF7). From the results of all three cases it emerges that this way of thinking should be present with more employees. Besides the importance of teaching the circular way of thinking to people (SF3), it is also important to listen to the people who already want to implement (an element of) circularity in projects.

The importance of a clear path for the future

In all three cases the importance of a clear path of the future comes forward (SF4). First of all contractors say that too many different innovation directions are requested in a tender, which makes it impossible for them to develop the knowledge (SF2) to explore all options (without any financial support (SF6)). Second of all, contractors do not know what to expect in future tenders which makes it difficult for them to plan and set a path for future directionality of the company (related to SF4).

4.5 Conclusion on the third sub-question

The third sub-question refers to which elements in the three cases are promoting and hindering the transition. The question is as follows:

What is promoting the transition and what is hindering the transition of the selected initiatives towards a circular infrastructure sector?

To answer this sub question, case-specific details were discussed. The answer here is specific to the studied agreements.

Promoting.

- A recommendation for achieving goals in this kind of social agreements is working from networks. Use initiatives that involve many clients. For example, in the Concrete Agreement, only five of the bigger municipalities have signed the agreement. By involving the interprovincial consultation network (IPO), indirectly all provinces will have to deal with it. Municipalities might not be directly involved, but through an organization like Pianoo, the actions of the Concrete Agreement affect also the parties that did not sign the agreement.

Hindering.

- From the structural analysis of all cases it became clear that one important characteristic of the construction industry is the influential role of the client. Most infrastructural projects are requested in a tender by a public client. In the commissioning process the clients have a steering role.
    - The commissioning process seems to be hindering the transition at the moment.

5. Discussion

In the previous chapter, the results of the analysis were presented. After presenting the results of the analysis, this chapter reflects on how the general findings from the cases relate to the existing literature. The aim of the study was to examine the transition to a circular Dutch infrastructure sector by analyzing three cases. In the previous chapters the research was executed and per case the results and key findings are concisely summarized. In the discussion chapter it is time to zoom out and look at the findings in relation to the literature discussed in chapter two. However, the results should be interpreted with caution, due to the limitations of the research, discussed later in this chapter. Finally, this chapter ends with a conclusion on the last sub-question.

5.1 Overall interpretation of results

The first paragraph of the discussion refers to the general interpretation of results with respect to the existing literature. Case specific results were presented in the previous chapter. These results have been generalized to the level of social agreements in the infrastructure sector. By generalizing the results, it is possible to assess how the outcomes of this research relate to the existing research discussed in chapter two.

Reflecting on the choice to delineate the scope on social agreements and specific materials

In the infrastructure sector, parties from the entire chain with regard to a specific material have chosen the approach to jointly work on circular goals. The delineation of a social agreement with regard to a specific material is something they all have in common. Due to the delineation, the system is bounded. The second dimension of Wals (2020) emphasizes the importance of keeping an overview of the entire system. Barriers can be seen as spaces with potential for learning.

Flexibility is required to enable upscaling in pilot projects

Flexibility in regulations together with keeping the entire system in mind while performing pilot projects, can help to scale up pilot projects. This result fits with the theory that breaking through boundaries is key while keeping an overview of the entire system. Certain aspects of the asset management cycle are innovative, but the overview of the entire system is insufficiently taken into account. The first step to enable upscaling, is to consider the entire playing field. Sustainable oriented learning concerns boundary crossing and systems thinking.

Creation of awareness of directionality

An important step in sustainably-oriented learning is the awareness of the direction in which we are moving and the contribution and position one has in this. This is also highlighted in the first dimension of Wals (2020) on sustainability learning where he stresses the importance to make citizens aware of the direction in which they move and their contribution on it. This is also a central concept in the MIS perspective. As Sterling (2009) mentioned, sustainability is an ambiguous and contested concept, which will cause disagreement and debate about the directionality of sustainability transitions. The goal of MIS is to combine multiple solution trajectories to provide directionality to successfully complete the mission (Schaile, et al., 2017). Disagreement about the directionality relates to the third dimension of Wals which makes learning in the field of sustainability transitions challenging (Stirling, 2009). In this case, dissonance between chain parties should be utilized to create directionality which helps to

successfully complete the mission. Also the definition of circular economy in the construction sector has to be clear to everyone.

Importance of creating a shared sense of urgency

The outcomes of this research support the claim of March (1991) that learning stimulates creating, enriching and sharing of knowledge. Due to the development of general knowledge on environmental problems, the urgency of the transition towards a circular economy was being felt by more and more actors. This also relates to the ethics and values dimension of Wals (2020). In this first dimension of sustainability learning everyone should be made aware of their contribution and position in the world. This growing level of attention, stimulates organizations to create knowledge on ways to apply circularity in practice. Also, one of the guiding principles of professor J. Cramer to successfully implement circular initiatives, is to have a shared sense of urgency (Cramer, 2020). At the moment, learning is visible in all cases through the development of the consciousness of the transgression of the planetary boundaries.

Limitations of the non-binding nature of social agreements

Forming a social agreement is a first step to bring actors together and create legitimacy on the topic. The non-binding nature of the social agreements makes it hard to get everyone on board at first. Making the actions and goals legally enforceable gives the opportunity to put consequences on not following the rules. This also matches with the literature and the interviews that creating a social agreement is a first step to create legitimacy. In order to really change the sector, the goals should be made mandatory by law.

Changing the system instead of changes within the system

The outcomes of this research have suggested that defining a social agreement mainly leads to solutions within the system. This has to do with the fourth dimension in sustainability learning about the transformative capacity. March (1991) claims that the two fundamental learning processes, namely exploitation and exploration, come at the expenses of each other. Transformation is different from optimization. In exploitation, the values upon which a system is based are left intact and the focus is on efficiency. Exploration focusses on radical innovations where prevailing systems will be redesigned. The cases for this research were demarcated by a specific material and by the social agreement. Taking this demarcation has as a consequence that solutions are mainly aimed at optimizing the current system within the system boundaries. To actually change the system outside the system boundaries, a broader formulation of the mission is required. Also the realization that the focus on exploitation is at the expenses of exploration is important. Both learning processes cannot exist next to each other.

Attention for destabilization of the incumbent market

Destabilization of incumbent market also refers back to the transformative capacity of Wals. Overall little attention was given to the destabilization of existing markets. The development of a new market does not automatically imply the destabilization of an incumbent market (Kivimaa & Kern, 2016). Depending on the maturity of the given market, more or less attention is required for destabilization. As Sandén and Azar mention, investing in early stages of research is risky because the creation of a new market is uncertain in terms of cost and performance. The infrastructure sector is overall highly optimized and margins are low. This

makes it almost impossible for innovative ideas to enter the market without destabilizing the highly optimized processes first. As Kivimaa and Kern (2016) mention, policy should also take into account the disruption of an old market. The industry is reluctant to change their way of working. Space has to be created before new ideas can be implemented. Destabilization is often a topic which receives less attention, however it is very important.

Put influential actors in the arena

The outcomes of this research have suggested that it is advisable to put influential actors in the mission arena. The process of establishing an agreement requires time and effort. However, conflict and dissonance are crucial for learning (Berlyne, 1960). From this research it became clear there is little time available for participating in agreements. Parties are willing to participate, however due to the lack of human and financial resources this is something an enthusiastic person from an organization will do next to its regular tasks. This research has shown parties set aside little time for this. For operational people formation of an agreement quickly becomes too much talk and too little action. The research suggested that the frontrunner approach is useful.

However, it is important to make sure actors are not ignored when they want to be in the arena.

Generalization by similarities

To discuss the results of the analysis more in general, a distinction has been made between an already established material and a yet to be introduced material. An already established material has advantages over a material which is unknown yet in circular applications. The process of applying often used materials is highly optimized. The downside is the standardized patterns are not easy to change. The studies of case I and III (concrete and steel) show a lot of similarities and are categorized as “already established materials”. Case II (wood) is different in many ways. The application of wood in circular solutions in the infrastructure sector is relatively new, which comes with other challenges compared to the application of concrete and steel. The table below (table 5-1) shows the important characteristics of the two categories. In the discussion, the aim is to get to a higher level of abstraction. After dividing the cases into two categories, a comparison on a more generic level can been made.

Already established material	**Yet to be introduced material**
Highly regulated	Requires new regulation
Low margins	Less formal contract
High sunk costs	Narrow scope
Formal contract	
Broad formulation of the problem	

Table 5-1: Characteristics of the categorization established materials versus yet to be introduced materials

5.2 Already established material

The cases about concrete and steel have been categorized as “already established materials”. To get to a dynamic model for this generalization, the first step is to make a dynamic model for the separate cases.

5.2.1 Dynamic model for the concrete case

The dynamic model below shows the interaction between the system functions for the first case about concrete. This model is based on table 4-4 in the previous chapter where all key results for the case about concrete have been highlighted.

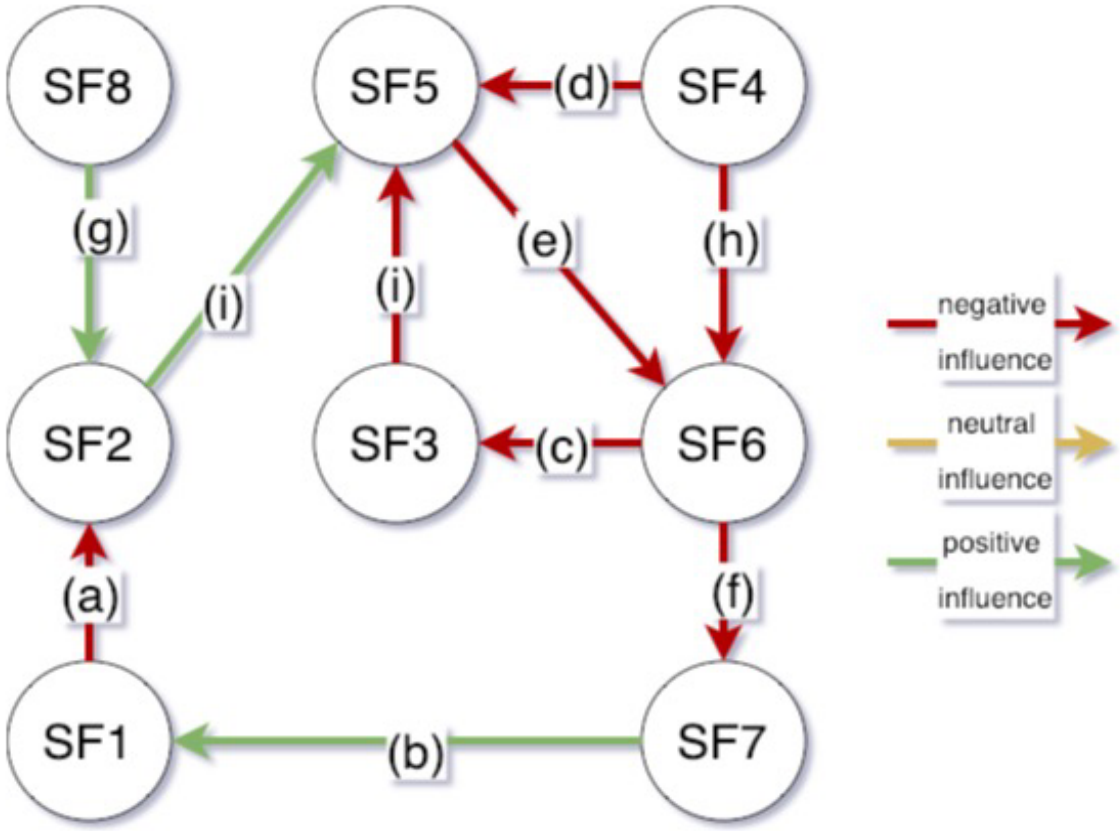


Figure 5-1: Interaction between system functions for concrete case

A: Valuable lessons (SF2) which can be learned from pilot projects get lost, because the limited attention for learning from these projects;
B: Increasing level of legitimacy has a positive effect on the entrepreneurial activities in the concrete agreement;
C: Knowledge and expertise gets lost (SF3) for example when employees retire (SF6);
D: Due to the lack of clear directionality (SF4) the market does not get certainty what will be requested in tenders and there is no clear incentive for destabilizing the existing (highly optimized) market (SF5);
E: There is a need for tighter requirements (SF5) to obtain financial resources (SF6);
F: Because there is a lack of (financial) resources, circular economy receives little attention;
G: Measurement methods are developed (SF8) which provides new knowledge (SF2);
H: The lack of clear directionality (SF4) results in parties being hesitant to provide (financial) resources (SF6);
I: Knowledge is developed (SF2) on market formation (tender requirements) (SF5), despite it is not widely applied yet because it is not diffused (SF3) enough.

5.2.2 Dynamic model for the steel case

The dynamic model below shows the interaction between the system functions for the third case about steel. This model is based on table 4-9 in the previous chapter where all key results for the case about steel have been highlighted.

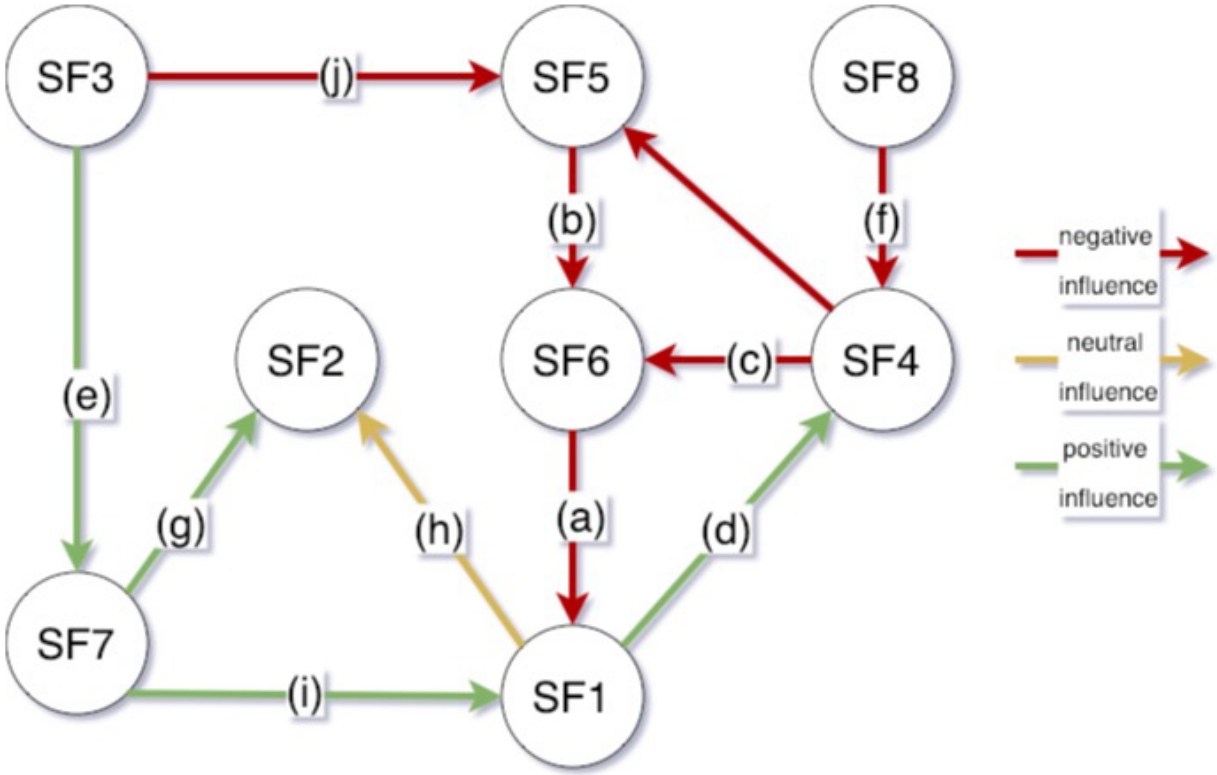


Figure 5-2: Interaction between system functions for steel case

A: There has been a lack of (human) resources (SF6) to initiate and continue the transition;
B: Limited demand (SF5) for circular steel construction which results in banks being reluctant to invest in these kind of projects;
C: Lack of directionality (SF4) which results in a limited release of resources (SF6);
D: The pilot projects help to provide directionality (SF4);
E: An event organized ("*Staalbouwdag"*) to show what is already possible in the field of circular steel (SF7);
F: Roadmaps (SF8) are required to provide directionality;
G: Legitimacy of the topic is growing which can be seen in the growing interest of students on this topic which results in the development of new knowledge (SF2);
H: Pilot projects do not sufficiently increase the level of knowledge (SF2), because valuable lessons from this gets lost;
I: The increasing level of legitimacy (SF7) has a positive effect on the number of pilot projects (SF1);
J: Sharing knowledge does not result in creation of market (SF5).

5.2.3 Dynamic model for the already established materials

The categorization of the already established materials in the infrastructure sector is based on the two cases mentioned above. The following model is a combination of both dynamic models (figure 5-1 and 5-2). The aim with this dynamic model in this paragraph is to make it more general applicable in other cases with mainstream materials.

Importance of market destabilization in established markets

Some dynamics can be either observed in only one of the two categories made before. One of the most important realizations for already established materials is the destabilization of the current market. The theory of Wesseling and Meijerhof (2021) emphasizes the importance of the destabilization of an existing regime in order to develop and adopt a new regime. The experience one has with concrete, along with the other advantages (price, strength and resilience) and the relatively stiff market formation, makes it challenging to destabilize the current regime. The results do fit with the theory that actors, networks and institutions are developed and improved in terms of costs and performance in existing innovation systems (Mazzucato, 2016). The emergence of friction creates a window of opportunity to reframe the way of thinking, to learn something new and to expand the horizon (Wenger, 2010). The initial formulation of the Concrete Agreement caused friction throughout the construction sector. As one of the interviewees mentioned, most of the parties who joined the Concrete Agreement wondered if this matter was really that urgent. The intrinsic motivation of the actors was low, which resulted in a wait-and-see attitude. Over the years the attitude changed. After the Concrete Agreement has been formulated, several other initiatives, such as those analyzed for this study, were established to make the construction sector more circular.

In figure 5-1 a visual representation of the interaction between the system functions for an already established material is presented, based on the outcome of this research.

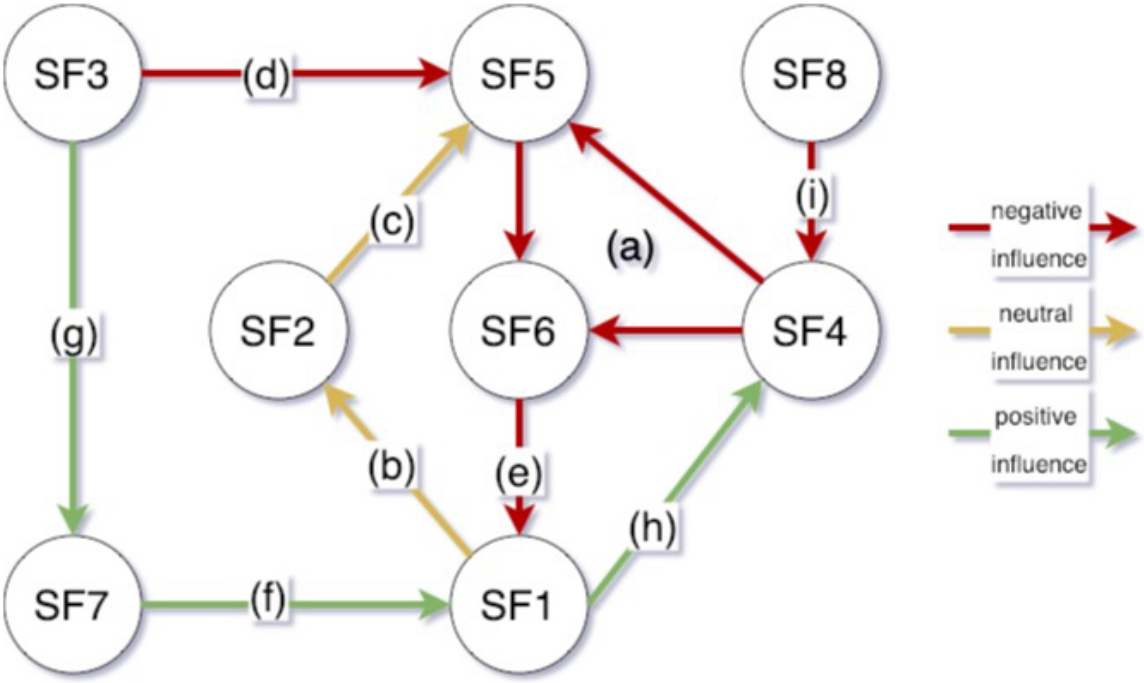


Figure 5-3: Interaction between system functions for an already established material

A: Due to the lack of clear directionality (SF4) the market does not get certainty what will be requested in tenders and there is no clear incentive for destabilizing the existing (highly optimized) market (SF5). This results in banks being reluctant to provide financing;
B: Entrepreneurial activities (SF1) do not sufficiently result in an increase of the level of knowledge (SF2);
C: The level of knowledge (SF2) does not hold back market activities (SF5);
D: Sharing knowledge (SF3) between clients does not increase the speed of the transition. Clients share information on how to formulate tenders and presented a set of minimum requirements which can be copied by other clients in their projects (SF5) but this does not have the desired effect;
E: Experimentation (SF1) is limited because of the limited financial and human resources (SF6);
F: Over time legitimacy (SF7) has been created which results in a shared urgency for the issue by most parties. This shared sense of urgency has a positive effect on the number of initiatives from companies to conduct experiments (SF1);
G: Coordination (SF8) in the chain of the industry of an already established material still hold back the speed of the transition. It is challenging for chain parties to find each other and have the right information available for everyone.

5.3 Yet to be introduced material

In this paragraph, wood from the second case of this study, is categorized in a wider and less case specific category. Wood is a known material, but its application a circular context is relatively new. To get to the generalization of a dynamic model for the "yet to be introduced materials", first a model for the case about wood is presented.

5.3.1. Dynamic model for the wood case

The dynamic model below shows the interaction between the system functions for the second case about wood. This model is based on table 4-6 in the previous chapter where all key results for the case about wood have been highlighted.

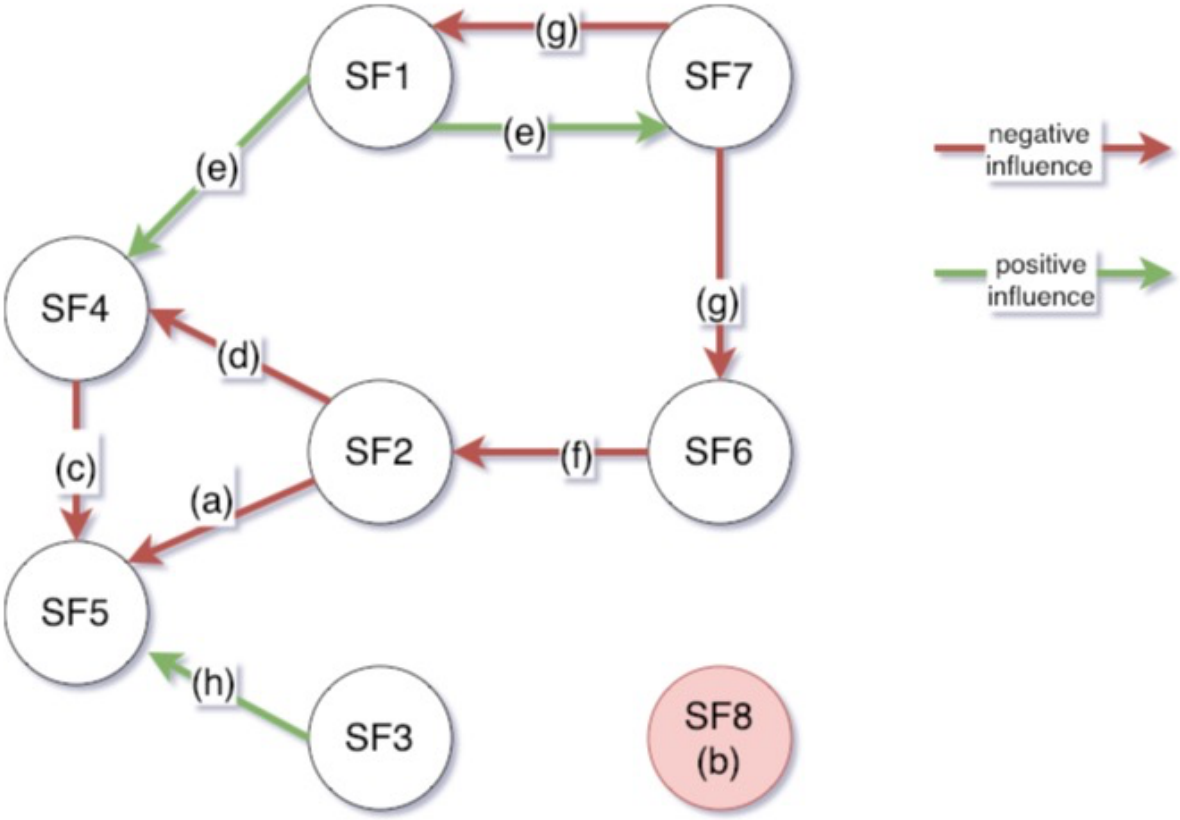


Figure 5-4: Interaction between system functions for wood

A: Because there is still a lot unknown about wood in circular applications, most clients are hesitant to specifically require wooden solutions in tenders. The market demand is limited;
B: The lack of coordination negatively influences the whole system.
C: Directionality in both the problem and solution space is lacking. Actors in this case mention the wide variety of solution to be explored. The lack of directionality makes the client hesitant to choose for wood in circular solutions;
D: The overall level of knowledge on wood in circular applications is insufficient to make an informed choice on the future directionality;
E: Many small scale pilot projects are done with wood. One of the main focus of these projects is to test characteristics and prove the possibilities with wooden solutions (SF7: create legitimacy). Also the directionality (SF4) is influenced in a positive way by entrepreneurial activities;
F: Due to the lack of human resources the level of knowledge remains insufficient;
G: The reticent attitude towards wood (SF7) has a negative influence on entrepreneurial activities and on providing resources. It takes time and costs money to do a pilot project, so when the overall legitimacy is low, actors are hesitant to initiate this. The same holds for resources, either human or financial. It makes it hard to attract any time of resources when the legitimacy for wood is low;
H: Sharing knowledge stimulates the market. Knowledge sharing can in this case be seen in open source sharing of knowledge in the SBIR project.

5.3.2. Dynamic model for the yet to be introduced material

Since the categorization of the yet to be introduced materials is only based on one case, figure 5-4 is the same as figure 5-5. The description in the box below is more general and less case specific. This makes it possible to apply this dynamic model to other cases with yet to be introduced materials in circular economy.

Pilot projects for yet to be introduced materials are more experimental

Pilot projects are carried out with the aim of increasing trust and proving its abilities. The studies that are done under this agreement are mainly related to the lifespan of wood and increasing the overall level of knowledge about this material. This relates to the transformative dimension of Wals (2020). Exploration as learning process focusses on radical innovations. The current system should be reconsidered and redesigned. This is one of the dimensions to design a learning space that enables people and organizations to contribute to sustainable development.

Starting with a smaller scope

When a material has to prove itself, it is advisable to start with a relatively small scope to get everyone on board and test properties before broadening the scope.

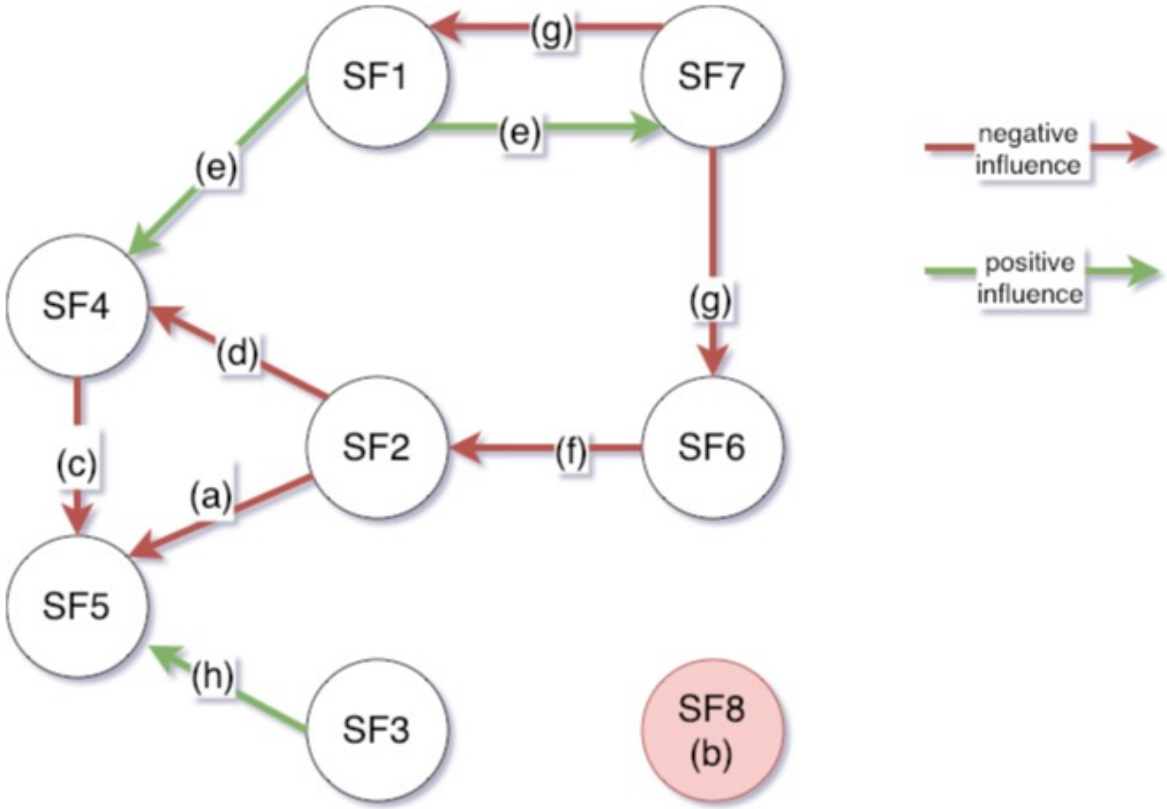


Figure 5-5: Interaction between system functions for a yet to be introduced material

A: The lack of knowledge affects the market demand;

B: The lack of coordination is something which negatively influences the whole system.

C: The lack of directionality negatively influences the market demand;

D: The general level of knowledge is insufficient to make an informed choice on the future directionality;
E: Entrepreneurial activities like pilot projects have a positive effect on the directionality and the legitimacy;
F: Due to the lack of human resources the level of knowledge remains insufficient;
G: The lack of legitimacy creates reluctance in entrepreneurial activities and providing resources.
H: Sharing knowledge stimulates the market.

5.4 Case specific discussion points

This chapter has been reflecting on the results of the research in relation to existing literature. In the previous paragraph the distinction between an already established material and an yet to be introduced material has been made. Table 5-1 shows the characteristics for these two categories. In this paragraph a few unique characteristics which can be seen as an exception per case have been highlighted.

Utilization of conflict and dissent to finally conclude the Concrete Agreement

Concluding the Concrete Agreement did not go without any setback. At first there was a lack of trust, support, consistent policy and incentive from the government. Because of this, both the concrete and cement industry were not willing to commit themselves to the original Concrete Agreement without additional principles. To utilize conflict and dissent, conflicting opinions are valued. In line with the theory of Wals (2010) it shows that conflict and dissonance are crucial for learning. This notion especially came forward in the building up phase of the Concrete Agreement.

Unique results for wood

The starting point of wood cannot be compared with the other materials. This makes the discussion and interpretation completely different from the other two cases. The outcomes of this research have suggested that the actors and companies in this trajectory are more open to explore options with a combination of materials compared to the already established materials. The data shows multiple combinations of wood and concrete solutions. The result supports the claim of Wesseling and Meijerhof (2021) that the current regime has to destabilized first. Wood is not yet a common used material in the construction sector with the consequence that it has to build up a regime without having to destabilize an existing regime. The focus can be on building the new regime.

Unique results for steel

The Construction Agreement Steel is seen as an "*improved version*" of the Concrete Agreement by people in the field. The role of J. Cramer as chairman of both agreements also supports this statement. Based on one of the interviews, the outcome of this research suggests that the time element in the establishment of the agreement has played an important role in the urgency and interest felt by the sector. The results support the claim of Wals (2020) that in sustainability-oriented learning actors should be made aware of the direction in which they move and their contribution and position in the world. Wals states that education helps to move in another direction when they are uncomfortable with the current

direction they move in. The increasing focus in the circular economy over time has made people more aware of the fact that something has to change.

In contrast with the Concrete Agreement, the actors in the Construction Agreement Steel felt the urge themselves to take action to maintain *their* sector. Remarkable was the fact that actors from this Agreement did not involve governmental organization, like Rijkswaterstaat, for financial reasons. The discussion for adopting circular practices in the construction sector started years before the plan to formulate the construction agreement steel.

5.5 TIS versus MIS

Compared to TIS, the predecessor of MIS, a few improvements can be observed. Three main criticisms have been highlighted in the literature.

1. Little attention given to the destabilization of the current regime.
2. TIS is less suitable for a large variety of solutions.
3. The goal of TIS is to converge actors in a specific technological trajectory.

Given the complex and wicked nature of the mission, the three points of criticism are problematic when TIS had been chosen instead of MIS. TIS is an useful approach when the solution space is already converged. In this already converged solution space, actors can be converged in one technological trajectory. When employing TIS in this research, a specific technological trajectory had to be chosen. Due to the lack of knowledge, this choice would have been more or less random. By neglecting the large variety of solutions, probably a lot of valuable knowledge and possibilities will be lost. The power of MIS is its ability to combine multiple solution trajectories to provide directionality to successfully complete the mission by changing the system. Also the lack of attention for destabilization would have been problematic. The construction sector is an highly optimized and developed sector. Without destabilizing the current regime there would not have been room for innovative solutions to be introduced. In short, the shortcoming of the TIS model would also have been problematic for this research. Therefore the choice of MIS over TIS can be justified.

5.6 Sustainable learning dimensions

To assess to what degree the dimensions have been developed for this case, every dimension will be elaborated.

- Ethics and values. In this dimension the focus is on the importance to make citizens aware of the direction in which they move and their contribution and position to the world. From the results of the research steps in the right direction can be clearly noticed. In 2016 actors were reluctant to join the Concrete agreement and it took a while to formulate values in the agreement. A change in the awareness of the contribution of citizens and their position in the world has been seen in the most recent example of the construction agreement steel. Developing and sharing knowledge has proven to be helpful in aligning ethics and values better.
- Boundaries and systems. There is still room for improvement in terms of boundary crossing and systems thinking. In this dimension Wals (2020) mentions the importance of the focus on the overview of the system rather than on relatively small parts in the system. By taking the three cases, limited by the boundaries of the material agreements, the broad view and the breaking through boundaries is limited. When looking outside the scope of this research, the broader view is also lacking. In this

phase of the transition it is essential to break through boundaries to enable sustainable learning.

- Diversity and dissonance. The first attempt to establish the Concrete Agreement was a nice example of utilizing diversity and dissonance. Conflicting opinions have eventually lead to a tipping point. After this point the agreement has been finalized relatively quick. Utilization of conflicting opinions is not observed often in this research. As educational psychology has shown that dissonance is crucial for learning, there are still steps to be taken here.
- Agency and transformative capacity. The final dimension relates to the ability to adapt to new situations. Especially for concrete and steel the power to oppose to unsustainable development seems challenging. As March (1991) mentioned, exploitation and exploration are at the expenses of each other. For example in the Concrete Agreement a distinction between short and long term innovation has been made. A trade-off between exploitation (focus on improving efficiency) and exploration (radical innovations) has been noticed. The implicit choices in the concrete and steel case are different from the wood case. The transformative capacity also still requires attention.

5.7 Conclusion on the fourth sub-question

Where the previous sub-question dealt with case-specific conclusions, this sub-question focuses more on general conclusions. To reiterate, the fourth sub-question reads:

What insights do the three social agreements provide for other initiatives to accelerate circular transition in the Dutch infrastructure sector?

The approach applied in this chapter to be able to make more general statements, was to look for characteristics of the cases that were not related to the materials. The three cases were divided into two more general categories. Dividing the three cases in two more general categories, enables future cases to take the lessons learned from this research. Table 5-1 shows the characteristics of the categories composed for this research to make statements at a higher level of abstraction. In paragraph 5.2.1 and 5.2.2 a visual representation has been presented of both systems dynamics for the already established materials and the yet to be introduced materials respectively. Generalizing the analyzed cases in two more general categories gives the opportunity to make statements on how to accelerate the circular transition for other initiatives in the infrastructure sector.

In this chapter, the cases on concrete and steel are generalized to the concept of already established materials in the infrastructure sector. An overall view of the system dynamics in both cases has been presented in figure 5-1. A negative feedback loop between the market formation and destabilization, availability of financial and human resources and the lack of directionality can be observed. The negative feedback loop suggests that this is something which requires attention for established materials in order to accelerate the transition in future initiatives. Coordination is also an important system function to focus on while trying to accelerate an initiative. The lack of coordination influences the whole innovation system negatively.

In figure 5-2 the system dynamics of yet to be introduced materials has been presented. In this chapter the findings from the case on wood have been generalized to a higher level of abstraction, namely the yet to be introduced materials. This generalization suggest that other yet to be introduced materials in the Dutch infrastructure sector will show similar dynamics. First of all, many negative influences have been noted. Overall, the lack of coordination has a negative influence on the development of the whole innovation system. Entrepreneurial experiments will help to create a supportive socio-technical environment. However, the non-supportive socio-technical environment is the root cause of many negatively influenced system functions. Due to the lack of a supportive environment, there is a lack of financial resources which causes insufficient development of new knowledge. The lack of knowledge has as a result no clear direction for the transition and little possibilities to create a market for the yet to be introduced material.

Figure 5-1 and 5-2 both indicate which dynamics hold back the circular transition in the Dutch infrastructure. Keeping the system dynamics in mind when studying other initiatives helps to focus on the system functions that are key in order to build a well-functioning innovation system. A well-functioning innovation system helps to accelerate initiatives in the transition to a 100% circular Dutch infrastructure sector.

6. Conclusion

The final chapter of this research refers back to the introduction. In the introduction the problem of this research was introduced. In the theoretical and methodological chapter the research was narrowed down to detailed choices about the execution of the research. In the results chapter, the key findings per case were presented. In the discussion, the relation of the theory with the findings from the results were discussed. The aim of this concluding chapter is to provide answers to the sub-questions and main research question. The limitations of this research have been highlighted and the chapter concludes with recommendations for future research and practical recommendations.

6.1 Answer to the sub-questions

In every chapter, one of the sub-questions has been elaborated and answered. For the concluding chapter, the key aspects of the answers to the sub-questions will be highlighted. These answers lead step-by-step to answering the main research question.

1) How can the concept of the Circular Economy be defined in the Dutch infrastructure sector?

To define circular economy in the Dutch infrastructure sector, multiple theoretical concepts have been explored. Subsequently the concepts of circular transitions, transition studies, innovation systems, MIS and sustainably-oriented learning have been explored. The starting point of a linear economy is the take-make-waste idea. A fully circular economy is based on these three principles:

- Eliminate waste and pollution;
- Circulate products and materials and;
- Regenerate nature.

Currently the society is somewhere in between a linear and circular economy. Circular activities can be categorized in four comprehensive categories, namely close the loop, slow the loop, narrow the loop and substitute.

A transition is required to get to a circular economy. The field of transition theory has received a lot of attention recently. Four prominent transition frameworks can be noticed. From these four frameworks, the innovation system approach has been further elaborated.

Important structural elements in innovation systems are: actors, networks and institutions. One of the early branches in the innovation system approach is the technological innovation system (TIS). The focus of this framework is on new technologies as a basis for fundamental socio-technical transitions. When facing a wicked problem with a large variety of solutions, the TIS framework is not sufficient. With the introduction of third generation missions, societal problems can be addressed. The TIS framework has been expanded to a mission-oriented innovation system (MIS). Taking a mission as a starting point will cut through national, regional, sectoral and technological dimensions, making it a promising research method in dealing with grand societal challenges.

Learning in the field of sustainability is different from traditional learning approach because sustainability is a collective good. The four dimensions that refer to both the process and the outcomes of sustainability learning are:

- Ethics and values;
- Boundaries and systems;
- Diversity and dissonance;
- Agency and transformative capacity.

2) How to map and analyze the circular transition process of the three recent social agreements in the Dutch infrastructure sector by employing the Mission-oriented Innovation Systems approach?

The MIS approach has been employed on the cases to map the transition process. A separate MIS analysis has been done per case. The research steps and data collection are described in detail to be able to compare the results of the separate analysis. The three subsequent steps in the MIS analysis are:

Problem-solution analysis.	The goal is to indicate level of convergence or divergence in the problem and solution space. This indicates how focused the problem is;
Structural analysis.	Gives an overview of all relevant actors, networks and materiality. Actors with steering power are placed in the mission arena. Other relevant that affect the rate and direction of solutions to the mission actors are in the overall MIS;
Functional analysis.	The innovation system in assessed on the MIS system functions. This step of the analysis provides a narrative explanation of events.

3) Which factors are promoting the transition and which factors are hindering the transition of the social agreements towards a circular infrastructure sector?

Promoting factor

An important factor which is promoting the transition is working with networks. Use networks that involve many clients. For example, in the Concrete Agreement, only five of the bigger municipalities have signed the agreement. By involving the interprovincial consultation network (IPO), indirectly all provinces will have to deal with it. Municipalities might not be directly involved, but through an organization like Pianoo, the actions of the Concrete Agreement affect also the parties that did not sign the agreement.

Hindering factor

A factor which seems to hinder the transition is the influential role of the client. Most infrastructural projects are requested in a tender by a public client. In the commissioning process the clients have a steering role. The commissioning process seems to be hindering the transition at the moment.

4) What insights do the three social agreements provide for other initiatives to accelerate circular transition in the Dutch infrastructure sector?

To accelerate circular transition in the Dutch infrastructure sector, the three cases from the case study have been categorized in two more general categories. This categorization has been made based on similar characteristics in two of the cases. The cases about concrete and steel showed many similarities. Because of their history in (circular) infrastructural projects, these two are groups as the "already established materials". This is different from wood, which has to be introduced as a new material to work with in circular infrastructural projects. Both groups show a different interaction between the system functions.

Accelerate the transition for the already established materials

To be able to say something about how to accelerate the transition in the Dutch infrastructure sector, for both groups a dynamic model shows the interaction (positive or negative) between the system functions. For the already established materials a negative feedback loop between the market formation and destabilization, availability of financial and human resources and the lack of directionality can be observed. The negative feedback loop suggests that this is something which requires attention for established materials in order to accelerate the transition in future initiatives. Coordination is also an important system function to focus on while trying to accelerate an initiative. The lack of coordination influences the whole innovation system negatively.

Accelerate the transition for the yet to be introduced materials

In the dynamic model of the yet to be introduced materials, many negative influences have been noted. Overall, the lack of coordination has a negative influence on the development of the whole innovation system. Entrepreneurial experiments will help to create a supportive socio-technical environment. However, the non-supportive socio-technical environment is the root cause of many negatively influenced system functions. Due to the lack of a supportive environment, there is a lack of financial resources which causes insufficient development of new knowledge. The lack of knowledge has as a result no clear direction for the transition and little possibilities to create a market for the yet to be introduced material.

As can be seen, both groups require extra attention on different functions.

6.2 Answer to the main research question

This research has explored the transition to a circular Dutch infrastructure sector through three social agreements by taking the MIS perspective. Each chapter started with the aim of finding an answer to a sub-question. Per chapter a sub question was discussed and answered. Based on the research and the answers to the sub questions, the main research question can be answered now. To restate, the main research question is as follows:

What can we learn about targeting the transition to a 100% circular Dutch infrastructure sector in 2050, through three social agreements if we take the perspective of Mission-oriented Innovation System (MIS)?

Based on a qualitative analysis, it can be concluded that:

- In terms of learning dimensions, it can be advised to utilize diversity and dissonance to break with existing routines and systems. Utilizing differences and conflicting opinions can actually lead to a tipping point. Reaching the tipping point can trigger to break with existing routines and systems. Also the transformative dimension to adapt to new situations and the power to oppose to unsustainable development requires attention.
- MIS is an appropriate method to study this research question. All elements relevant for answering the research question have been addressed.
- Difficult to note successes that narrow the loop. More intensive or efficient use of a product will normally not be noticed. To show the progress in the transition process it is important to pay attention to these successes.

To answer the main research question, learning about targeting the transition to a 100% circular infrastructure sector by taking the MIS perspective gave many useful insights. By analyzing three material agreements in the Dutch infrastructure sector, this thesis has shown how the selected agreements contributed in the transition to a fully circular infrastructure sector in 2050. Learning, transition, circular Dutch infrastructure sector and MIS are the four keywords in the main research question.

Learning

By pursuing the four dimensions of sustainability-oriented learning of Wals (2020), properties have been developed to take steps towards building a circular infrastructure sector. Learning stimulates creating, enriching and sharing of knowledge which is required in the mission to fight climate change.

Transition

Transitions take place in socio-technical systems. Changing an existing socio-technical system is often a slow process. Both technical and non-technical innovations should be considered to successfully complete a mission. Most of the recent societal problems cannot be solved by linear, rational or scientific methods of problem solved. Taking the entire playing field into account and the awareness that projects have to be seen as a transition is a first step into enabling upscaling of pilot projects.

Circular Dutch infrastructure sector

The R-ladder has been categorized in four strategies. Substitute, narrow the loop, slow the loop and close the loop are the four categories. Wood can clearly be classified in the substitute category. Steel and concrete can mainly be classified in slow and close the loop. It is important to notice that every strategy is required in the transition. The goal is not only to aim for the R-strategy highest on the ladder. Indicating the successes in the strategy narrow the loop is difficult.

Reflection on the MIS perspective for this research

Initially, the MIS perspective has been taken as research approach because it complements the research from Utrecht University on this subject. By taking the mission as demarcation for the selected cases, the national-, regional-, sectoral- and technological boundaries were crossed. In such a wicked problem as the transition to a circular Dutch infrastructure sector, crossing these boundaries is inevitable. The MIS perspective has proven to be a useful and

well-structured approach for this research. The three steps in the MIS analysis provided a clear guideline. By taking the MIS perspective as research method, data has been collected in a well-organized way in order to answer the research question.

The MIS perspective emerges around the system functions. When applying the innovation systems approach in a research, it is important to realize the importance given to the system functions. System changes and dynamics are important in studying transitions. This step from system functions to system changes and dynamics requires attention in MIS.

Contribution of this research to the existing literature

Targeting the transition to a 100% circular Dutch infrastructure sector in examined through three social agreements in this research. The extensive analysis makes this research the best to date comparison between social agreements in the infrastructure sector. This knowledge adds to the literature by examining the useability of social agreements to target to a 100% Dutch infrastructure sector. Furthermore, it provided detailed insights in the three agreements that have been extensively studied.

6.3 Limitations

Throughout the analysis various improvements were discovered. These limitations should be considered.

The generic validity is limited due to the number of cases. By considering the results of this research it is important to take into account the relatively little number of cases analyzed for this research. Conclusions are based on the results of only three cases. The scope of this research is limited to three cases to keep it manageable within the given timeframe.

Interview data is collected by purposive sampling method. This is a subjective way of sampling, relying on the judgement of the researcher to select participants in the interviews. The findings from purposive sampling do not always have to be statistically representative, they can be biased by the researcher.

Scope of data collection. The aim is to look at (voluntary) social agreements. So much is happening on the topic of circular transition. It makes it hard to determine what directly has to do with the agreement or what is initiated because of the agreement. This is something important to keep in mind when choosing the scale of social agreements to study a mission. In a social agreements, sub-missions can be formulated. The agreements selected for this research were broad enough to contain all elements of the MIS, but not too broad to lose track.

The level of detail of the events. What are you taking out of a document and how do you formulate it into an event? And when are you done searching for events? What is a stopping criteria to stop collecting events? These are questions which have been tried to address as much as possible in the methodology section, but it is inevitable to leave things open to interpretation.

6.4 Recommendations

To conclude this research, a few recommendations can be given. First, academical recommendations provide other researches with possible directions to look into for future research. The practical recommendations are aimed at the parties that are interested in how these scientific conclusions can be applied in practice.

6.4.1 Academical recommendations

To better understand the implications of these results, future studies could address a different demarcation of the system. The boundaries for this research have been put on one specific material per case and every case is a social agreement with chain parties voluntary collaborating to reach circular goals in the sector. Future researchers should consider investigating what happens outside of these social agreements. Does the formulation of a social agreement contributes to reach circular goals, or will it also happen in a sector without a formulated social agreement.

Future studies could also address the generalizability of the categorizations made in the discussion section. In an attempt to speed up the transition process in different sectors, a distinction between already established materials and yet to be introduced materials has been made. Due to the limited number of cases analyzed for this research, the generalizability is relatively low. Especially for the “yet to be introduced” category, only one case was analyzed. To add knowledge and assess the system dynamics of this categorization, it could be considered by future researchers to investigate more cases. It is interesting to expand the cases beyond the scope of the infrastructure sector to analyze whether this categorization also holds for a wider scope.

6.4.2 Practical recommendations

- Give special attention to the successes in the strategy narrow the loop in the future. Although this is a highly promising strategy, the successes here can easily be overseen. Using products more intensively or efficiently is something which can hardly be noticed. To make everyone aware of the achieved successes, this has to be shown in another way. Being aware of achieved successes is motivative and gives a positive vibe to continue.
- The four learning dimensions by Wals (2020) have to be addressed in sustainability learning. The second (boundaries and systems) and fourth (agency and transformative capacity) still require the most attention. The ability to adapt to new situations, especially in the case of already established materials has to be taken into account. And also boundary crossing and system thinking requires attention. The material agreements give valuable insights bounded by the scope of the agreement. Wals (2020) emphasizes the importance of the broader view. Breaking through the boundaries of material agreements is essential to enable sustainable learning.

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Appendix A: Reliability check event analysis

In this appendix a table with the events checked by an experienced reviewer is shown. The table shows the description from the event analysis and the score by both the research and the reviewer. In total 17 events were checked. The content of these events is captured by 33 nodes. A different coding has been noticed in six out of the 33 nodes.

#	Event	Researcher	Reviewer
1	In 2018 vond in opdracht van Rijkswaterstaat een verkenning plaats naar hout in de GWW. Ronde tafelgesprekken met de hele keten hebben geleid tot een inventarisatie van kansen en mogelijkheden, belemmeringen en acties om hout in de GWW te stimuleren.	SF4a, SF8	SF8
2	Tijdens de week van de Circulaire economie ondertekenen de ketenpartijen een samenwerkingsovereenkomst. Zij committeren zich hiermee aan het traject en stellen kennis en kunde beschikbaar om opdrachtgevers een stap verder te helpen	SF3, SF8	SF3, SF8
3	Onderzoek Tauw in opdracht van RWS naar de haalbaarheid voor een retoursysteem afkomstig van kunstwerken in de GWW- Conclusies 1.Hergebruik van hout afkomstig uit GWW kunstwerken vindt nu ook reeds plaats, zonder dat hiervoor vanuit de keten een specifiek retoursysteem is opgezet en ingericht. Voor opschaling van dit volume lijkt een systematische aanpak echter een noodzakelijke voorwaarde. 2. Vanuit het oogpunt van een circulaire economie is het toepassen van meer hout in de GWW het primaire doel, hergebruik van vrijkomend hout is daar een verdere optimalisatie van. Voor ontwikkeling van afzetmogelijkheden voor secundaire materialen dienen dan wel aanvullende gunningscriteria te worden opgenomen bij inkoop door opdrachtgevers. 3. Er zijn op dit moment onvoldoende gegevens beschikbaar om een betrouwbare inschatting te kunnen geven van de huidige 'installed base' aan hout in kunstwerken en om het potentiële jaarlijkse marktvolume en beschikbaarheid van secundair hout afkomstig uit de GWW te kunnen vaststellen. Sommige opdrachtgevers hebben geen goed beeld van het areaal aan (houten) kunstwerken dat zij in beheer hebben en ook zijn er nog grote verschillen in de volledigheid en kwaliteit van gegevens bij de registratie in een asset management systeem. 4. Een belangrijke voorwaarde dat secundair hout daadwerkelijk beschikbaar kan komen voor hergebruik, is dat feitelijk al bij de opdrachtverstrekking voor slopen deze mogelijkheid nadrukkelijk wordt meegenomen. Indien het hout vrijkomt als afvalstof, dan blijken de kansen op hergebruik in de praktijk een stuk lager te zijn. 5. Een business case voor hergebruik van hout uit de GWW lijkt mogelijk, maar deze kent een groter risicoprofiel en de haalbaarheid ervan is afhankelijk van een groter aantal randvoorwaarden dan wanneer virgin hout wordt toegepast. 6. In de praktijk bestaan er verschillende business modellen voor secundair hout, die met name verschillen in het aantal betrokken ketenactoren en de vorm waarin eigenaarschap en risico voor het hout zijn belegd. In alle modellen is betrokkenheid van partijen met specialistische houtkennis onontbeerlijk.	SF2, SF5, SF7, SF8	SF2, SF5, SF7,SF8
4	Voorlichtingsbijeenkomst georganiseerd door SHR over bouwen met hout en milieu met als onderliggend doel de houtwereld te vereniginen en met 1 stem te laten spreken waarmee een vuist gemaakt kan worden om tot eeen realistische milieuberekening te kunnen komen	SF3, SF8	SF3, SF8
5	Bij de aanbesting van de brug de Blauwe Loper in de Provincie Groningen heeft een houten burg gewonnen omdat duurzaamheid een belangrijk element was in de aanbestedingscriteria. Het project de Blauwe loper is indrukwekkend omdat er zoveel hout op een unieke	SF5	SF5

	manier is verwerkt in het project, met hout uit duurzaam beheerde bossen.		
6	Projecten - De Blauwe Loper. Interessant is de vraag hoe de beheerder, de gemeente Oldambt, uiteindelijk vertrouwen kreeg in de houten brug. Volgens Robert Wicker en Freerk van der Molen hebben verschillende aspecten hieraan bijgedragen. Inhoudelijk is veel moeite gedaan om de ontwerplevensduur van 100 naar 80 jaar te brengen. Daarmee was het mogelijk om voor het houtontwerp de beoogde levensduur voldoende te onderbouwen. Deze flexibiliteit is essentieel voor het toepasbaar maken van innovatieve producten. De aanbesteding in twee fasen (ontwerp-realisatie) bood alle belanghebbenden de kans om tussentijds nog inbreng te hebben voordat het uitvoeringsbesluit genomen werd (inclusief raadpleging van omwonenden). Bovendien werden alle betrokkenen vroegtijdig betrokken bij het ontwerpproces. Met name de participatie van de afdeling beheer&onderhoud bij het hele proces bleek essentieel. Dat heeft zo positief uitgewerkt, dat ondanks beperkte ervaring met houten bruggen er nu al een kant-en-klaar onderhoudsplan ligt van de gemeente Oldambt, dat concurrerend is met andere bruggen van andere materialen. Zo vormt de Pieter Smitbrug bij Blauwestad een inspirerend voorbeeld: ondanks een beperkt budget en een complexe beginsituatie is een hoge duurzaamheidsambitie succesvol gerealiseerd.	SF1, SF7	SF7
7	Ontwikkeling van herstelmethode Protek Aqua, deze herstelmethode helpt bij het herstel van hout in de waterbouw. De oprichter zag dat houten waterbouwwerken zoals bruggen, remmingswerken, meerpalen en sluizen compleet vervangen werden terwijl vaak slechts een klein deel aangetast was	SF2, SF4b	SF2
8	Het actieplan ''Versterking hout in de gww' is een initiatief van de Koninklijke Verenging van Nederlandse Houtondernemingen (Kon VVNH). Zij maakt onderdeel uit van het kennisplatform voor de houtsector, Centrum Hout ,en is aangesloten bij de campagne 'Hout. Natuurlijk van nu". De bij de branchevereniging Kon. VVNH aangesloten bedrijven reserveren jaarlijks een bedrag voor het ontwikkelen en het uitdragen van objectieve kennis over de grondstof hout en houtproducten.	SF3, SF8	SF3, SF4b, SF8
9	Het Actieplan Bos en Hout is opgericht om een optimale keten te realiseren met de gezamenlijke inspanning van boseigenaren, houtproducenten en -verwerkers, papier- en kartonindustrie, palletbedrijven, bouwbedrijven, recyclingindustrie, bio-energieproducenten en natuur- en milieu- organisaties	SF8	SF8
10	Het Actieplan Hout heeft als doelstellingen "een toename van de Nederlandse houtproductie, dankzij uitbreiding van het bosareaal en een productiever bosbeheer' en "slimmer benutten van hout als duurzaam materiaal door cascadering en hoogwaardige toepassing"	SF4b, SF8	SF4b, SF8
11	Er zijn inkoopcriteria opgesteld voor duurzaam hout. Dit zijn de TPAS (Dutch Procurement Criteria for Timber). De toetsingscommissie Inkoop Duurzaam Hout, ook wel TPAC genoemd, toetst certificatiesystemen, zoals de Forest Stewardship Council (FSC) en het Programme for the Endorsement of Forest Certification (PEFC) en de bijbehorende handelsketen aan deze inkoopcriteria.	SF5, SF8	SF5, SF8
12	Startbijeenkomst om te markeren voor een traject waarin gewerkt en geleerd wordt richting gezamenlijke inkoop van houten bruggen. Het gaat dan specifiek om fiets- en voetgangersbruggen, waar ook geleerd kan worden van houten verkeersbruggen. Vragen van aanwezigen staan centraal in de sessie	SF3, SF5	SF3, SF5
13	Oproep gedaan vanuit de Bouwcampus om deel te nemen aan de leidraad. Doel van de leidraad is andere opdrachtgevers inspireren en informeren over wat er allemaal mogelijk is op het gebied van houten bruggen en hoe op te schalen of te versnellen.	SF8	SF8
14	Verdiepingssessie "is hout wel duurzaam, en hoe meten we dat?" georganiseerd vanuit De Bouwcampus, waarin drie presentaties	SF3, SF8	SF3, SF7, SF8

	worden gegeven. 1. Mantijn van Leeuwen over de grote vraag hoe hout is vertegenwoordigd in de MKI scores, wat de issues zijn en wat NIBE heeft voorgesteld om te verbeteren aan de score. 2. Mark van Benthem is kritisch op de impact van projecten. Hij focust zich met name op de herkomst van hout en voor welk soort hout je zou moeten gaan. Tot slot gaat hij in op de vraag hoe bestuurders te overtuigen voor het gebruik van hout. 3. Tunis Hoekstra ontwikkelde een TCO model voor sluisdeuren. Hij legt uit hoe deze methode kan bijdragen aan de materiaalkeuze voor houten bruggen.		
15	Dit kennisdocument biedt inzichten in kansen en belemmeringen voor het stimuleren van hout in de GWW. Daarnaast biedt deze verkenning een eerste inzicht in de meest prominente stakeholder, hun belangen, de meerwaarde van hout en kosteneffectiviteit.	SF7	SF7
16	Verkenning ketensamenwerking hout: Hout kan een oplossing bieden voor de klimaatdoelstellingen van Nederland en biedt kansen voor RWS en andere partijen om circulaire ambities in praktijk te brengen. Daarnaast bieden houten innovatieve toepassin- gen zoals een houten geleiderail ook mogelijkheden om duurzame ambities zichtbaar te maken en er- over te communiceren. Toepassingen met snelgroeiend hout sluiten mooi aan op de circulaire ambities. Een versnelde kringloop van hout, zorgt ervoor dat er effectief meer hout geproduceerd kan worden.	SF4a, SF4b	SF4a, SF4b
17	De ketenpartijen zien in 2030 een wereld voor zich waarin de houtsector minder versplinterd is en er meer onderling kennis wordt gedeeld en wordt samengewerkt zodat er ook een sterke lobby kan plaatsvinden. Producenten, ontwerpers en inkopers weten elkaar makkelijker te vinden en bij gebrek aan specifieke kennis wordt deze gemakkelijk uit de markt gehaald bij houtbedrijven. Aannemers zijn het gewend om met hout te werken. Sterke ketensamenwerking zorgt voor verhoogd kennisniveau, verbeterd inkoopbeleid en dat het niet alleen maar blijft bij pilotprojecten maar dat houten innovaties gerealiseerd en opgeschaald kunnen worden.	SF3, SF6, SF7	SF3, SF7

Appendix B: Interview protocol

- Voorstelronde
- Korte toelichting negen systeem functies MIS methode
- Toestemming vragen om het interview op te nemen

Algemene vragen (zelfde per akkoord)	
Vraag 1	Wat is volgens u de reden dat het *akkoord* is opgericht?
Vraag 2	Bij welke onderdelen van het *akkoord* bent u nu nog betrokken?
Vraag 3	Welke (belangrijke) actoren zijn er betrokken bij het *akkoord*?
Vraag 4	Wat heeft het *akkoord* opgeleverd? • Op welke manier draagt het *akkoord* bij aan de missie naar circulariteit? • Wat is de waarde van het *akkoord*?
Vraag 5	Wat is de belangrijkste functie van het *akkoord*? • Experimenten opzetten, kennis ontwikkelen/delen, richting uitzetten, markt creëren, middelen ter beschikking stellen, legitimiteit creëren, coördineren
Vraag 6	Waarom heeft u zich aangesloten bij het *akkoord*? Wat is volgens u de reden dat partijen zich wel/niet aanmelden voor het *akkoord*?
Vraag 7	Wat zit er voor partijen in om zich aan te sluiten bij het *akkoord*?
Vraag 8	Wat zijn belemmeringen waar men in het *akkoord* tegenaan loopt?
	Wat zijn tekortkomingen van het *akkoord*? • Hoe kan dit voorkomen worden? • Wat zijn volgens u lessen geleerd voor volgende akkoorden?
Specifieke vragen (verschillend per akkoord)	
Vraag 9	Worden partijen actief benaderd om deel te nemen?
Vraag 10	Welke successen (van een) van de akkoorden zijn belangrijk om mee te nemen voor andere akkoorden?

Appendix C: Participants in the group session

In this table an overview of the participants in the group session is included. This gives an overview of the number of participants per organization type.

Organization description	# Contractor	# Client
1. Contractor	6	
2. Recycling branch organization	1	
3. Consultancy	3	
4. Network organization		1
5. National government		6
6. Water authority		2
Total participants	**10**	**9**

Appendix D: Extended version functional analysis Case 1

Execution teams

Theme	**Interpretation of the theme**
Roadmap CO2 reduction	Further reduction of CO2-emissions of 30% to 49% with respect to the year 1990 by agreements on the application of a decreasing MKI and making CO2-reduction transparent in the chain
Circular design	Stimulating circular design by developing and applying a system based on the R-ladder
Reuse of concrete residual streams	Creating a route to reuse 100% of concrete streams flows in new concrete in 2030
Impact on natural capital	The concrete chain will create a net positive value of natural capital on the entire chain in 2030
Descending MKI	Creating a route such that projects and products have a verified decreasing MKI over time
Knowledge and innovation	Creating an annual plan to organize and stimulate knowledge development, knowledge diffusion and innovation
Education and knowledge sharing	Creating an annual plan to link knowledge development and knowledge diffusion to education and training

SF1:
And as Jacqueline Cramer, chairman of the Concrete Agreement, mentioned in an interview:

> *"We Dutch, are good at pilot projects. But, after that it stops. We do not aim for scaling up and because of that pilot projects become commonplace. This approach is insufficient. However, the urgency to become more sustainable is now so high that we all have to accelerate and start working. Yes, individual interests will sometimes clash, but the common interest is more important." (event 99, vakblad bouwen met staal).*

SF 4b:
During the building up phase, five innovation clusters, based on the results of the execution teams, are set up to achieve the set. The innovation clusters are presented in the box below. The innovation clusters give direction to the solution. In the progress meeting of the Concrete Agreement, an overview of innovations categorized by their TRL was presented.

- Low-carbon concrete
- Lifetime expansion
- Smart, modular and adaptive design and circular construction
- CO2 reduction in the concrete industry
- CO2 reduction in the transport chain (including construction site)