The use and implementation of circularity by water boards

Master's thesis report

Construction Management and Engineering

T.W.T. Plomp

AN EXPLORATIVE STUDY INTO CIRCULAR STRATEGIES AND THEIR IMPLEMENTATION WITHIN DUTCH WATER BOARDS

In partial fulfilment of the requirements for the degree of

Master of Science (MSc)

in Construction Management and Engineering
at the Delft University of Technology

by

Thijmen Plomp - 4711254

July 2021

Final version

Supervising Professor:	Prof.dr.ir. Marleen Hermans
1st mentor:	Dr.ir. Ad Straub
2nd mentor:	Ir. Leon Hombergen
1st company mentor:	Ir. Harold van Steeg
2nd company mentor:	Ir. Toine van Liebergen

EXECUTIVE SUMMARY

Climate change has dominated a lot of recent political debates about the construction industry. A shortage of fossil raw materials will be an emerging problem in the coming decades. This may cause significant problems to earth-living, in all its aspects such as physiology, effects on distributions, phenology and adaptation of species. The national government of the Netherlands decided to focus on a perspective for a futureproof, sustainable economy, for future generations. Therefore, it set up a national program to achieve this named: Nederland circulair in 2050.

In order to reach the goals of this program, it is of the utmost importance to change the construction industry. The construction industry is one of the most underlying reasons for the mentioned problems. The assignments in the construction industry are mainly put on the market by public clients. This research focuses on the water boards and their influence on the construction industry. Changing the way the water boards initiate projects and organise their asset management is complicated and will not give the desired result at once. Therefore, this research aims to answer the following question:

> *How can water boards use and implement circularity and thus contribute to the prevention of resource depletion and counteract climate change?*

Key developments concerning circularity are derived from academic and grey literature, such as policy documents that initially mentioned the goals for 2050. It can be concluded that one of the main goals mentioned in the policy documents is the avoidance of primary raw materials. This research argued this is not likely to be achievable in the coming decades. Moreover, circularity is being treated as a goal, instead of being used as a method to overcome certain problems. This seems to bring forth positive results at first, but it will not solve the problems of resource depletion and climate change over time. Circularity should not only solve the resource depletion but should be in conjunction with other themes such as climate change, the energy transition and the reduction of greenhouse gasses. This is according to the core principles of circularity. It is argued that circularity should be used in a systematic approach, rather than a project-based approach. The research reviews multiple circular measurement tools and assigns the Core Measurement Method (CMM) as an appropriate systematic method for the construction industry. This method uses circularity to achieve three main goals:

- Protecting materials streams;
- Protecting the environment;
- Protecting or creating value.

Problems regarding implementing circularity are identified and have various underlying reasons. The key factors in these are identified as low virgin material prices, high investment costs and a hesitant innovative culture. Especially the first two can be attributed to the fact that our (construction) economy still is linear and project-based.

These results from the literature are used in semi-structured interviews with different actors within the chain. The gathered data is used to sketch the water board as an organisation. Water boards are a form of public clients in the Netherlands and their core business closely relates to the problems such as GHG. It turns out that an overarching circular strategy with clear ambitions and implementation strategies for the water boards is absent. Most of the water boards are experimenting on their own. Condition of assets, information provision or maintenance strategies are examples of things that vary between the boards. Innovative ideas are mostly applied in the realisation phase of an asset, whereas little or no attention is paid to circularity in the maintenance part due to various reasons, such as internal conflicts of interest. Most of all, the maturity of the asset management of water boards lacks, resulting in not making full use of possibilities that are already available.

This research sketches how circularity as a systematic method can contribute to a (partly) solution to climate change and resource depletion. It is explained that the use of primary materials does not necessarily need to be a problem. However, insight into what exactly is the problem for which material is needed to tackle the problems. This is required for the use of circularity for the water boards, as they have the power to steer the actors in the material chain. These actors need to have a stable future perspective to ensure that they have a business case in the future. Therefore, it is important that the investments these actors do, actually contribute to the use of circularity.

The research developed an implementation tool that can be used by the water boards. It shows which design criteria exist within the CMM. These design criteria consist of 7 indicators. It is advised to use these indicators as circular ambitions for the water boards. These indicators can be measured over time, in which the water boards can effectively steer and measure these ambitions. This research showed 42 circular strategies, which have been connected to the ambitions of the CMM through an implementation tool. Strategies are connected to one of the 9 life cycle stages of an asset. These strategies, however, can conflict which each other. For example, solar panels might generate green energy, but if the alloys used can not be recovered, this results in a valuable loss of scarce materials. Moreover, some strategies are dependent on other strategies or can create synergy. An overview of these interactions is provided.

In order to use this tool, the water boards should have a widely supported definition of circularity as a systematic approach. The acting of water boards as separate islands does not contribute to a systematic approach. Secondly, all the boards together should define clear circular ambitions for each type of material, as this research shows that different materials require different moments in their chain in which circularity can be used. It is therefore argued this needs to be done by as many actors within a chain because otherwise skew growth and divergent processes might happen. The market benefits from an unambiguous vision and working method to have a stable perspective of the future. For this research, this would mean that all water boards in the Netherlands share these actions.

The systematic approach discussed in this research emphasises that implementing circularity requires a fundamental shift rather than an incremental shift of the current system. Currently, the prevailing thought is to treat circularity as an 'extra item' in program requirements. This might lead to some positive results at first, but will very likely not contribute to circular intervention development, let alone a successful systematic approach to the real problems of resource depletion and climate change. Intervention developments enable actors to apply new circular solutions in the construction industry. These intervention developments should be high on the agenda of all water boards, as most of the interventions cannot be executed by one actor. Multiple actors need to contribute to these interventions. This research shows a systematic approach aiming for jointly developing knowledge and further developing circular strategies, which enables not only the waterboards, but the full sector to learn and apply these interventions to use circularity and thus prevent resource depletion and climate change.

PREFACE

This report contains the findings of an exploratory study towards circular strategies and their implementation within water boards. It is the closure of my master program Construction Management and Engineering at the Delft University of Technology.

The topic of circularity barely had my attention during my study. However, in the search for a scientific subject that was at the same time practically applicable, I came up with this research idea. Although I still am not a green knight or a climate activist, I am well aware of the need for change regarding circular behaviour and technologies. Through this thesis, I hope to contribute to the transition, by offering perspective to the sceptical people who have doubts about the implementation of such a big change.

In my attempt to do so, I sometimes turned this research into a PhD research. I want to thank Leon Hombergen and Marleen Hermans for their guidance on scoping and framing this research. They were very important at the beginning of this research in determining what to focus on and what not to focus on. In particular, I want to thank Ad Straub, for his time spent on feedback and brainstorming with me. It must have been tiring to be overloaded with new information every session we had.

I want to thank To Interface for offering the opportunity to do this research in-house. Special thanks to Harold van Steeg. Despite your busy schedule, you have made enough time to coach and challenge, and to provide me with feedback. But above all, I admire your enthusiasm for the things you do in the beautiful construction industry.

I want to thank all the other persons who contributed to this research. In particular, all the (anonymous) persons which wanted to be interviewed and thus contribute to the small steps we take in the construction world.

During the period of this research (February 2021 - July 2021), the pandemic of Covid-19 caused me to not physically meet any supervisor or work daily at the office. In order to get structure in the working days, I worked together with two other graduates. I want to thank Lennart van de Vliert and Georgette van Driesten, both soon to graduate as well, for collaborating, brainstorming on our weekly Tuesday afternoon meetings. Together we brought some fun and structure to the graduation period! This pandemic caused me to be locked up with my roommates as well. At last, I want to thank my student-house, De Roos van Suyd, for being a pleasant but also motivating workplace.

Thijmen Plomp
Delft, June 2021

...

NOMENCLATURE

CDW	Construction demolishing waste
CE	Circular Economy
CMM	Core measurement method of circulair bouwen 2023
EAF	Electric arc furnace
EoL	End of Life
GHG	Green house gasses
GWW	Grond- weg- en waterbouw
MEAT	Most economically advantageous tender
POV	Project overstijgende verkenningen
RCC	Rapid circular contracting
SMSC	Stony materials supply chain

CONTENTS

1 INTRODUCTION 5
1.1 Background of the problem 5
1.1.1 Depletion of resources 5
1.1.2 Circularity, from concept to policy 5
1.1.3 Life cycle of materials 7
1.1.4 Public clients 8
1.1.5 Civil objects 9
1.2 Problem definition 10
1.3 Research questions 10
1.4 Scope of the research 11
1.5 Methodology 12
1.5.1 Method description 12
1.6 Interviewees and subject overview 13
1.6.1 Data analysis 14
1.6.2 Quality of the research 14
1.7 Approach to sub-questions 15
1.7.1 Approach to sub-question 1 15
1.7.2 Approach to sub-question 2 16
1.7.3 Approach to sub-question 3 16
1.7.4 Approach to sub-question 4 16
1.8 Relevance of this research 17
1.8.1 Scientific relevance 17
1.8.2 Societal relevance 18
2 THEORETICAL BACKGROUND, KEY DEVELOPMENTS AND BARRIERS 19
2.1 The need for change 19
2.1.1 Problems of this earth 19
2.1.2 Circularity as the solution 20
2.2 Defining circularity 21
2.2.1 The definition of circularity in policy documents 21
2.2.2 The definition of circularity in scientific literature 23
2.3 Requirements for measuring circularity 23
2.4 Assessment frameworks for circularity 25
2.4.1 Existing frameworks 25
2.4.2 Framework: Circulair bouwen'23 - CMM 27
2.5 Barriers for the circular construction sector 31
2.5.1 Regulatory 31
2.5.2 Technological 31
2.5.3 Micro - Market 31
2.5.4 Legal 32
2.5.5 Macro - Market 32
2.6 Learned lessons and conclusions from SQ1 34
3 WATER BOARDS AS PUBLIC CLIENT 35
3.1 Introduction 35
3.2 Developments within the waterboards 37
3.2.1 Literature review on Developments 37
3.2.2 Interview Review of Developments 39
3.2.3 Analysis of literature and interview data 40
3.3 Barriers for circularity in water boards 41
3.3.1 Regulatory 41
3.3.2 Legal 41

3.3.3 Micro Market . . . 41
3.3.4 Technological . . . 42
3.3.5 Organisational . . . 42
3.4 Learned lessons and conclusions from SQ2 . . . 44
4 THE MATERIAL CHAIN AND ITS ACTORS 45
4.1 The concrete industry . . . 46
4.1.1 Concrete composition . . . 46
4.1.2 Circular concrete . . . 47
4.2 The steel industry . . . 48
4.2.1 Steel composition . . . 49
4.2.2 Circular steel . . . 51
4.3 Actors in the material market . . . 52
4.3.1 Actors typology . . . 52
4.3.2 Circular transition of the chain by actors . . . 53
4.4 Learned lessons and conclusions from SQ3 . . . 57
5 CIRCULAR DESIGN CRITERIA AND IMPLEMENTATION STRATEGIES 58
5.1 Requirements for an implementation tool . . . 58
5.1.1 A systematic approach . . . 59
5.1.2 Circular assessment / ambitions . . . 59
5.2 Using an implementation tool . . . 63
5.2.1 Types of interventions . . . 63
5.2.2 Intervention development . . . 63
5.3 Life cycle phases and circular strategies . . . 65
5.3.1 Life cycle analysis phases . . . 65
5.3.2 CE strategies . . . 65
5.4 Implementation tool . . . 68
5.4.1 Strategies to intervene in certain circular ambitions . . . 68
5.4.2 Analysis of circular strategies . . . 69
5.5 Learned lessons and conclusions from SQ4 . . . 70
6 IMPLEMENTATION EXAMPLE: PUMPING STATION 71
6.1 The use of the implementation tool . . . 71
6.2 Ambitions in overarching programs - strategic level . . . 71
6.3 Circular strategies and interventions for a pumping station - operational level . . . 73
6.3.1 Maintenance and re-use . . . 74
6.3.2 Realisation . . . 75
6.3.3 Intervention development . . . 76
7 CONCLUSION 77
8 DISCUSSION 79
8.1 Discussion of the research design . . . 79
8.1.1 Scientific literature . . . 79
8.1.2 Grey literature . . . 79
8.1.3 Interviews . . . 80
8.2 Quality and limitations of the research . . . 80
8.2.1 Quality and limitations of the research methods . . . 80
8.2.2 Quality and limitations of the research outcomes . . . 81
8.3 Recommendations for future research . . . 83
A CLARIFICATION OF SYNERGIES, DEPENDENCIES AND POTENTIAL CONFLICTS 91
B INTERVIEW PROTOCOL 95
B.1 General topics . . . 95
B.2 Topics SQ3 . . . 95
B.3 Topics SQ5 . . . 96
C MEASURING CIRCULARITY – EXAMPLE FORMAT CB'23 97
D LIFE CYCLE ANALYSIS 98
E MEASUREMENT UNITS OF THE CMM 100

F MATERIAL-PASSPORT FRAMEWORK CB-23 102
G EXERTING PURCHASING POWER THROUGH EXISTING PROCUREMENT TOOLS 104
G.1 Selecting of the tenderers (voortraject) 104
G.1.1 Partnerships 105
G.1.2 Knowledge sharing 105
G.1.3 Governmental policies 105
G.2 Specification of an object 105
G.3 Award criteria 106
G.4 Collaboration forms 106
G.4.1 Current contracts 107
G.4.2 Rapid Circular contracting 107
G.4.3 Transfer of ownership of an asset 107
G.5 Recommendation 108
H INTERVIEW TRANSCRIPT 1 109
I INTERVIEW TRANSCRIPT 2 110
J INTERVIEW TRANSCRIPT 3 111
K INTERVIEW TRANSCRIPT 4 112
L INTERVIEW TRANSCRIPT 5 113
M INTERVIEW TRANSCRIPT 6 114
N INTERVIEW TRANSCRIPT 7 115
O INTERVIEW TRANSCRIPT 8 116
P INTERVIEW TRANSCRIPT 9 117

LIST OF FIGURES

Figure 0.1 Sequence diagram . . . i
Figure 1.1 Types of economy . . . 6
Figure 1.2 The intended circular process according to the transitionagenda . . . 7
Figure 1.3 The ladder of Lansink . . . 8
Figure 1.4 Interviewees overview . . . 13
Figure 1.5 Criteria for quality in research . . . 14
Figure 1.6 Thesis outline . . . 15
Figure 1.7 Triangulation . . . 17
Figure 2.1 Chapter overview . . . 19
Figure 2.2 Demand for steel and concrete vs world population . . . 20
Figure 2.3 9R Strategy . . . 22
Figure 2.4 Circular value chain of an object (own image, adapted from Ellen MacArthur Foundation [2017]) . . . 25
Figure 2.5 Circular tools aimed at organisations . . . 26
Figure 2.6 Circular tools aimed at products and services . . . 26
Figure 2.7 CMM method to determine circularity in an object (Own figure - derived from CB23 [2020a]) . . . 28
Figure 2.8 CMM - indicator 1 (Own figure) derived from CB23 [2020a]) . . . 29
Figure 2.9 CMM method - indicator 2 and 3 (Own figure) derived from CB23 [2020a]) . . . 29
Figure 2.10 CMM - indicator 4 (Own figure) derived from CB23 [2020a]) . . . 30
Figure 2.11 CMM - indicator 5 till 7 (Own figure) derived from CB23 [2020a]) . . . 30
Figure 2.12 Bottlenecks from literature compared with desk research (own image) . . . 33
Figure 3.1 Chapter overview . . . 35
Figure 3.2 Waterboards in The Netherlands . . . 36
Figure 3.3 Evaluation process within HWBP . . . 37
Figure 3.4 Barriers for implementing circularity (own figure) - validated overview after interviews of Figure 2.12 . . . 43
Figure 4.1 Chapter overview . . . 45
Figure 4.2 An average concrete chain in the Netherlands. (Own image, adapted from Wouters [2019]) . . . 46
Figure 4.3 Environmental impact indicators . . . 47
Figure 4.4 An average steel chain in the Netherlands (Own image) . . . 48
Figure 4.5 Expected stock of rare alloys processed in steel . . . 50
Figure 4.6 Ferrous Metals Waste Management . . . 51
Figure 4.7 Actors visualised in concrete chain . . . 53
Figure 5.1 Chapter overview . . . 58
Figure 5.2 CMM indicator 1 - 3 (containing 5 output numbers) . . . 60
Figure 5.3 CMM indicator 4, containing 18 output numbers . . . 61
Figure 5.4 CMM indicator 5, 6 and 7, containing 6 output numbers . . . 62
Figure 5.5 Developments of interventions over time (own image) . . . 64
Figure 5.6 Circular value chain of an object . . . 65
Figure 5.7 Example of identifying strategies for a certain ambition related to a material . . . 69
Figure 6.1 Possible ambitions for a water board . . . 72
Figure 6.2 Render of a pumping station . . . 73
Figure 6.3 Strategies and intervention for life cycle 8 and 9 of a pumping station (own image) 74
Figure 6.4 Implementation possibilities within realisation phase . . . 75
Figure 6.5 Photograph of a pumping station . . . 76
Figure A.1 Clarification of synergies . . . 91
Figure A.2 Clarification of synergies . . . 92

Figure A.3	Clarification of dependencies	93
Figure A.4	Clarification of potential conflicts	94
Figure C.1	Example of communication format	97
Figure D.1	LCA - model	98
Figure D.2	Cradle-to-gate and Cradle-to-grave approach LCA	99
Figure D.3	Life cycle inventory - Flow model	99
Figure G.1	Water boards purchasing plan	104
Figure P.1	Sequence diagram	119

LIST OF TABLES

Table 5.1 Circular strategies per life cycle part 1 66
Table 5.2 Circular strategies per life cycle part 2 67
Table 5.3 Circular strategies in relation to CMM (authors interpretation) 68
Table 5.4 Internal relations of strategies 69

1 INTRODUCTION

This chapter aims to clarify the theoretical background of the problem. Topics included within the research are briefly introduced. Thereafter, the problem is defined, followed by the main research question and relevant sub-questions. The method which is used to answer the questions is addressed thereafter, followed up by an elaboration of scientific and societal relevance.

1.1 BACKGROUND OF THE PROBLEM

1.1.1 Depletion of resources

Climate Change has dominated a lot of political debates about the construction industry. Pachauri and Meyer [2014] states that the high greenhouse gas emissions caused by humans since the pre-industrial era are most likely the main cause of global warming. Countless reports state that this event is likely to evolve in long-lasting climate change. This may cause significant problems to earth-living, in all its aspects such as physiology, effects on distributions, phenology and adaptation of species [Matthews et al., 2017]. A shortage of fossil raw materials will be an emerging problem as well in the coming decades [Ritchie, 2017], mostly because of the increase of usage, but partly because of redundant waste. In the past century, the world has consumed 34 times more materials [Shafiee and Topal, 2009]. Reducing the CO2 emission and dealing more consciously with the use of materials can reduce the earlier addressed consequences and bring the world to a better future.

The construction industry is one of the most important sources within these problems, as it produced 25 million tonnes of waste in 2012 which is more than three times as much as all the household waste in the Netherlands [Bouwagenda, 2020]. European countries do not perform better. The built environment is estimated to be responsible for around 40% of energy consumption and 36% of CO2 emissions in the EU [EU, 2019], as well as 50% of all extracted materials. On top of that, 40% of used materials are imported from outside the EU which in which the current linear economy might be threatened by price volatility as well [Bourguignon, 2018]. Therefore, it is conceivable to wish to limit the use of these resources for the sake of, for example, the environment. This means that limiting the import of new raw materials into the economic system is needed as much as possible - whether because of necessity or wish. The same holds for reducing waste. All these events have been on the political agenda for quite some time, and the subject came to a climax in 2015 during the Climate Conference of Paris.

1.1.2 Circularity, from concept to policy

After the conference, the national government of the Netherlands decided to focus on a perspective for a future-proof, sustainable economy, for the future generations and has therefore set up a national program to achieve this named: *"Nederland circulair in 2050"* [Dijksma and Kamp, 2016]. This program relates to all industries and sectors in the country. As said before, the construction industry is one of the most important areas to apply this vision as it produces significant amounts of waste [Bouwagenda, 2020]. Recycling these materials is not enough to fulfil the national program. Recycling does not imply that the material holds its original value as a building material. An example is using concrete as a foundation slab for a road. Although this may seem like recycling and therefore re-use, concrete does not has its original function anymore and new raw material needs to be added to the chain of materials.

According to Schut et al. [2015] in the end, this will not be sufficient and stated that an important tool to reach the goals of the national program is to apply circularity within the construction sector. Circularity closes the cycle of materials, as shown in Figure 1.1. The national government strives for a circular construction economy [Compendium voor de Leefomgeving, 2015]. That is: building, using and reusing buildings, areas and infrastructure, without:

- unnecessarily depleting natural resources;
- pollute the living environment;
- affecting ecosystems.

This should be executed in a way that is economically responsible and contributes to the welfare of humans and animals [Compendium voor de Leefomgeving, 2015]. However, especially the construction industry is known for a lack of innovation [Koenen, 2013] and the people involved tend to be sceptical about the need for change and the beneficial results. MacArthur et al. [2015] addresses this problem, and resolves some of the basic counter-arguments for a circular economy, such as: 'Let the market do its work' or 'It is not cost-beneficial to built-in a circular way'. Although the second argument is true for now, MacArthur et al. [2015] state that the public clients steer the market of today, through infrastructure investments, public transport, zoning laws and building standards which is why circular building is not profitable by now or sometimes even impossible because the plans are not accepted. Besides regulations and investments, there are more methods to steer the market [Coste, 2019] such as soft and economical instruments. Soft instruments are applied in The Netherlands by making CE an obligatory part of every relevant study [De Groot, 2019], while subsidies for circular initiatives are available as an economic instrument [Rijksdienst voor ondernemend Nederland, 2019]. These subsidies might be a thorn in the eye for some criticisers, as this looks like a non-realistic economy. However, as several studies show, a circular economy may, when managed in a proper way, economically compete with the economy of today [MacArthur et al., 2015].

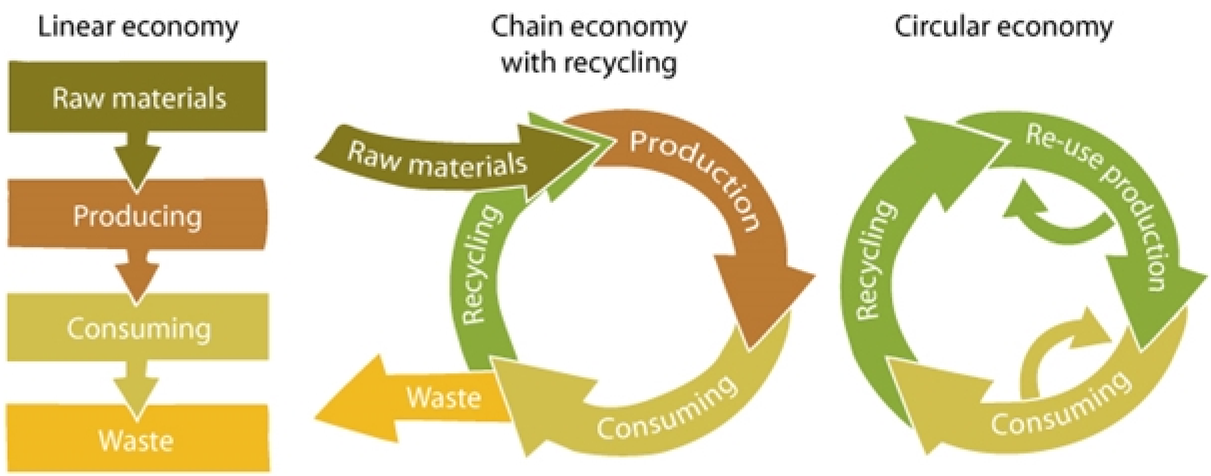
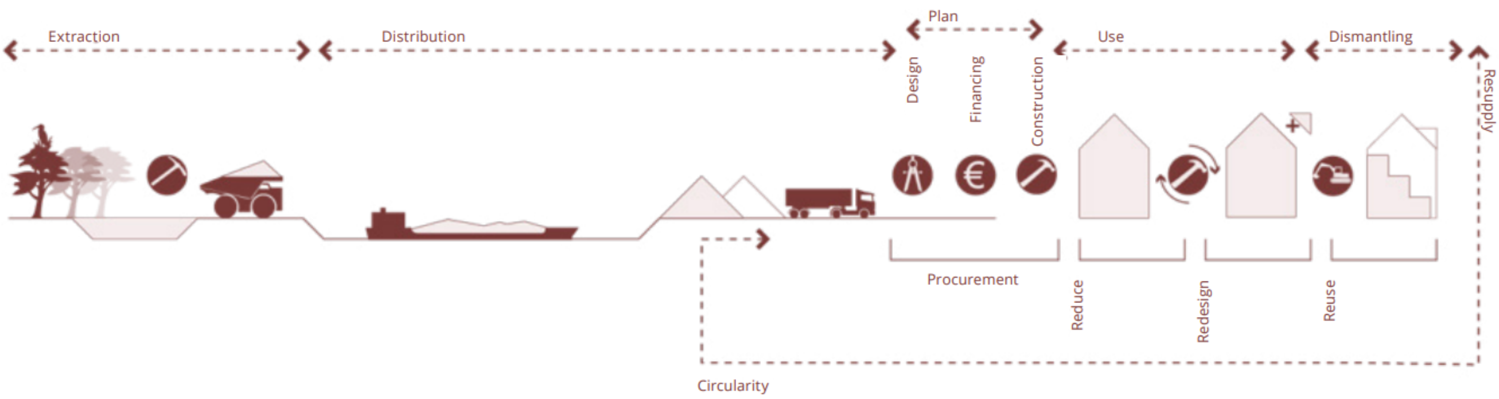


Figure 1.1: Types of economy
[Milin, 2017]

Besides that, it will create employment opportunities and will strengthen or even highly improve the position of the Dutch knowledge economy [Stegeman, 2015], due to price volatility which is being expected [TNO, 2013]. On top of that, rebound effects will happen after the circular economy has been implemented [MacArthur et al., 2015]. The increases in resource productivity in the study sectors have historically responded to elastic demand response. When relative prices fall, consumers use more individualized transport, floor space and food, while a circular economy aims to make all this more efficient: 'Sharing is caring'. That's why there is a big opportunity for public clients such as the water boards to steer the market towards this change and making an impact by innovative projects as an early adopter.

However, just changing the way of initiating projects for the sake of circularity will not give the desired result at once. The government strives to gradually change this process together with the market and consumers [Rijksoverheid, 2018]. Where possible, changes should be made on a global level which might be possible, as comparable developments are going on [Corona et al., 2019]. Implementing Circularity within a centuries-old building economy raises questions. Examples are: 'What is the definition of circularity?', or: 'How can circularity be measured?' [De Valk and Quik, 2017]. In order to realise this ambition by 2030, several short term actions are defined within the transition agenda [Rijksoverheid, 2018]. This agenda describes an urgent need to define circular construction. Several tools have been developed to measure the degree of topics touching upon circularity, such as the MKI [Hillege, 2019], DuboCalc [Rijksoverheid, 2019] PRP-tool, Circular IQ and EcoChain [Overmars, 2020]. A circular material passport has been initiated [CB23, 2020b]. A fully operational material passport provides insight into the materials and resources used in buildings and other works and facilitates the exchange of data. This information is at first needed to evaluate new projects, but the real circularity shows up at the end of the project. As shown in Figure 1.2, at the end of the lifetime, these building will be dismantled and the materials again in the construction cycle. Used materials have to be suitable for re-use, that is why the ability of materials' re-usage should be evaluated on beforehand. Or even better, circular materials and principles should be at the start of every design.



[Rijksoverheid, 2018]

Figure 1.2: The intended circular process according to the transitionagenda

1.1.3 Life cycle of materials

As Figure 1.1 shows, the input of materials should be brought to zero. Therefore, new buildings should be designed with products already existing in the current supply. Nowadays designers design according to linear standards, with no limit of material types. When trying to implement circularity in the procurement process, companies try to focus on the use of recycled materials, or materials from recycled raw materials (such as concrete with recycled concrete granulate); recycled products (such as StoneCycling bricks or New Horizon window frames). Other possibilities are future reusable materials or products (such as the metal framework of The Green House) or bio-based products, such as the wooden structure of Circl [Overmars, 2019]. In current projects, designers and project managers struggle to design with re-usable materials as their availability is unknown. One of the main characteristics of current developed circular prototypes is that they are most often temporary and therefore modular. Modularity is a principle that can contribute to a circular economy, but the concept itself is not one of the main problems within the building sector [Potemans, 2017]. Modularity can be useful, but it is not a condition for circular construction. However, it is a potentially important building block for circularity in construction practice. The chain of materials is all that matters. In order to achieve this, some local clients run their own initiative. For example, the waterboard of Drents Overijsselse Delta has its own database of available materials. Other projects look for nearby demolition assignments and try to combine that with a construction assignment. Based on this course of action, circularity will be marginally embedded in projects, as the right materials are unlikely to be there on the right time. Moreover, an integral approach of circularity seems to be absent.

[RecyclingNL, 2021]

Figure 1.3: The ladder of Lansink

As mentioned before, the construction industry does perform well in terms of recycling materials. However, numbers can be deceiving. Recycling in terms of circularity means that materials remain their value. A well-known model of determining the value of recycled materials is the ladder of Lansink, see Figure 1.3 in which circular recycling is reducing and re-using. The currently used definition of recycling is different. A well-known example in which things can be improved is concrete being re-used as a foundation of roads. This can be categorised as recycling, however, the cycle of Figure 1.2 is not being closed. If the road will be replaced, the foundation will most likely be landfill or waste. In front, new concrete needs to be added to close the cycle.

1.1.4 Public clients

Public clients are some sort of customers. They have a need for specific objects. They require different kind of products, such as buildings, infrastructure, waterworks, etc. Hermans [2014] illustrates the difference of a client from a customer given the fact their objects mostly are about coherently functioning systems. A highway is not an object on its own. Moreover, the client does not only buy the object, the object becomes part of the asset management of that specific client. In the building sector, public clients act together with semi-public clients and private parties. Hermans [2014] explains the difference between public and private clients as an organisation with a specific social core business, such as managing the waterchain or providing housing solutions for social rent. Besides their core business, Hermans [2014] claims that public clients need to contribute more than private parties to spatial quality and sustainable solutions.

The 21 water boards in The Netherlands are public clients within a particular region in the Netherlands, and have the task of regulating water management and related subjects. The water boards core business is highly influenced by the pre-described climate change and depletion of resources, as their main assets are closely related to nature. Therefore, circularity is something which might contribute to an enhancement of the activities of the water boards. Water boards have the power to influence the market and use circularity by their purchasing power. However, water boards cannot just buy what they want where they want. They are required by law to execute their purchasing management according to procurement law. Procurement is a phenomenon in a lot of industries, each with each own procedures. From the circular projects until now, conclusions about whether the current procedures facilitate circular projects are that possible restrictions are limited. Regular procedures are barely used yet for this kind of projects. A review of Mutsaers [2019] recommends to further enhance tools to judge tenders, to smooth-en the procedure. Pots [2018] concludes that current procedures are sufficient to include circularity principles, but participants should be aware of the fact that the procurement process is different from current procurement processes because it focuses on realizing an ambition, instead of finding the solution. Burger et al. [2020] evaluated current circular principles within the Dutch Construction sector and concluded that circular procurement demands a better systematic and integral approach. It also encourages to scale up, as enough pilots have been finished.

This up-scaling currently is hard to achieve. Ashokkumar [2020] has investigated how to implement design for disassembly, which is one of the strategies in CE, in the purchasing process to realize circular ambitions. The client has to include eligibility requirements for the design team as well as the contractor. Burger et al. [2020] concluded from evaluating projects of Rijkswaterstaat that there is a demand for other collaboration forms as barriers are experienced within current circular projects, and innovative circular ideas are not entering the market. This claim is supported by Ashokkumar [2020]. This research gap is expressed as well by Sönnichsen and Clement [2019], which described the need for practical hands-on to bring this policy to success. Examples for such a hand-on is the CO2 Prestatieladder, which is considered as a success and can be a base for future guidelines [SKAO, 2017].

Special attention needs to be given for the asset management. Circular building is a hot topic, but how about circular asset management? Hermans [2014] points at this as well, given the fact that for a public client the spendings on maintenance and operations more or less equalise the spendings for the realisation of new objects. Moreover, the asset portfolio of public clients of course already exists and just a minor part will be added in the future.

1.1.5 Civil objects

Earlier in this proposal, the transition agenda [Rijksoverheid, 2018] has been addressed. An important policy instrument that is being used is the stimuli for R&D, experiments, prototypes, and specific projects through prototypes. Between now and the release date of the document, several projects have been initiated. Well, known is the temporary court building of Amsterdam, realised back in 2016 which will be disassembled in 2021 [Jeltya, 2016]. Rijkswaterstaat has, in collaboration with some contractors, also carried out a pilot project for a circular crossover [Rijkswaterstaat, 2019]. This project has been finished on December 4, 2018, with the placement of the circular viaduct near Kampen. However, as these projects might give the signal that we are heading in the right direction, the general opinion from market involved specialists is quite negative. According to Koenen [2013], circular building strategies are hindered by fear of not executing procurement processes in the right way. These rules also hindered some potential advantages in the city court hall of Amsterdam [Burger et al., 2020], and this research states some examples from other projects.

The water boards have done some pilots with embedding circularity as well, but a clear definition amongst the water boards about what it is and how to use it is nowhere to be found. Moreover, it is the question of whether concepts used today such as modularity actually solve the problem. The usage of frequently used products in the assets of the water boards such as concrete and steel are at question as well.

Per inhabitant of the Netherlands, every year 0.75 m^3 concrete is produced in the industry, summing up to 14 million m^3 every year which is added [Kramer, 2020]. The main components of concrete are a binder (often cement), aggregates (sand and gravel) and water. With the production of cement, large amounts of CO2 are produced. According to [Favier et al., 2018], the production of concrete on its own is the source of 8% of the global emissions produced worldwide. The material steel is just like concrete a widely used material in the construction industry. Steel consists of two main components, iron and carbon. According to Kuijpers [2020], the production of steel is the source of 7% of the global

Co2 emissions. Thus, comparable with concrete and therefore an important subject within the topic of climate change.

However, just replacing these cornerstones of their assets is barely possible. Therefore the need arises to dive into the chains of these materials in order to investigate where possibilities for circularity arise and how these chains differ and how that impacts the steering possibilities of the boards.

These problems are being acknowledged by To Interface (graduation company) as well. In their expertise of project and tender management, they recognise these problems in conversations with the water boards. During the project of the replacement of 60 weirs and pumping stations carried out by the water board Drents Overijsselse Delta, quite some attention is paid towards sustainability and circularity within the selection and awarding criteria [WDO Delta, 2019]. These criteria are quite a struggle to define and assess, everyone understands that a modular weir can be moved to another location, but what if the new weir is needed earlier than the older one can be removed? How can this weir be developed in a way that no new raw material is being used, and no waste is produced? This arises a specific demand for research to what circularity exactly is, how it can and should be used by water boards, and how they accordingly can implement it, in order to counteract resource depletion and related problems.

1.2 PROBLEM DEFINITION

Currently, the research conducted to climate change and the importance of changing our behaviour on this earth is enormous. As the literature has shown, several plans have been developed for the construction industry. To reach the goals of the Circular Economy treated in the literature for the Dutch construction sector, it is of the utmost importance that within the transition the circular cycle is making progression until further closing. However, barriers and challenges hinder the transition, while also an environment of complexity and uncertainty exists since this domain does not yet know the majority and is seeking to properly manage circularity. Several strategies such as modularity or re-use are often mentioned, but how can water boards use these strategies in such a way they actually contribute to the problems of resource depletion and climate change properly? To Interface, the graduation company, acknowledged that this question yet is unsolved for water boards. The research to practical implementation tools concerning closing the cycle of materials from the client perspective is very limited and the market is struggling. Just a few projects have been finished and possibly could be evaluated in order to improve the process. Meanwhile, water boards have the opportunity to use circularity in the way they set up procurement and close contracts with the market, in order to counteract resource depletion and related problems.

Therefore, the question arises how water boards can use and implement circularity in their assets in order to contribute to the prevention of resource depletion and counteract climate change.

1.3 RESEARCH QUESTIONS

The results of this thesis can help improve the transition of a circular economy in the Dutch construction sector by giving handhold and guidance in the perspective of water boards. In line with the problem definition and literature review, the main research question can be framed as:

- How can water boards use and implement circularity and thus contribute to the prevention of resource depletion and counteract climate change?

In order to answer the main research questions, multiple sub-questions are formulated to support the realisation of the research question and cover relevant key aspects within the topic of interest:

1. **What is circularity, and what are current developments and bottlenecks within the Dutch construction sector regarding this theme?**

2. **What are current innovation enablers and bottlenecks within the Dutch water boards with respect to the implementation of circularity?**
3. **How do the chains of concrete and steel as a building material look like, which (type of) actors are present within that chain and what do they need to implement circularity?**
4. **Which ambitions and different circular strategies can be defined for civil structures, and how can these be combined towards a circular implementation tool for the water boards?**

1.4 SCOPE OF THE RESEARCH

Defining the scope and the boundary of this thesis is crucial to clarify the domain in which the research takes place. After finishing the research, the thesis should provide direction to investigate more knowledge within the domain. This research has a limited duration of 22 weeks of 40 effective hours of work per week, thus setting scope constraints.

The Circular Economy is an enormous subject. This thesis focuses on the circular transition of a specific type of public client, the water boards. The water boards are closely connected to nature in multiple ways, therefore having a great need to implement circularity. The thesis addresses the circular developments of today and aims to provide insight into the question of how to achieve the desired goals in 2030 and provides context for these goals. Moreover, the water boards are in close contact with nature, hence experiencing the consequences of climate change, making them one of the main stakeholders of the transition towards a circular economy.

Within the CE, multiple topics could be addressed. This thesis aims to provide a clear insight into relevant topics, but mainly focuses on closing the circular cycles with respect to the usage of construction materials. On beforehand, this theses addresses mostly the construction itself, thus ignoring biodiversity themes. In more detail, it addresses the supply side of the materials to the construction industry, or more generally its business operations. Material streams within the construction sector of the water boards are countless. The number of used types of materials are huge, not to talk about different substances applied within those materials. Each of the materials has its own part in the context of climate change. Wood for example requires a lot of space, while cement produces a lot of GHG. More specifically, the water boards have quite a broad portfolio. This research, therefore, focuses on two of the most used materials with a high damaging influence on the climate; concrete and steel [Favier et al., 2018] [Carles, 2019]. This means that activities in quarries of mines are barely treated. Instead, attention is drawn to different involved market stakeholders such as bigger contractors but also the material suppliers.

The thesis aims to create a clear overview of which circular strategies can be used in the coming years by water boards and in what way they contribute to circularity. In order to illustrate the theory of this research, an implementation example is given regarding a pumping station. Pumping stations are important objects for water boards in their core business. On top of that, they are largely built from concrete and steel, thus fitting the scope of this research and being a suitable example for this research.

1.5 METHODOLOGY

This section elaborates the approach which is used to answer the different research questions mentioned. Within this research, a variety of tools is used. Before the start of the actual research, exploratory research has been conducted to the main problem by means of a research proposal, to investigate the main principles of a circular economy, and its relevance towards the construction industry and the problem statement. This has been presented at the kick-off stage of this research.

1.5.1 Method description

This research focuses on a relatively new concept and therefore uses an exploratory method approach. This method generally is studied with qualitative data [Binnekamp, 2020]. Qualitative research aims to define and interpret unclear phenomena, such as circularity, through non-quantitative methods of research that focus on meaning and insight [Kakabadse and Steane, 2010]. This type of research tends to be descriptive and depends on the experience and interpretation of the authors [Gioia et al., 2013]. As this research is about exploring and implementing new scientific concepts and policies, only desk research would not suffice due to a lack of literature and the fast developments in the field. Therefore, a mixed-method approach is chosen and the literature study is combined with desk research to grey literature. Moreover, interviews are conducted to gain real-time data and insights to provide insight into the current state of affairs and to obtain additional information, in order to supplement or validate literature.

1.5.1.a (Grey) literature review

According to Creswell [2014], a literature study is useful in every research as this helps to investigate research gaps. It provides information from previous research but also integrates the current state of the art of the construction sector. Due to the fact that the number of scientific publications related to circular implementations is limited, grey literature is used to gain supplemental insights. Moreover, internal documents of the water boards addressing the topic are analysed as well.

1.5.1.b Interview methodology

Within the gathering of data, several methodologies can be used. As argued before, this thesis uses a qualitative approach. Interviewing with a qualitative approach can be achieved using different types of structure.

STRUCTURED INTERVIEWS is a method where all the questions being asked are prepared beforehand. The questions are close-ended. Amongst different persons, the interviews are the same and have a standardized format. The strengths of this method are: easy to quantify and reliability testing. Large samples are possible due to the short period both of the interview and processing. However, answers from structured interviews do not contain specific details and guide answers in a certain kind of direction. Therefore this method a barely used as a qualitative approach Dew [2007]

SEMI-STRUCTURED INTERVIEWS within this method, the interviewer may have lists of themes or problems to be addressed. It up to both the participants and interviewer to treat the themes in a way that suits them. Participants can appoint relevant themes or problems that were not initially identified by the researcher Dew [2007].

UNSTRUCTURED INTERVIEWS is a very flexible method, in which every interview feels like a natural conversation without any bias. Moreover, it generates increased validity as it gives the interviewer the possibility to dive deeper into a topic for better understanding. The limitations of this method however are that it is a very time-consuming way of interviewing, as is the processing. Comparison of results is very difficult and requires a lot of work. On top of that, it requires specific skills from the interviewer.

This research is exploratory and therefore new concepts or ideas are being discovered, evaluation barely takes place. However, certain themes are being identified in the literature study, thus giving possibilities to structure the interviews. The method of semi-structured interviews is, therefore, most suited.

1.6 INTERVIEWEES AND SUBJECT OVERVIEW

The people involved in the interviews need to be in a key position of implementing circularity in their organisation, because it is a new subject not everyone has experience with. Relevant organisations of which their participation is included:

- Contractors;
- Water boards;
- Concrete and steel manufacturers/ suppliers.

See Figure 1.4 for an elaborated list of companies and people of interest and corresponding positions within the company. As the circular economy has just recently gained massive interest, no long experience can be desired from the participating people. Therefore, this thesis aims for front runners organisation within the contractors, client and manufacturers with at least some circular projects.

The interviews have been planned as a 60 minutes schedule, in which first the participants and the research itself are introduced. The interview protocol that is used is shown in Appendix B. The persons who were interviewed are asked for permission in order to tape the audio.

Company	Function	Date	Interview reference
Concrete supplier	Senior Advisor	17-03-2021	[1]
Material miner	Circular Supply Specialist	22-03-2021	[2]
Steel supplier	Sustainability manager	25-03-2021	[3]
Water board 1 *	Technical manager Asset manager Advisory	02-04-2021 30-03-2021 25-03-2021	[4] [5] [6]
Water board 2 *	Technical manager Asset manager Advisory	02-04-2021 30-03-2021 25-03-2021	[4] [5] [6]
UVW	Advisory CE	08-04-2021	[7]
Contractor	Sustainability manager	01-04-2021	[8]
Contractor	Projectmanager & Planner *	07-04-2021	[9]
* Interview marked concerned duo interviews			

Figure 1.4: Interviewees overview

1.6.1 Data analysis

Within the inductive semi-structured analysis, the Gioia et al. [2013] approach is selected to analyse the data. The Gioia approach is a way of 2-stage open-coding data assessment. It consists of first-order categories which are derived from interview or literature quotations. These categories are then collected in second-order themes. This open-coding assessment takes place in Miro and are obtained by means of visual displays, diagrams and memos made by hand. Therefore, this approach is suitable to analyse the gained data through the semi-structured interviews.

1.6.2 Quality of the research

Qualitative research depends on the interpretation of the researcher. This interpretation may be subject to subjectivity. In order to validate quality in qualitative research, Lincoln and Guba [1985] propose the concepts of credibility, transferability and consistency. For multiple sub-questions in this research, obtained information (by interviews, grey literature and scientific literature) is compared. The application of multiple sources of data (triangulation) can enhance the reliability of the study results [Fusch and Ness, 2015]. A triangulation qualitative approach is therefore considered suitable for this research since it cross-checks a topic through different channels [Kakabadse and Steane, 2010]. The method therefore can combine theory from practice, internal documents and literature. The criteria mentioned are supported by different tools, which are shown in Figure 1.5

Credibility	- Using multiple methods (interviews, (grey) literature) (triangulation). - Make use of scientific literature. - Make use of grey literature (policy documents, newspapers). - Different viewpoints within interviews (multiple departements within multiple water boards, multiple contractors, multiple material suppliers).
Transferability	- Thick description of the findings. - Implementation example through chapter 5. - Relatively large variation in the interviewed organizations.
Consistency	-Triangulation is used to ensure a consistent thesis. If data contradict each other, it is argued why which data is preferred. -A validation session with relevant actors could possibly have improved the implementation tool.

Figure 1.5: Criteria for quality in research

1.7 APPROACH TO SUB-QUESTIONS

In the next sections, the approach is elaborated for each of the sub-questions. The thesis outline is shown in Figure 1.6, which gives an overview of the cohesion between the sub-questions and the desired outcomes.

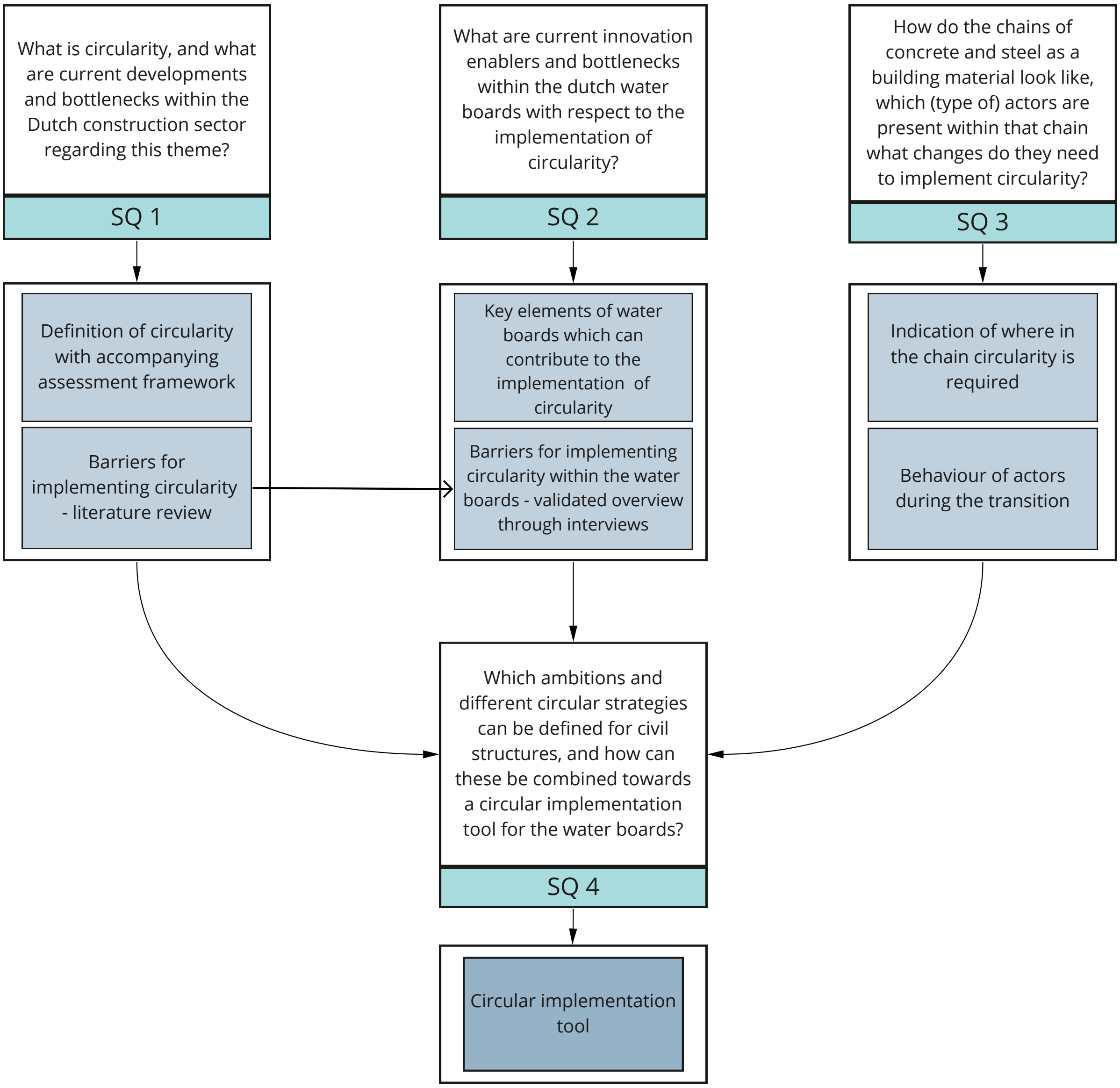


Figure 1.6: Thesis outline

1.7.1 Approach to sub-question 1

1. What is circularity, and what are current developments and bottlenecks within the Dutch construction sector regarding this theme?

The first sub-question is defined in order to define the current state of the art of circular developments and bottlenecks recently encountered in the construction industry. Where possible, developments within the cycle of materials are highlighted. Key developments are investigated and analysed in relation to their specific position within the transition, in order to prepare for the second to fourth questions and related interviews. In order to substantiate the answer to the first question, a literature study is executed to examine the state-of-the-art of the circular economy and its specific regulations set in current policy. The findings of the first chapter form a basis for the thesis. Which key developments do we need to take into account for an implementation tool and why? Which barriers possibly can prevent this implementation?

1.7.2 Approach to sub-question 2

2. What are current innovation enablers and bottlenecks within the Dutch water boards with respect to the implementation of circularity?

The second sub-question focuses on the public client which is being addressed in this thesis. In order to substantiate the questions which determine the strategy for the water boards, these type of organisations and their current focus on circularity and procurement strategies are analysed. The main objective of the analysis is to get insight into the water boards as a construction client, key moments in which innovations can be applied and possible organisational barriers. The findings of the second chapter provides insight into the way the water boards are organised, and how that influences their decision making in project realisation and asset management. A literature study is executed, supplemented with interviews and grey literature from the water boards themselves in order to understand which aspects contribute to the transition. Where do innovative ideas tend to be successful, and why is that?

1.7.3 Approach to sub-question 3

3. How do the chains of concrete and steel as a building material look like, which (type of) actors are present within that chain and what do they need to implement circularity?

The third sub-question focuses on the current chain of materials used within the construction sector, more detailed to concrete and steel. How does such a chain look like and which part is problematic in a circular economy? Which actors are involved and which place do they have within the chain. How are responsibilities divided within this chain and which actor has which incentives to move towards a circular economy? This question provides an answer to changes that are going to be the consequence of this transition or which changes are needed to achieve the circular ambitions.

1.7.4 Approach to sub-question 4

4. Which ambitions and different circular strategies can be defined for civil structures, and how can these be combined towards a circular implementation tool for the water boards?

The fourth sub-question starts by defining circular design criteria. Key developments and measurement tools from chapter 1 are used to define to which extent circular levels can be defined, in relation to the 50% demand in 2030. These design criteria and accompanying assessment say something about how circular a building is at certain particular criteria. After that, the question addresses the implementation of circularity. How can the degree of circularity between different criteria be defined and which strategies of circular building can be used within those levels? The goal is to create a systematic approach in which the water boards can steer on a circular ambition in the long term. Circular strategies which can realise these ambitions are showed. These strategies are determined with the results from the literature review from sub-question 1 and grey literature. Moreover, this question combines the measurement tools with the available strategies in order to develop an implementation tool. If designed as such, lessons learned can be applied in a systematic way in order to upscale circularity towards the future.

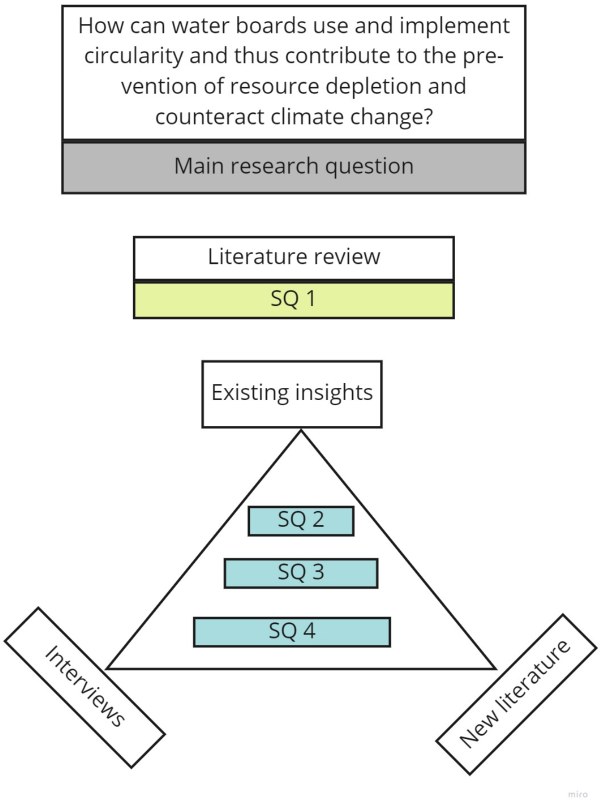


Figure 1.7: Triangulation

1.8 RELEVANCE OF THIS RESEARCH

This research is carried out with the scientific support of Delft University and by a market company To Interface, together with some other experts from other market parties. Therefore, the expected result should be relevant to the academic world as well as to the market. In underlying chapters, relevance for both sectors is explained.

1.8.1 Scientific relevance

The Circular Economy has gained a lot of attention in the past few years, not only within the political debate but in science as well. At the current state, literature most often has addressed issues on defining circularity as a concept to involve within certain sectors [Kirchherr et al., 2017]. The national government has taken the lead in tackling these issues by setting the standard for circularity in the Netherlands. Before these standards, some literature was published to give guidance and show possibilities for circularity in practice [Tsolis, 2017].

However, as some more detailed plans are yet to be worked out or unknown, circularity still raises a lot of questions. This leads to confusion and difficulties for the market to achieve the ambitions set by the government [Mentink, 2014]. This implies a gap between the theory and application of the principles developed in practice which is supported by the company of To Interface as well. Despite all the literature published about Circularity, it is not focused on the process that is required for its implementation.

Therefore, this research is one of its own because:

- It provides insight on which areas barriers are experienced and which changes are therefore needed to close the cycle of materials in practice. This is done for the construction sector, material chain and the water boards in particular;
- It clearly defines what the core principles are of circularity and what that implies for the current project-based approach of the water boards;
- It provides an implementation tool that incorporates existing measurement tools that focus on materials in the Dutch construction sector, such that it can be used for multiple assets of the water boards.

1.8.2 Societal relevance

The European construction industry is a major contributor to climate change, as it uses a major part of all extracted materials. It is therefore needed to handle the resource usage within the construction sector to reduce the usage, as materials are not inexhaustible. The Dutch government has set the target for the Netherlands to be at least 50% circular by 2030. Therefore, the government has decided to take to lead and circularly procure all projects by 2023.

In order to prepare the market for this change, public clients such as Rijkswaterstaat and water boards have initiated several platforms and pilots. Several ideas are being implemented and tested. As normal decision-making within civil projects has a long lead time, the market expects several problems and hick-ups by this goal. Therefore, this research aims to help avoid the mentioned negative side-effects by providing the water board with an implementation tool to contribute to the implementation of circularity for these public clients.

2 THEORETICAL BACKGROUND, KEY DEVELOPMENTS AND BARRIERS

This chapter provides an answer to the first sub-question of this research, which has been formulated as:

- What is circularity, and what are current developments and bottlenecks within the Dutch construction sector regarding this theme?

The chapter starts with mentioning the results from the literature study to the motivation and an explanation of the circular economy in scientific literature and Dutch policy documents, which is treated in Section 2.1. Thereafter, the definition of circularity is addressed in Section 2.2. How materials should be observed and assessed and what requirements that brings, is addressed in Section 2.3. Assessment frameworks are discussed in Section 2.4. The chapter closes in Section 2.5, by addressing and identifying barriers for the circular economy as a whole and comparing those results specific with the construction sector.

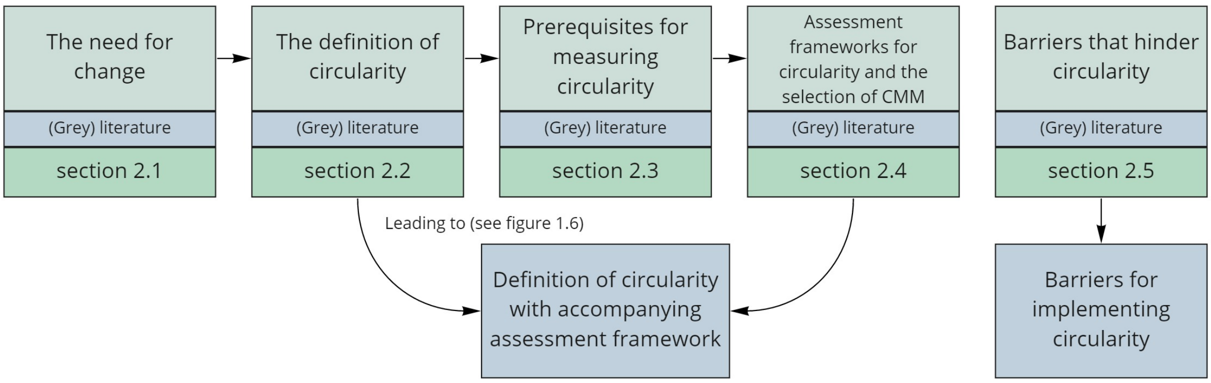


Figure 2.1: Chapter overview

2.1 THE NEED FOR CHANGE

Climate change has dominated a lot of political debates about the construction industry. Various plans have been made in order to prevent these problems to grow further. This section addresses the need for change and how the Dutch government wants circularity to solve these problems.

2.1.1 Problems of this earth

Pachauri and Meyer [2014] states that the high greenhouse gas emissions (GHG) caused by humans since the pre-industrial era are most likely the main cause of global warming. Countless reports state that this event is likely to evolve in long-lasting climate change. This may cause significant problems to earth-living, in all its aspects such as physiology, effects on distributions, phenology and adaptation of species [Matthews et al., 2017]. It also resulted in a higher demand for resources. A shortage of fossil raw materials becomes an emerging problem in the coming decades [Ritchie, 2017], mostly because of the increase of usage and partly because of redundant waste.

In the western world, the energy and material consumption usage levels are so high that approximately 3 worlds need to exist in order to have enough resources and CO2 healing abilities to fulfil these demands [European Commission, 2020]. In the past century, the world has consumed 34 times more materials than the century before, and this trend will not relapse [Shafiee and Topal, 2009]. The construction industry is one of the most important sources of these problems, as it produced 25 million tonnes of waste in 2012 which is more than three times as much as all the household waste in the Netherlands [Bouwagenda, 2020]. European countries do not perform better. The built environment is estimated to be responsible for around 40% of energy consumption and 36% of CO2 emissions in the EU [EU, 2019], as well as 50% of all extracted materials. On top of that, 40% of used materials are imported from outside the EU, which causes the current linear economy to be threatened by price volatility as well [Bourguignon, 2018]. Therefore, the sector has a huge negative impact on climate change (external drive) and might as well shoot themselves in the foot (internal drive) when not addressing the resource scarcity properly [Ghaffar et al., 2020]. Reducing the CO2 emission and dealing more consciously with the use of materials can reduce the earlier addressed consequences and bring the world to a better future.

Between today and 2050, the expected rise of the world's population is about 2 billion people. Therefore, the demand for housing and infrastructure and therefore material sources will not decline [Favier et al., 2018], thus emphasizing the need for change. 100% circularity in the form of re-used products will therefore be very hard to accomplish.

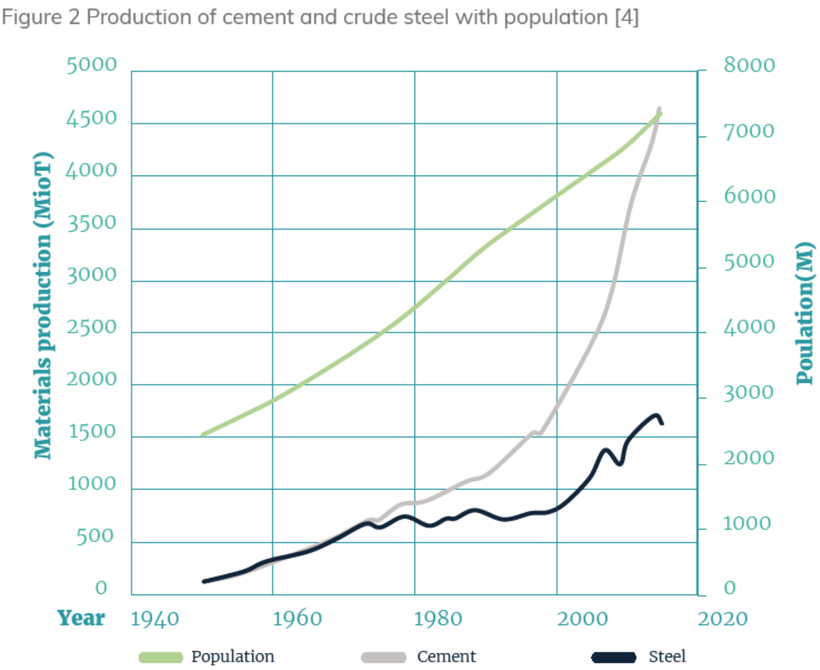


Figure 2.2: Demand for steel and concrete vs world population [Favier et al., 2018]

2.1.2 Circularity as the solution

The given problems show that limiting the import of new raw materials into the economic system is needed as much as possible - whether because of necessity or wish. The same holds for reducing waste. Resource scarcity and CO2 emissions can be reduced by various measurements and tools. The Dutch government has decided to focus on a circular economy, to meet the arrangements of the Climate Conference of Paris. The government aims for a future-proof, sustainable economy, for future generations and has therefore set up a national program to achieve this named: *"Nederland circulair in 2050"* [Dijksma and Kamp, 2016]. A program that relates to all industries and sectors in the country.

The policy document of Dijksma and Kamp [2016] addresses five specific areas of the Dutch economy; biomass and food; plastics; manufacturing industry; consumer goods and the construction industry in which circularity can solve the named problems. The construction industry can be viewed as key since its emissions and resource usage are enormous. The strategic goals for the construction industry are defined as:

- Raw materials in existing chains should become high-quality utilized;
- If new raw materials are needed, fossil, critical and non-sustainable produced raw materials should be replaced by sustainability produced, renewable ones and commonly available raw materials;
- New production methods are being developed, usage chains might be changed which leads to developments to reduction and circular replacement.

The Netherlands Environmental Assessment Agency (PBL), the Central Bureau of Statistics (CBS) and the National Institute for Public Health and the Environment (RIVM) will monitor the arrangements set in the Rijksoverheid [2018] of the circular construction economy [Arnoldussen et al., 2020]. In the end, this goals will have to lead to:

- Reduce CO2 emissions by 49% in 2030 compared to 1990;
- Reduce usage of primarily raw materials with 50% by 2030 since 1990;
- Ambition of procuring all tenders circularly by 2023.

2.2 DEFINING CIRCULARITY

The concept of Circular Economy is developed to change the current way of consumption and production mindset. In the previous section, it is explained what circularity can be used for. It should reduce input and waste of resources, emissions and energy leakages can be minimized by slowing, closing and constricting energy and equipment loops [Afshari and Górecki, 2019]. This can be realised and implemented in all parts of the construction process, such as design, but also and mainly within the period after lifetimes such as maintenance, repair, reuse, remanufacture, renovation, recycling and upcycling [Geissdoerfer et al., 2017]. This means that circularity should not only be implemented in the realisation phase, but also in the asset management.

The circular economy applies to five main sectors of the economy. Therefore it has gained traction by all types of participants of the industries, such as practitioners and scholars, because it is viewed as a future-proof business plan [Kirchherr et al., 2017]. This resulted in many studies, policies and other activities regarding circularity and therefore the circular economy can be interpreted in many ways, leaving no key player with the authority to define the circular economy [Prieto-Sandoval et al., 2018]. Moreover, it creates the risk of naming wrong concepts circular, thus not heading in the right direction [Moss, 2019]. Therefore, the question arises of what the definition of circularity is.

2.2.1 The definition of circularity in policy documents

Worldwide, one of the most accepted definitions of the circular economy is defined by Ellen MacArthur Foundation [2017], which defines a circular economy as:

Looking beyond the current take-make-waste extractive industrial model, a circular economy aims to redefine growth, focusing on positive society-wide benefits. It entails gradually decoupling economic activity from the consumption of finite resources and designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital. It is based on three principles:

- *Design out waste and pollution;*
- *Keep products and materials in use*
- *Regenerate natural systems*

The circular approach of the Dutch government in Dijksma and Kamp [2016] elaborates on the focus for the Dutch circular economy. The policy plan adopted the definition of Ellen MacArthur Foundation [2017]. In more detail, the policy plan of Dijksma and Kamp [2016] states the use of a certain R-Framework, which has been derived from the given definition, showed in Figure 2.3. Hanemaaijer et al. [2019] created such a framework, forming the base for multiple policy documents. This framework was derived from Potting et al. [2017] (some authors overlap) and first published by Meijdam et al. [2015]. Its main principles are that in a certain activity, every element needs to be assessed on this framework, and if an element is higher on the framework, the more circular it is.

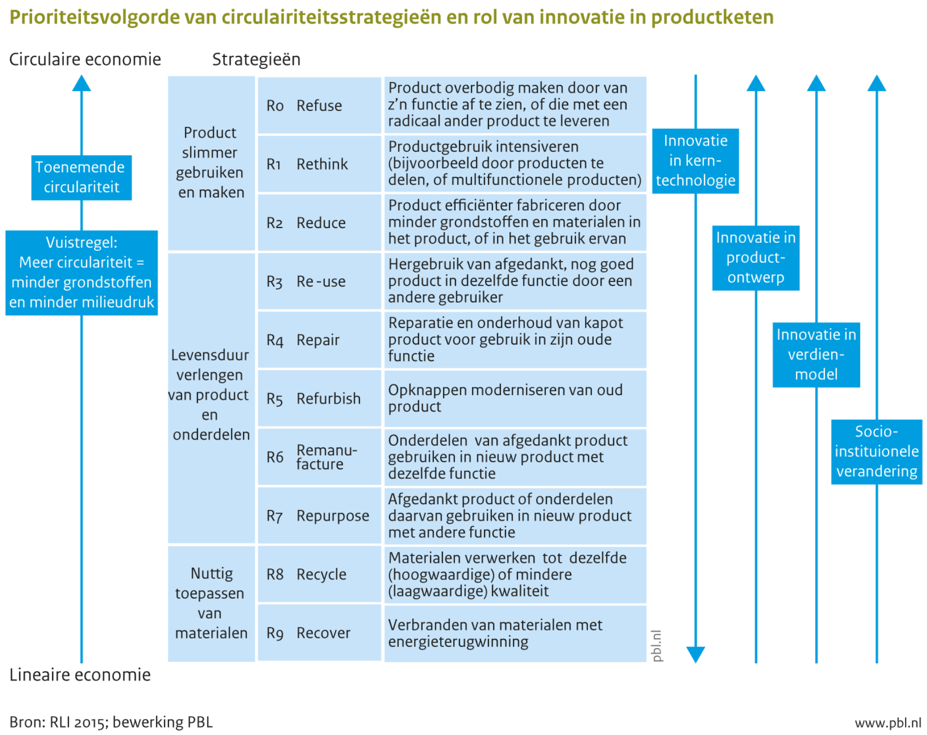


Figure 2.3: 9R Strategy
[Meijdam et al., 2015]

In the evaluation and monitoring reports of IenW [2020], it is argued the use of the R-framework is successful and therefore continuation of this framework is supported. However, [De Valk and Quik, 2017] - a policy document especially for the circular construction industry - already mentioned the pitfalls of this theory for the construction industry. This is being acknowledged by a recent monitoring report for the Dutch economy Hanemaaijer et al. [2021], opting for another approach.

The pitfalls of this framework are being discussed in Reike et al. [2018] in which the biggest argument against the framework is that one needs to fundamentally rethink production and distribution and consumption processes before using the recycling process and thus essentially maintaining a waste hierarchy which essentially is a part of the linear economy. R-frameworks are considered as a tool that one can use in today's processes, but which will eventually run up against the limits of the linear market. For example, the R-frameworks does not think beyond 1 lifecycle.

2.2.2 The definition of circularity in scientific literature

In the previous section, it is explained that the construction industry plays a major role in the circular economy. However, the definition of circularity in policy documents is not yet unambiguous for this sector. Therefore, no clear definition of circularity can be defined from policy documents for this research and the water boards. In order to determine a correct definition, this section addresses the **core principles** of circularity in scientific literature.

The definition of CE or circularity, in general, is being addressed quite a lot in scientific research. Kirchherr et al. [2017] performed a review of the definition of circularity, and gathered 114 CE different definitions which have been coded on 17 dimensions. The findings of this paper show that the definition of circularity frequently depicted as a combination of reducing, reuse and recycle activities, resembling the R-frameworks used by the Dutch government, whereas it is oftentimes not highlighted that CE necessitates a systemic shift, a claim set by Kirchherr et al. [2017]. The paper codes all the principles and concludes that two core principles can be identified, both of which arose with the definition of Ellen MacArthur Foundation [2017] as starting point:

1. R-FRAMEWORKS R-frameworks have been used to define CE quite a lot over time. No singular definition of these R-frameworks can be found. 3R frameworks have been proposed by Ghisellini et al. [2016] and Manickam and Duraisamy [2019], defining Reduce, Reuse, and Recycle as the core elements of CE. Kirchherr et al. [2017] uses the 4R principle introduced by European Commission [2008], which adds the R 'recover'. 5R - 10R principles exists as well [Chen et al., 2020] [Jawahir and Bradley, 2016] [van Boerdonk et al., 2021]. The definitions of these R globally can be seen in Figure 2.3. Most of the R-frameworks also include a waste hierarchy, which is assumed to be circular. Essentially, this framework treats circularity as a goal. The higher on the framework, the better.

2. SYSTEMS PERSPECTIVE The papers mentioned by Kirchherr et al. [2017] emphasize that CE requires a fundamental shift rather than an incremental shift of the current system, a shift that is accepted as sufficient for the R-Framework. Cited papers such as Jackson et al. [2014] but also various Dutch policy documents mention the system approach which requires a radical change in thinking and doing as it comes to the macro, meso and micro levels of the economy. A systematic approach does not treat circularity as a goal, but as a method to gain certain results over time [Moss, 2019]. Kirchherr et al. [2017] claims that this approach becomes more dominant when it is about defining the circular economy and implementing it on a bigger scale.

The dominant R-framework principle is criticised because it would oversimplify the circularity concept, therefore not being suitable for long-term transitions Reike et al. [2018] de Jesus and Mendonça [2018]. Current policy documents in the Netherlands acknowledge this as well. Therefore this research adopts the systematic perspective as the main definition to explain what circularity can be used for. It is a method, and therefore not a goal, which can contribute to the prevention of various problems, such as resource depletion and climate change, over time. Moreover, this means that circularity is not limited to material streams only, but incorporates problems such as GHG as well.

2.3 REQUIREMENTS FOR MEASURING CIRCULARITY

In order to full fill the requirements of the circular ambitions, a project or building should be measurable. In the previous section, it is argued that circularity should be treated as a method to reach certain goals over time, not in a specific project. Therefore, the need to be able to measure this progress arises.

This section treats elements or tools mentioned in literature which can meet this need.

As circularity can be used as a systematic process, a building can be partly circular and partly linear. Potting et al. [2017] describes what is meant by ultimate circularity. This is a status in which used materials from products normally addressed as waste, function as a resource material for a new product. However, 100% circular state is quite difficult by now, and might never be achieved by 2050 [Mentink, 2014]. This is because the building sector will be developing more than demolishing. So input will be needed, even if every demolished element is being re-used.

This means that 100% circularity maybe is not a suitable goal. However, certain goals, for example the amount of re-used materials, need to be measurable. On the one hand for politics and climate goals, on the other also for assessing designs. Different literature describes methods to do so. Geldermans [2016] composed two main elements of an object, which both are more elaborated.

- Intrinsic elements
  - Quality of functional aspect
  - Sustainable origin and future
  - Non-toxic elements or used processes
- Relational elements
  - Dimensions (over dimensioning might ensure future employability)
  - Connections (Standardisation)
  - Performance time (defining the lifespan)

Analysing the list of properties, it could be concluded that homogeneous products which therefore are easier to recycle are preferred over more complex systems with high maintenance. Geldermans [2016] states this is not the case but it is important to think about possible use and reuse paths in a certain object before using them.

Measuring the circularity at a certain point is not enough. For example, one of the most often named counterarguments regarding the R-Frameworks is that a certain position on this ladder indicates nothing about the future. For example, reducing the amount of concrete now, may reduce the chance of re-using it in the future.

To tackle this issue, research recommends using LCA based methods to assess circularity [Medina and Fu, 2021]. The document of De Valk and Quik [2017] proposed the first strategy to define and measure circularity, based on the current knowledge of LCA-experts [RIVM, 2011]. In order to develop an LCA tool for circular objects, seven specific points are allocated to include within that tool [De Valk and Quik, 2017]. If done properly, this should lead to a usable measurement method in the Netherlands. The goal for such a method is defined as [RIVM, 2011]:

> *An LCA method such as the Assessment Method aims to calculate the environmental performance over the life cycle of products, construction works and civil engineering works in an unambiguous and verifiable manner.*

An extensive elaboration on LCA can be found in Appendix D.

This tool should be combined with a product life cycle, which shows the steps of the life of an object De Valk and Quik [2017]. There are various variants for a product life cycle. A product life cycle for civil objects with enough attention between stages with possible circular components is derived from Ellen MacArthur Foundation [2017] and shown in Figure 2.4. This figure aims to provide enough life cycles to explain that circular choices need to be made in every stage of an asset. Later on in this research, this figure will be used to explain different circular strategies for each phase.

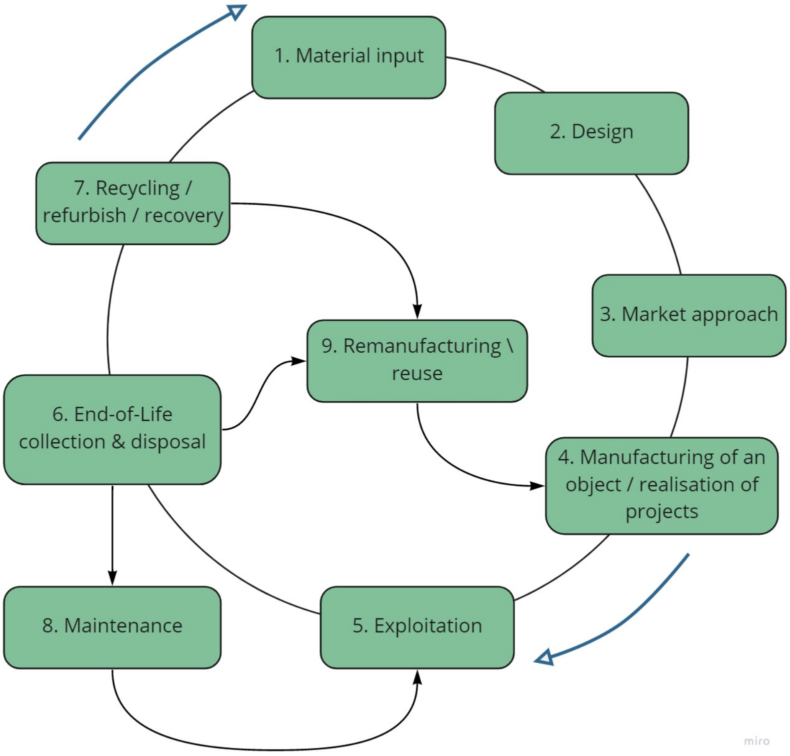


Figure 2.4: Circular value chain of an object (own image, adapted from Ellen MacArthur Foundation [2017])

In conclusion, a suitable method to asses circularity would consist of:

- A systems perspective;
- A LCA;
- Intrinsic and relational elements;

2.4 ASSESSMENT FRAMEWORKS FOR CIRCULARITY

The previous section described the need for an assessment framework of circularity. This section describes existing frameworks which can be used to assess circularity. A method to define and assess will be selected, for the further course of this research.

2.4.1 Existing frameworks

Since the publication of De Valk and Quik [2017], which described the need to assess circularity, multiple organisations have been working on the assessment of circularity, incorporating the before-mentioned items. The tools they developed are showed in Figure 2.5 and Figure 2.6. The different tools aim at different products and therefore require different data parameters. Concepts from different tools can however inspire.

Circle Scan	Metabolism Analysis	Circulytics	Circular transition indicators	Circle assessment

Figure 2.5: Circular tools aimed at organisations
[Beumer, 2020]

Impact TNO	Ecopreneur	Optimal scans	Circular IQ	Kernmeetmethode CB23
Metabolism analysis	C2C - Cradle to Cradle products innovation institue	ReNtry	Circularity Calculator	

Figure 2.6: Circular tools aimed at products and services
[Beumer, 2020]

It is important to note that circularity incorporates different subjects and goals. The original goal of the government for implementing circularity is (see Section 1.1.2)

- Unnecessarily depleting natural resources;
- Pollute the living environment;
- Affecting ecosystems

The mentioned measurement methods in Figure 2.6 all focus on different areas within circularity, but the method of CB23 stands out right away. This method is developed by the Dutch construction industry, initiated by two of the biggest public clients of the Netherlands (RVB & Rijkswaterstaat). This method has been specifically developed for construction, thus unique in that aspect. Moreover, it includes an existing successful method, the milieu-kosten indicator (MKI), a single-score indicator, which simplifies and unites different environmental data points into one number [Hillege, 2019]. In addition, it has the advantage of being developed by a public body, which makes the method public available. As a result, no problems are experienced by measuring methods that are commercial and therefore opaque, an issue which a lot of the other showed methods have.

Moreover, the CB23 method meets the requirements set in the previous section:

- **A systems perspective:** by including multiple life cycles, and multiple sustainability issues;
- **A LCA:** the assessment framework uses the LCA principle;
- **Intrinsic and relational elements:** by using the MKI which incorporates relational elements such as performance time and initiating intrinsic elements for the asset itself.

Therefore, it is concluded the 'kernmeetmethode' (CMM) of CB23 is suited and will be used in this research. It must be noted that all of these tools are in a preliminary stage and therefore a complete evaluation is suggested for later further research.

2.4.2 Framework: Circulair bouwen'23 - CMM

This section will elaborate on the method selected in the previous section which will be used further on in this research.

Circulair bouwen 2023 is an organisation launched in 2018 by Rijkswaterstaat, RVO, NEN and the bouwcampus [RWS, 2018]. Platform CB'23 has the intention to act as a connector between the many existing initiatives, share knowledge and offer a place where all parties involved build joint images and reach agreements. This platform executes some of the plans mentioned in Rijksoverheid [2018] and its related program [IenW, 2020]. It has determined its goals as:

- Building and sharing knowledge;
- Identifying and putting obstacles on the agenda;
- Drawing up construction sector-wide agreements.

In other words: co-create, construct and conclude. The intended result is a joint route to circular agreements. CB'23 has multiple focus areas, in which measuring the circularity of a building is one. In CB23 [2020a] the 'Leidraden voor het meten van circulariteit' are being published. Within this guide, three goals are being determined which follow from the basic circular principles of the government mentioned in Section 1.1.2:

1. Protection of material supplies;
2. Protection of the environment;
3. Protection and creation of existing value.

The developed method of CB'23 is known as the 'kernmeetmethode' (Core measurement method) (CMM) and based upon existing tools used in the Dutch Construction sector such as the MKI. It uses the same way of thinking in life cycles and the basis in material flows and a material balance. Therefore, the needed input data is the same. However, the protection of the material supplies and existing value are not part of existing LCA methods. These parts do play an important role in the circular economy and therefore are embedded within the CMM.

In line with earlier defined core principles of circularity, the CMM does not use the R-Framework but incorporates systematic perspective together with the thematic fields of Kirchherr et al. [2017], which states that when defining the CE, most often the approach is one-sided by excluding one of the goals. As the report mentions itself :

> *A modular bridge deck can be re-used four times in two hundred years. Parts of the bridge deck are then no longer functional or technically adequate. If a new bridge deck can be made from composite materials (recycle), the use of primary raw material will also be avoided after those two hundred years. If this is not possible, it must be weighed whether the advantages of modular design for four cycles outweigh the disadvantages of a design that is not recyclable after those cycles.*

By the introduction of the CMM, the organisation wants to emphasize that circularity should not be the goal. A systematic approach argues choices for the best situation over time. Space is needed for development, long term strategies need to be set out to come towards the best solution regarding the basic three principles. Circularity can play an important role within the principles, in order to enhance the current situation of the earth. The design of the CMM is further elaborated on in the following subsections.

An important tool to execute a measurement method is the so-called material passport. A framework for this is developed by CB23 and is introduced in Appendix F, but not further elaborated in this research.

2.4.2.a *CMM - Overview*

The CMM created by CB23 [2020a] consists as mentioned earlier of 3 main pillars. These lead together towards a certain end score. This is illustrated in Figure 2.7. The figure shows the principle of the CMM and it can be observed the CMM has three main pillars:

1. Protecting material supplies;
2. Protecting the environment;
3. Protecting and creating existing value.

These pillars all have their own assessment framework, with input and output indicators and with a certain impact assessment, leading to an overall circularity score. It should be noted that this version of the CMM is still in development and a revised version is expected to come out in July 2021.

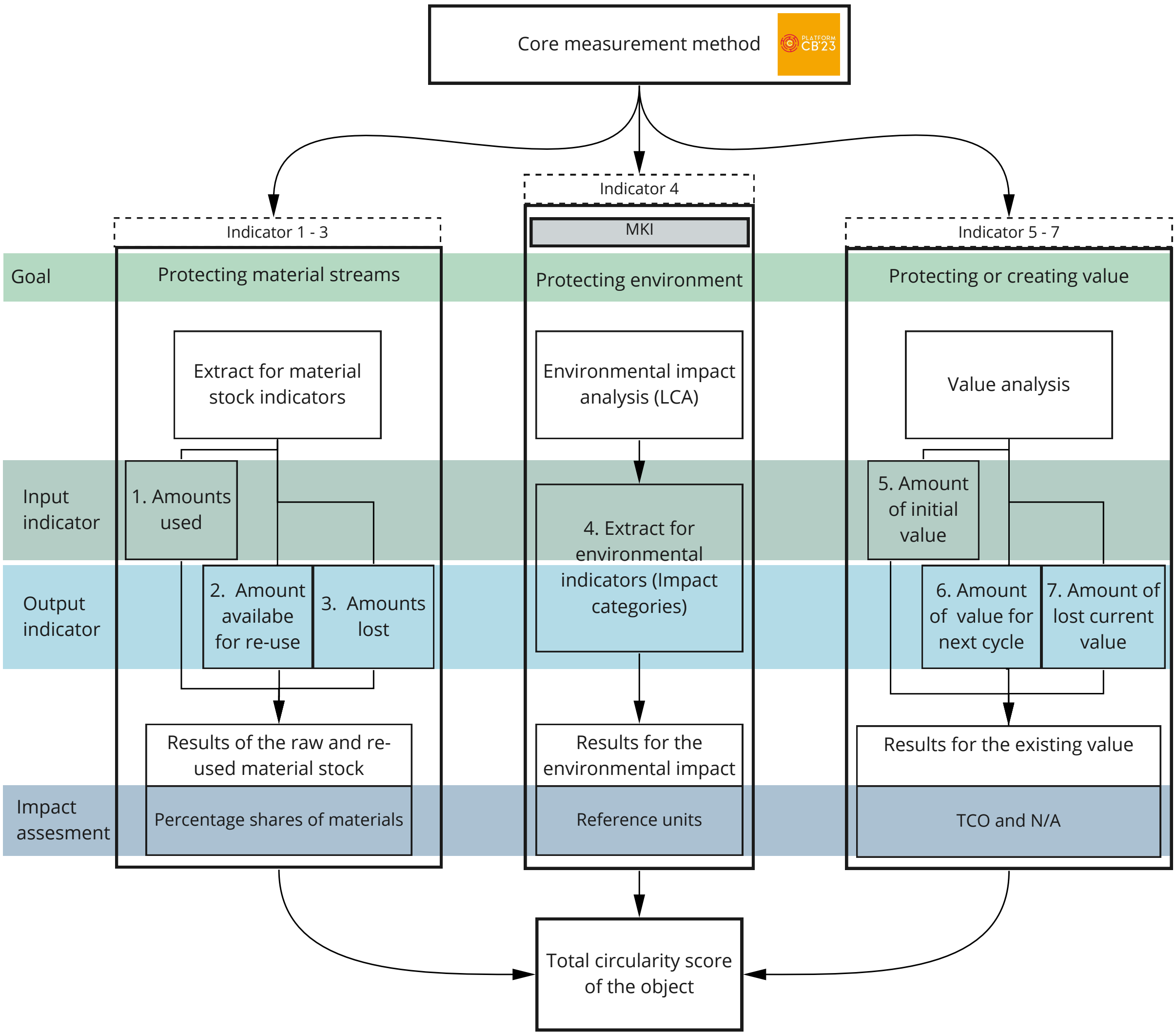


Figure 2.7: CMM method to determine circularity in an object (Own figure - derived from CB23 [2020a])

2.4.2.b *Protecting material streams, indicator 1 - 3*

Each material flow is assigned to one of the indicators between 1.1 and 1.2.2. in Figure 2.8. A distinction is made between primary and secondary material. Primary material becomes then subdivided into renewable (which becomes renewable material subdivided into sustainably produced and non-sustainably produced) and non-renewable material. Secondary material is divided into reuse and recycling. After the materials have had a score for indicator 1, materials are jugded again to their physical scarcity and socioeconomical scarcity. These don't exclude each other, so a material can be both physical and socioeconomical scarce. In total, these scores combined are called input indicator 1.

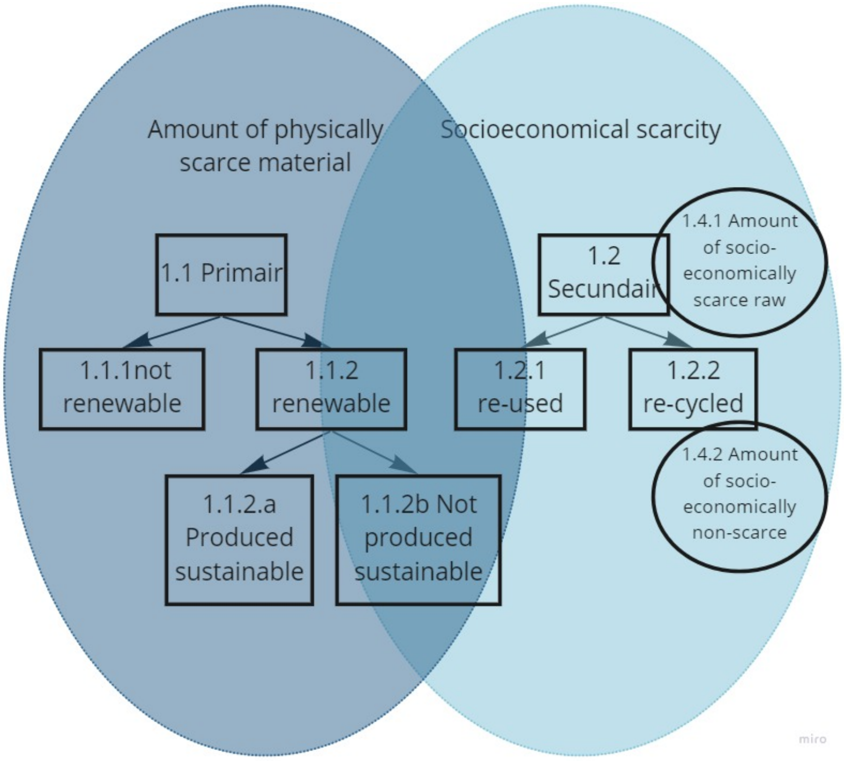


Figure 2.8: CMM - indicator 1 (Own figure) derived from CB23 [2020a])

All of the used materials are then assessed again, but focused on their up following life cycle. Materials either be assigned in indicator 2, when they are available for re-use. If not, they are assigned to 3 and considered not usable again, thus lost materials. This is being shown in Figure 2.9.

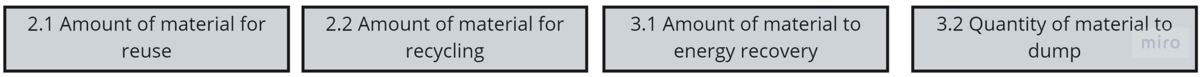


Figure 2.9: CMM method - indicator 2 and 3 (Own figure) derived from CB23 [2020a])

2.4.2.c Protecting environment, indicator 4

Indicator number 4 is the already mentioned MKI-score or climate impact (pillar 2). It uses several sub-indicators, which in total form the score on this indicator. These sub-indicators are shown in Figure 2.10.

This indicator is not further elaborated in this research, as there is no research gap identified regarding this indicator and the level of detail within the different themes mentioned are out of scope. Therefore, the different sub-indicators will be considered as one in this research, being indicator 4.

4.1	4.7	4.14
Climate change – overall	Eutrophication - freshwater	Emission of particulate matter
4.2	4.8	4.15
Climate change – fossil	Eutrophication - seawater	Ionising radiation
4.3	4.9	4.16
Climate change – biogenic	Over-fertilisation - soil	Ecotoxicity (freshwater)
4.4	4.10	4.17
Climate change – use of land and changes in use of land	Occurrence of smog	Human toxicity, carcinogenic
4.5	4.12	4.18
Ozone depletion	Depletion of abiotic materials – fossil energy carriers	Human toxicity, noncarcinogenic
4.6	4.13	4.19
Acidification	Use of water	Impact/Soil quality related to the use of land

Figure 2.10: CMM - indicator 4 (Own figure) derived from CB23 [2020a])

2.4.2.d *Protecting or creating value, indicator 5 - 7*

The value of the object, pillar three is assessed as well, showed in Figure 2.11. Circularity can improve the value of a certain element, by improving it's functionality possibilities thus increasing technical and economical value. Technical value can contribute to the implementation possibilities in a second life cycle, while economical value can contribute to a viable business case.

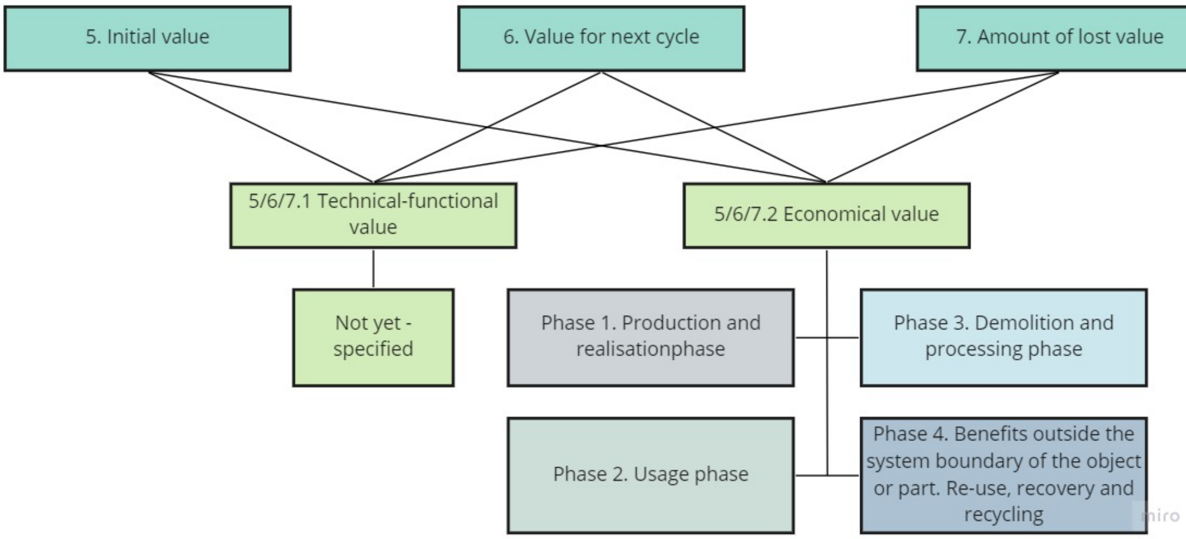


Figure 2.11: CMM - indicator 5 till 7 (Own figure) derived from CB23 [2020a])

2.5 BARRIERS FOR THE CIRCULAR CONSTRUCTION SECTOR

Circular initiatives are going on for a few years. By now, hick-ups and potential barriers in various areas are being experienced by different parties involved. Research towards barriers to the implementation of the circular economy worldwide has been done by Kirchherr et al. [2018] and de Jesus and Mendonça [2018], which reviewed n=114 and respectively n=141 literature findings towards the circular economy. Independent from these results, Rotmans [2021] evaluated that despite all the effort that has been done, no significant changes can be noted in emissions or used materials in relation to the goals of the Dutch government.

In order to gain insight into the barriers for the Dutch construction market, various articles have been read and will be analysed in the following sections. Thereafter, the results will be compared to provide insight into whether the general bottlenecks of a CE overlap with specific bottlenecks from the construction industry, and which elements differ. A visual result of this analysis is being shown in Figure 2.12.

2.5.1 Regulatory

Amongst De Leeuw [2020a] PIANOo [2019a] and others, it is mentioned that a lack of circular selection criteria (such as TCO) are hindering market parties in their need to innovate. If they do so, their investments are not valued accordingly. These investments themselves are relatively high which makes it even more unattractive to do the transition yourself [Vos, 2018]. If a market party does decide to invest in circularity, it requires more guidance. As this thesis has shown so far, defining circularity is a troubling issue. Valuable circular examples are therefore lacking as well which deters stragglers both at the market and client-side [Koops, 2020]. Practical guidance through design standards is highly desired [Jongeneel, 2020] and multiple parties demand more input from the government [De Leeuw, 2020b]. The fact that multiple organisations are publishing about the subject (even multiple ministries) without a clear 'leader' is confusing as well [De Vries et al., 2018].

2.5.2 Technological

In the technological aspect, it is mentioned as well that clear standards are missing to design and quantify circularity [Vos, 2018]. This has as a result that guarantees are difficult to specify. Clear rules for guarantees and certificates hinder the re-use of materials as well [De Vries et al., 2018]. Knowledge sharing lacks as well, available knowledge is not shared efficiently [Castelein, 2018] which might call for another way of collaborating.

Available design standards such as the MKI do work well in practice. However, databases (such as the NMB) that exist for these tools are not obliged and therefore a lot of data is not available [Oostdijk et al., 2019] which hinders the circular progress. In 2020, some improvements are possible since the publication of the 'Leidraad'. This document is highly appreciated by the market [PIANOo, 2019b] and has been mentioned earlier in this thesis.

2.5.3 Micro - Market

The building industry is doing well since the crisis of 2008. Generating revenue is not a problem and therefore the financial need for innovation or changing building methods is absent [De Leeuw, 2020a] [Vos, 2018]. On top of that, the culture of experimenting is not embedded in the construction industry. Involved stakeholders would not bet their money on experiments [Oostdijk et al., 2019] [De Vries et al., 2018]. On the other side, clients have a lot of projects to develop and are risk-averse. especially smaller clients who do not want to be early adopters and would rather wait and see which developments and examples work best in practise [Koops, 2020]. The underlying reason for this might be that circular building is labour intensive. Labour costs are highly taxed, while re-used materials are taxed as well while there are no real financial disadvantages to new raw materials. On the contrary, those materials are relatively cheap [De Vries et al., 2018]. According to Emmelot [2021] this is because the omission of external costs (social, environmental) are not included in the raw material price. In the way to a different approach, the biggest obstacles are laws and rules. Projects always span a (very) limited timeframe. Market parties must have sufficient time to earn what they use to pre-finance their innovation. Many processes are too short to be able to apply the innovation and earn back while we all want to go that way. At last, there is the problem that the offer of secondary materials is expected to be way lower than the demand for materials [Hanemaaijer et al., 2021]. [De Vries et al., 2018] [Rotmans, 2021]

2.5.4 Legal

Some legal problems can be seen upfront as well, even though legal problems tend to show up during or at the end of the realisation of a project. An example can be found in the section on water management, in which the waterboards already wrote advice on how to overcome these problems *" Adviesrapport Taskforce herijking afvalstoffen"*. Two of the most mentioned laws which quite be a problem, especially for modular building, is the fact that Dutch property law makes a distinction between movables and immovables (Book 3, Article 3 Dutch Civil Code) [Ploeger et al., 2017]. The same can be encountered in (Book 3, Article 5 Dutch Civil Code) [Van de Vondervoort, 2019]. On top of that. environmental permits are not designed for possible displacements of objects [Burger et al., 2020] [Castelein, 2018]. Practical laws such as the Building Decree are designed to guarantee safety by law but therefore might hinder innovative products of services from entering the market [Jongeneel, 2020]. For example, the Building Decree provided only guidelines to calculate with cement. organisations have to use the crisis and recovery law in order to achieve this, but obviously, this is not the way to go.

2.5.5 Macro - Market

The above-written problems are all about implementing circularity in a linear system, which is a system that uses primary material and production waste, showed in Figure 1.1, with accompanying standards, certificates etc. Organizations, construction projects, methods and contracts today have this as a starting point [Castelein, 2018]. Voices raise that circular working requires a different approach, with different perspectives on for example ownership. This system perspective has been addressed earlier in Section 2.2.2. Changes could be for example a change from ownership to leasing [Ploeger et al., 2017] [Castelein, 2018]. Ownership creates certain demands for risk division and financial obligations [De Leeuw, 2020a] [De Vries et al., 2018]. Product as a service is frequently named as well. Rotmans [2021] claims that one should get rid of the traditional client contractor relationship - some sort of service relationship is required to speed things up and accompanying risk division and business models.

The outcomes of the previous 5 sections are summarised in Figure 2.12.

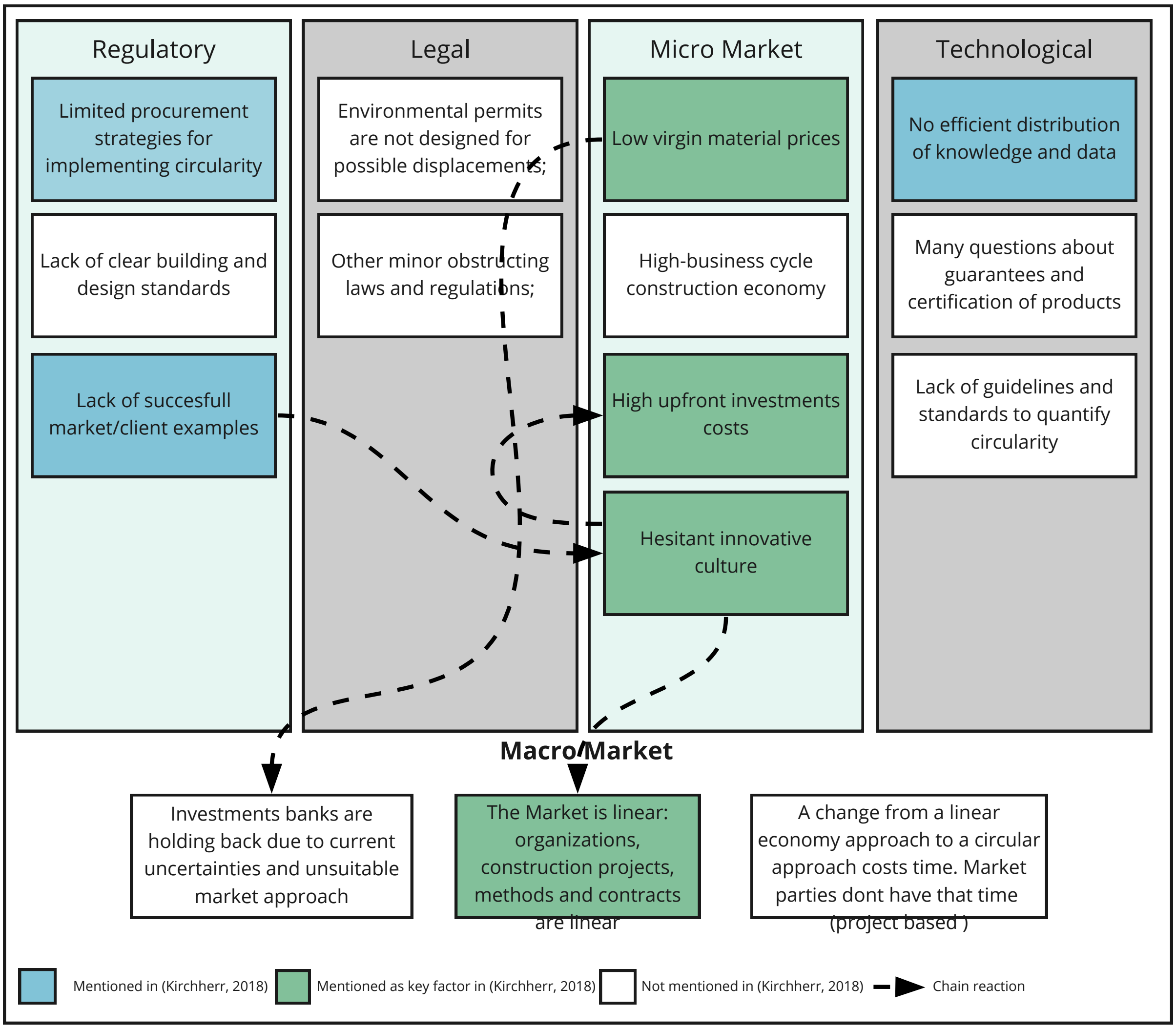


Figure 2.12: Bottlenecks from literature compared with desk research (own image)

2.6 LEARNED LESSONS AND CONCLUSIONS FROM SQ1

This chapter elaborated on the problems of this earth and how circularity can be used as a solution to this. Section 2.1 mentioned five sectors in which the Dutch government would like to work with circularity, of which the construction industry plays a significant role. It is mentioned that certainly by 2050, the construction sector will be developing more than demolishing, so material input will be needed in the coming decades. This already concludes that closing the circle is not achievable, however, it even more challenges the market to achieve the targets op 2030 by focusing on eliminating waste and optimise material input for circularity by focusing on multi-purpose design.

Section 2.2 described the subject of circularity and the issue of being used frequently in policy documents and literature, leaving no one with the authority to define what circularity exactly is. The section described the developments of defining circularity and showed that it first has been defined by the R-frameworks, but a gradual change can be observed towards a more systematic approach. This change can be observed in literature as well and it is argued to use the system perspective for this research. This means that circularity should not be the goal, and is not restricted to material streams only.

Section 2.3 described the requirements and need for measuring circularity and argues that an LCA should be used. On top of that, this framework should adopt a systems perspective to ensure a correct definition of circularity. Moreover, it explains the difference between intrinsic and relational elements and argues this should be part of such a method.

Section 2.4 reviews the current frameworks of circularity that exists and argues that the CMM method of CB23 immediately stands out. The CMM is further introduced in this chapter. It builds upon the MKI, extending this LCA with other concepts besides material streams, thus defining circularity in a systematic view. The CMM includes the pillar of 'protecting material streams' and 'keeping and creating value' on top of the current environmental MKI approach.

Because the CMM is developed by the Dutch construction industry, it builds upon the successful MKI and defines circularity with a systematic approach, this study will use the CMM as a base for further study in order to transfer the concept of circularity to reality.

Barriers regarding implementing circularity have various underlying reasons which are mentioned in Section 2.5. This section compared key literature towards the barriers of a circular economy with the literature of the construction industry, to provide an overview of barriers and accompanying typology. The key factors in these are identified as low virgin material prices, high investment costs and a hesitant innovative culture. Especially the first two can be attributed to the fact that our (construction) economy still is linear based and project-based. Moreover, the absence of a clear leader or definition of circularity is recognised as well.

3 WATER BOARDS AS PUBLIC CLIENT

This chapter provides an answer to the second sub-question of this research, which has been formulated as:

- What are current innovation enablers and bottlenecks within the Dutch water boards with respect to the implementation of circularity?

Note: the answer to this question is limited to the scope of the research, as a complete answer would be too extensive, take too much time and have little added value. Section 3.1 introduces the water boards as an organisation and their core task. The section address the role of the water board as a public client, and their motivations to use circularity. Section 3.2 dives more deeply into the water boards and their recent developments, internal policies directed at innovations or circularity. Moreover, it uses interview data to expend these developments, and uses this data in Section 3.3 to address specific barriers for the water boards which might hinder the correct use of circularity.

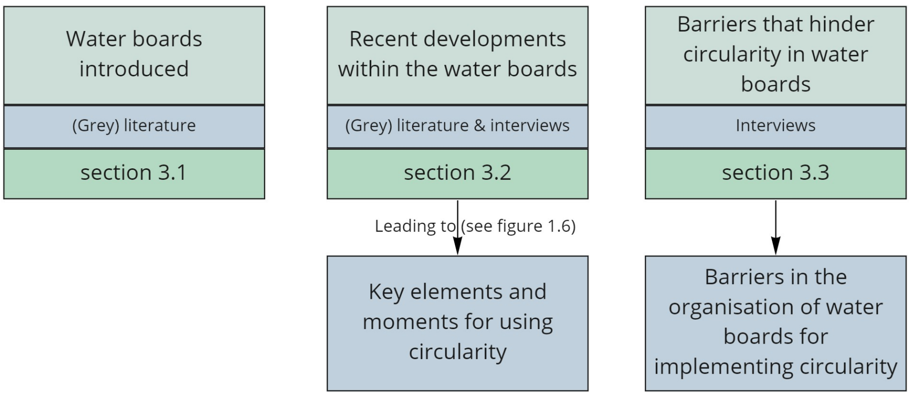


Figure 3.1: Chapter overview

3.1 INTRODUCTION

The 21 waterboards in The Netherlands are a public body within a particular region in the Netherlands, and have the task of regulating water management. The term water board is also used to indicate the region over which that body has control. The 21 different regions are depicted in Figure 3.2.

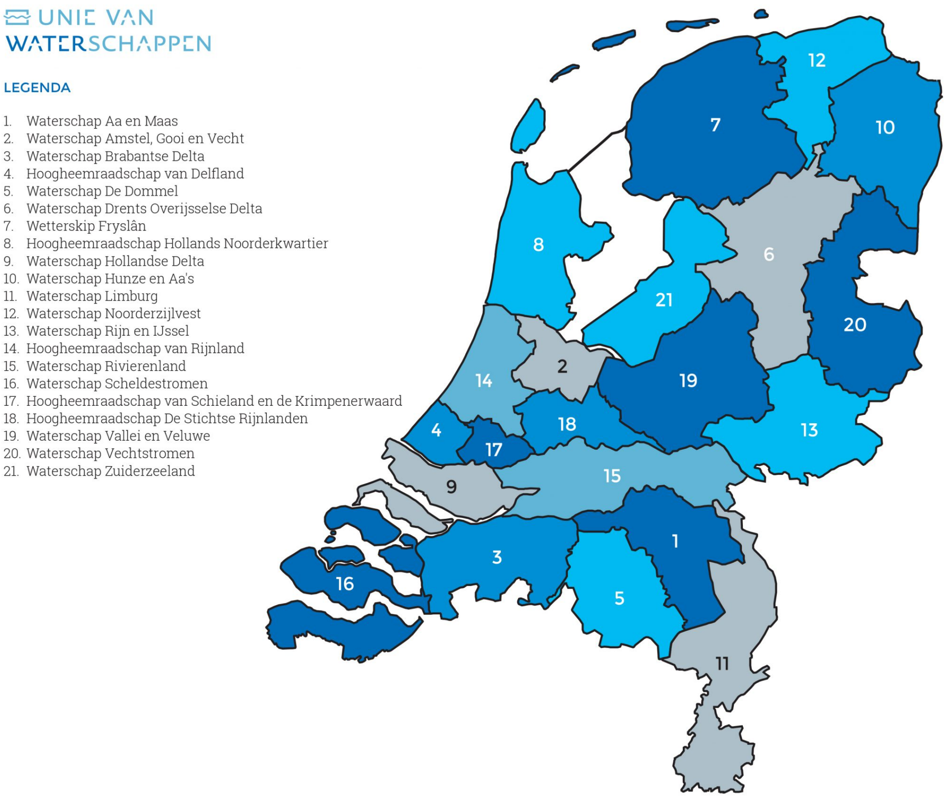


Figure 3.2: Waterboards in The Netherlands
[UVW, 2021]

Holland is known for its well-regulated water management and its waterworks designed and implemented. The objects, such as several huge flood defences are not only impressive to look at, but they also ensure the safety of almost 10 million people who are living below sea level. Besides safety, water boards are responsible for dry feet, clean drink water and water management. In order to reach these goals, they manage different assets, for example, dikes, waterways, pumping stations and sewage treatment plans.

The water boards have a large variety of assets. The 21 water boards ensure dry feet, clean water and sufficient water. To this end, they manage approximately 18,000 km of dikes, 225,000 km of waterways, 6175 pumping stations and 325 sewage treatment plants, on which 2 billion m3 of wastewater is treated annually. 5 water boards also manage roads. Together they manage some 6,600 km of roads [UVW, 2021].

The waterboards in The Netherlands have had quite some changes in the last few years [UVW, 2021]. Back in 1950, there were 2600 of them which since then are combined. The 21 boards that exist today are united in an overarching organization, the Unie van Waterschappen, which provides advice on policies and implementation plans.

The water boards are a unique form of a public body in the World. The boards are represented by a general board and a daily board, of which the general board is elected for four years through water board elections. This seems like a normal procedure, however in recent years a lot of discussions have been going on about the future of these waterboards and whether they should be removed/replaced or not, which doesn't influence policymaking positively. Activities of the water boards are not being paid by national tax funds. Instead, water boards levy tax, which they use to finance their tasks almost entirely. This means that the water boards differ greatly from provinces and municipalities, which have a general task and are largely dependent on the national government for their income. With a purchasing volume of approximately € 3 billion per year [UVW, 2021], water boards are playing an increasingly important role as a client and launching customer within different themes. Therefore they can have a considerable impact on sustainability issues and stimulating a more environmentally friendly construction industry, in order to counteract climate change.

Moreover, the Waterboards are internally driven to counteract climate change as their main assets are closely related to nature. Nowadays, they experience the results of climate change in their portfolio. The people involved within the water boards are likely motivated to accept the circular transition since circularity strives to counteract climate change. The boards themselves have as a core task to protect nature and ensure harmony between people and nature, a task which is becoming more difficult and important at the same time, through climate change.

3.2 DEVELOPMENTS WITHIN THE WATERBOARDS

In order to get insight into the recent developments of the boards, desk research has been done on existing grey literature of the boards. However, the available literature is limited, therefore interviews have been conducted with actors within or working with the boards, to present a complete overview of recent developments which have happened in the water boards. The circumstances of these developments are analysed, in order to understand what is needed are to implement circularity.

3.2.1 Literature review on Developments

From the beginning of the 21st century, the collaboration between the water boards and market parties can be described as one of fear [UVW, 2016a]. This culture has been identified and actively opposed by both parties. It has resulted in various plans in which the desired way of being a public client and collaborating with the market parties are described, in policies such as the 'De waterschappen als publieke opdrachtgever'. Developments since then could be monitored and evaluated. This resulted in an extensive report in 2016 in which conclusions about the two topics are described and recommendations are done [Groot and Visser, 2016].

Although a circular economy has been identified as a possibility for somewhere in the future, no real direction can be observed. Sustainability and related innovations however have been evaluated. Four key success factors are mentioned [Groot and Visser, 2016]:

1. Major programs such as the Flood Protection Program (HWBP) have been a strong catalyst for innovation. However, the use of this programs still is limited across the water boards projects. Within these overarching programs, certain best practices can be observed. For example within the HWBP, there was a certain department called: 'POV' (Project overstijgende verkenningen). Through this POV, a fixed process for the innovations is set up every year, and money is available for the discovered innovations. Evaluation and knowledge sharing were an important pillar of these programs, to enable project overarching learning processes.

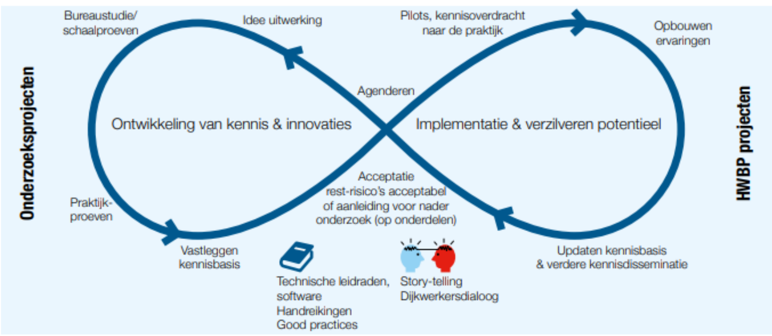


Figure 3.3: Evaluation process within HWBP

A more recent example is a project procured by a water board to revise multiple bridges [De Saar, 2021], which focused on learning on the job, in which every new bridge project can improve by the learned lessons from the previously realised bridges;

2. Innovations or developments are mainly focused on initiation design and realisation of a project. Asset management and maintenance are much less connected to the new ideas, while projects still are considered linear since the production of waste is not described as unwanted. The market vision is therefore not yet having the desired impact in all directions;

3. Steering the market is being done by MEAT (Most Economically Advantageous Tender) criteria. However, MEAT has not been applied on a bigger scale yet and just on certain small projects. Therefore, price is something that still players a major role in tenders;

4. LCA's are being initiated but not a standard process. However, Struker et al. [2020] mentioned MKI (LCA) as a successfully implemented steering method. LCA's can be part of a systematic approach, as they are coupling multiple phases of an asset, such as the realisation phase and maintenance.

As this document dates from 2016, items on this list might be outdated. More recent reports are in development but not yet published.

The current diversity between the circular approaches and dealing with knowledge sharing of the water boards still is quite high. This can be observed from different initiatives are going on which use different core methods of circularity. Some use the R-framework [Struker et al., 2020], and system perspective is in projects as well [De Saar, 2021]. In Chapter 2, it is explained that a correct way of implementing circularity is by the use of a systematic approach. A systematic approach includes learning beyond projects. Knowledge sharing is important in general, not only between clients and contractors. The overarching programs of the water boards such as the HWBP seems to be a sufficient base for such processes and thus could kick-start implementing circularity.

Moreover, knowledge sharing processes are initiated by the UVW, which tries to offer a platform for knowledge sharing. The UVW could also help by offering a clear strategy upon which the water boards could rely. During this research, the Unie van Waterschappen reflected on the report from PBL [Hanemaaijer et al., 2021]. From the abbreviations mentioned, the UVW want to improve on [UVW, 2021]:

- Further stimulate collaboration between market parties;
- Further improve knowledge sharing of the circular economy between different boards.

At this point, a great opportunity arises for the use of overarching programs to achieve these goals, thus contributing to the implementation of circularity. Beyond the UVW, water boards can also take part in Buyer Groups, which focus on specific innovations such as concrete in relation to procurement. Another opportunity arises in just collaboration with some other boards. In all three options, water boards should work together with the same definition of circularity and determining suitable ambitions for those programs. It is suggested that, the UVW, as an overarching organisation, is perfectly suited to take the lead within determining circular ambitions and discover which ambitions are suited for which materials, and be responsible for the evaluation part.

3.2.2 Interview Review of Developments

Literature towards developments within the water boards lack. Therefore, all interviewees have been asked about elements or processes, in order to understand what is needed are to implement circularity within the water boards and their assets.

Because of the reorganisation of the recent years, there is a knowledge shortage of the current assets of the water boards (interview 5). Monitoring of current assets does barely happen (interview 5 & 9). Therefore, asset management is not properly organised by the boards and the boards see future problems arising by for example material passports (interview 5). This can partly be explained because of the division of time and money between the internal departments (interview 4 & 5). Water boards have a project-based approach towards their assets. This comes forward in new projects having relatively high budgets (interview 4), while little money is available for maintenance which sometimes results in a replacement decision while maintenance is very well possible (interview 4). Moreover, project design specifications are framed to come up with solutions with a long lifespan even in integrated contracts, with as little maintenance as possible (interview 4 & 5). The aim is to reduce maintenance and therefore uncertainty in exploitation as much as possible (interview 4 & 5).

People matters. The people working in the water boards are likely to have a connection with the system of the water boards, as at a certain point they chose to work at the water boards because they wanted to stay in touch with nature (interview 6, 7, 8 & 9). As climate change influences this system, the water boards might be internally motivated (interview 6, 7, 8 & 9). However, within the water boards, different levels have different tasks, which causes the levels to have different interests and ambitions towards circularity. Some levels may want to take more risks in new ways of working, while others may be more risks adverse (interview 4, 5 & 6).

The different ambitions of the levels are caused by the prior tasks of the internal levels. The advisory boards are dealing with long term ambitions and barely have to deal with the main tasks of the water boards today (interview 4, 5 & 6). The project management teams are busy with implementing these ideas into new realisation objects and try to implement the ambitions in their project initiation and see the results back in a timespan of 3 years. However, the asset management department see the influence of their decisions immediately and therefore have serious issues if something turns out wrong (interview 4, 5 & 6). This internal situation may work as a boomerang and result in self-censorship (interview 7), which may block internal initiatives. Successful implementation of innovative ideas closely seems to be correlated with the attention a certain project has had in contract management, by for example an own IPM team (interview 6). Moreover, the success of a clear strategy such as the HWBP is acknowledged (interview 4, 6)

The UVW helps the water boards on a strategic level. However, the UVW and the water boards acknowledge a real clear strategy or overarching program for circularity such as the HWBP is missing (interview 4, 6 & 7). The water boards experience circularity as an ambition of their own organisation and therefore something they need to deal with their own organisation. Knowledge sharing does happen but is the first thing being wiped from the agenda (interview 4 & 5). The UVW try to stimulate knowledge sharing between the boards but see that the subject is becoming way to complex to discuss just a few times a year (interview 6). Moreover, there is a need for more extensive knowledge sharing, as contractors argue the water boards do not use the existing knowledge to the full potential (interview 8 & 9). Also, finding the right people within a water board who can contribute to the transition still is a challenge and is caused by the lack of prioritisation circularity has within the boards (interview 7). This is key, as this most likely will result in a successful implementation but is a big pitfall which has been observed before (interview 4).

Water boards are internally divided about whether 50% circularity is the best possible agreement, but all departments agree on setting hard demands on certain ambitions instead of process agreements. Hard quantifiable agreements make people aware that something is getting real (interview 6).

3.2.3 Analysis of literature and interview data

Implementing circularity means that a shift is required from the current project-based approach to a systematic approach for the water boards, whereas circular strategies on LCA phases such as asset management and realisation are combined. These two phases of an object therefore both are key moments for water boards to implement circularity. The literature review shows that the use of LCA offers possibilities in terms of combining strategies in a systematic approach for the water boards, but is not being used frequently. This will enable innovations to be applied in asset management too. Circular strategies in a systematic approach therefore need to be derived from overarching programs, which focus on systematic goals such as resource depletion, not restricted to realisation only. However, such an overarching program for circularity does not exist, the most recent strategy still considered project-based projects [UVW, 2016b]. It is therefore advised to create overarching programs like the HWBP for all the water boards to implement circularity.

From the interview review, it can be observed that the recent reorganisations of water boards mentioned in the literature still causes problems. For example, a lot of up-to-date information is missing about the current state of the objects. The state of the objects also varies a lot. Asset management is not properly organised. It can be observed as well that when it comes to innovation success, innovations in new projects are way more likely to be a success than implementing innovations in a maintenance phase, thus showing the water boards still are project-based. Interview data shows that actors acknowledge the need for a better asset management system, which will very likely be needed for circular strategies.

Moreover, the differences in time and money between the realisation department and the asset management still is possible due to the current focus of projects specifications. From the interviews, it can be observed that objects are designed for a long life span with as little maintenance as possible. However, due to the ambitions of the strategy and advisory departments, the possible circular approaches are expected to conflict with this, as circularity sometimes require more attention from the asset management department, which does not have the time and money to do so in combination with their main tasks. This makes the asset management department unwilling to adopt some circular strategies. This fear can be removed as well by overarching programs in which knowledge sharing happens more frequently.

3.3 BARRIERS FOR CIRCULARITY IN WATER BOARDS

The results of Section 2.5 provided an overview of barriers mentioned in the literature of current circular initiatives. These results were addressed in the interviews, to gain insight into whether this scheme was complete and correct. With these results, water boards have insight into which barriers need to be tackled in determining circular approaches, for example procurement and contracting tools. The people interviewed are showed in Figure 1.4 and the used interview protocol is shown in Appendix B.

3.3.1 Regulatory

Regulatory wise, contractors criticize the way contracts are used by the clients. The obstacle for circularity is not in the procedures themselves but in the way the water boards implement them (Interview 8 & 9). For example, there is no clear prospect of what is in the coming questions for the contractors (Interview 8 & 9). Remarkable is that (Interview 6) at first blamed the procedures, but gradually realised that a lot is possible and mentioned that other factors hinder the correct use of these procedures for the implementation of circularity. Material suppliers have possibilities to replace primary raw materials but are hindered by law and building standards and business models (Interview 1 & 2). This comes for example forward in the way specifications are drawn (Interview 6). Traditional specifications are demanded, and because of that traditional design standards should be met (Interview 6, 8 & 9). Different interviewees acknowledge the lack of successful examples (Interview 1 & 4).

Therefore, it can be concluded that current procurement tools do fulfil the needs of today's market. Clients should use them correctly, which can be explained as more systematic, where the same ambitions and thus prospects are applied within multiple procurement procedures. More example projects are likely to change the current fear and might contribute to future developments for building and design standards. However, the current way in which standards are drawn may disappear, and new forms will occur, for example, performance standards. Water boards must be open to this.

3.3.2 Legal

Some small legal issues are expected by the clients when using circularity (Interview 6), other interviews indicated that they did not see this as a problem. Therefore, no clear expectations or conclusions about changes in the legal aspect can be drawn based on the data obtained.

3.3.3 Micro Market

Micro market-wise, low virgin material prices are a problem, together with a high tax on labour and low tax on products (Interview 8). Moreover, all material suppliers describe the lack of availability of second-hand materials as the main reason for not being able to build everything circular by now, and they doubt whether this is possible in the future (Interview 1, 2 & 3). Some renewable material flows are not big enough to immediately support the transition of primary to secondary material use with respect to a positive business case (Interview 1 & 3). A hesitant innovative culture within the water boards is experienced as well, because of for e.g. performance demands and shortage of budget and time (Interview 4 & 5). This leads to hesitation for new investments. However, contractors mention they need to invest anyway and it is up to the internal motivation of the buyer if those investments contribute to the circular economy (Interview 8 & 9). .

Moreover, the water boards are not very enthusiastic about replacing the legal ownership of their assets and circular strategies which incorporate that (Interview 5 & 6). It is considered as moving their main task to the market (Interview 5 & 6). Moreover, recent events in history resulted in the desire to have full power over the instruments in order to provide water quality and safety (Interview 4). However, possibilities for strategies for a specific product are considered as an option (Interview 4 & 6).

Within the water boards there is a lot of attention for the realisation phase, rather than for the asset management, avoiding high maintenance activities or spendings. The interview data of Section 3.2.2 showed this extensively. Circular strategies have the need to adjust things during the life cycle of an object, which increases the need for labour and money. This is a problem, as new projects have relatively high budgets (Interview 4), while little money is available for maintenance which sometimes results in a replacement decision while maintenance is very well possible (Interview 4).

It is expected that the focus of taxes might change in the future to support a change of focus from the realisation phase to asset management strategies (interview 8). Moreover, as the transition continues, a new market within secondary materials is expected. There may also be skewed growth in the life of various parts within an asset. The water boards should adjust their asset management plan accordingly, in order to prevent that a part needs to be removed because another part is out of its lifespan.

3.3.4 Technological

Technological wise, the expectations around digital twins, material passports and information distributions are high (Interview 5, 6, 8 & 9). However, water boards are mainly acting on their own (Interview 4 & 6) with just little shared guidance (Interview 7). Moreover, the expectation is that monitoring will play an important role in the specifications of products (Interview 1, 6 & 8). However, this is option is barely used (Interview 1 & 8). Construction techniques are not going to be the problem (Interview 4 & 6), it is more about the ownership of the risk and responsibilities (Interview 4 & 6).

Therefore, it can be concluded no problems are expected when it comes to building techniques. However, the question is who is going to be the risk owner of an object, in which still a lot is uncertain and the expectation is that companies are more cautious about this. Moreover, as well as concerning other topics, it is expected that monitoring will be more important in the future, in order to successfully manage the ambitions and interventions. The data obtained from this monitoring will then also provide a possible solution to the guarantee and certification issues, as through for example performance certificates insight can be provided into a certain material.

3.3.5 Organisational

A new barrier introduced through the interviews is the aspect of organisational challenges. Although the barrier hesitant innovative culture is identified under the label micro-market and can be assigned to the organisational bar, interviewees thought that the organisational challenge is the biggest challenge of all (Interview 6, 7, 8 & 9). Convincing all people to the importance of circularity, and to make circular choices every day, will be hard (Interview 6, 7, 8 & 9). Therefore, a new organisational bar is added to the overview of barriers. Eventually, it are the people that decide which decide on ambitions, policies, budget and people etc. The attention to the organisational element will have to result in a better evaluation and learning processes, to enable circular strategies (interview 8).

In Figure 3.4 the results of this analysis are shown. This figure is a validated form of Figure 2.12, which came forward out of the literature.

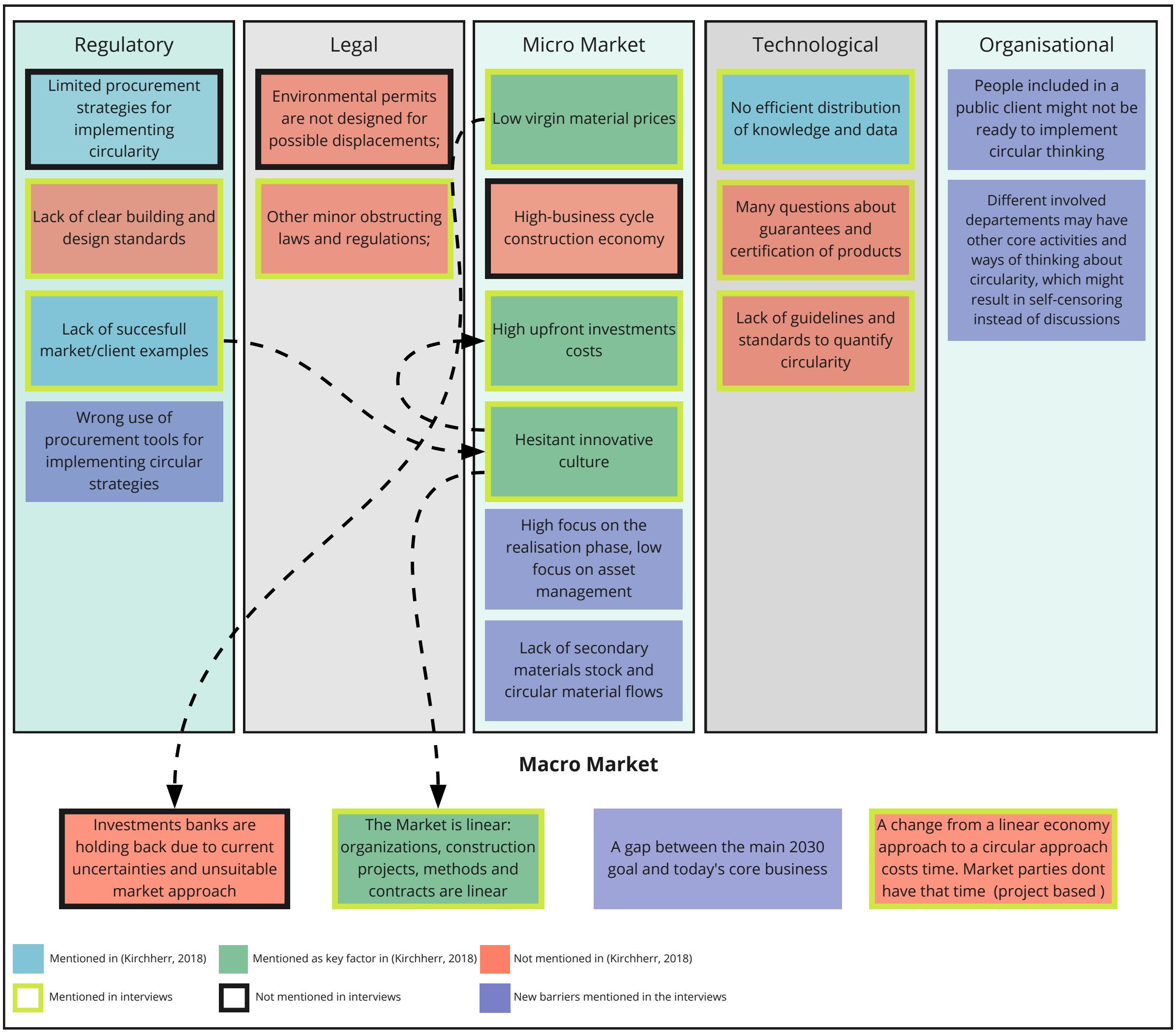


Figure 3.4: Barriers for implementing circularity (own figure) - validated overview after interviews of Figure 2.12

3.4 LEARNED LESSONS AND CONCLUSIONS FROM SQ2

The water boards are decentral organised. Section 3.1 showed that changes have happened quite a lot in this area by decreasing the number of boards in the last few years. Circularity relates closely to the core task of the water boards. Therefore, internal people are likely to be motivated, since the water boards are pre-eminently the organization that experience the effects of climate change directly in their daily work.

However, the history of the water boards causes them to differ quite a lot in asset management levels, the status of assets etc. Nowadays, water boards differ to those topics between themselves, but within a single water board, these topics differ as well. Section 3.2 shows that despite the existence of the overarching UVW, the waterboards experience the transition as something which mainly plays a role in their organisation. Moreover, the internal organisation of the water boards have different interests and different definitions of circularity. This results in having different ideas about circularity in the organisation and how to implement this. The analysis in Section 3.2 emphasizes the need for a good implementation plan / overarching program. It shows that an overarching program such as the HWBP can be beneficial. Such a program has several advantages, such as an overarching ambition, possibilities to focus more on asset management, as was shown by the example of POV, thus enabling knowledge sharing, which is key in a systematic approach. Such a program is necessary because the water boards consist of separate departments, all with their own interests. The current lack of joint goals results in different ambitions and visions of circularity in a project.

Besides the circular implementation of the water boards altogether, Section 3.2 has shown that innovative ideas in water boards mostly occur in new realisation objects. However, in this way innovations are only possible in a project-based approach. This research already argued that circularity should be implemented of the whole life cycle and therefore barriers need to be removed in order to use it in asset management. An LCA approach and according methods suit this. Asset management is important since most of the assets already exist and still have opportunities to use circularity, because circular strategies can have some serious challenges for asset management. From the interviews, it can be concluded that the asset management department requires more attention when it comes to these innovative circular ideas. Improving the maturity of the asset management department might result in a positive attitude of the asset management team towards changes in the design culture of the water boards, for example designing with materials with a shorter lifespan or a higher frequency of maintenance. Realisation and maintenance within asset management, thus the overarching phases in an LCA are therefore moments to implement circularity.

At last, this chapter presented a validation of the barriers in of Chapter 2 in Section 3.3. The section reviewed the barriers of literature by presenting which barriers are identified by the interviews and added new undiscovered barriers. The point that current tendering forms would not suffice was disputed. Moreover, it confirmed certain measures named by the literature and interviews, such as reducing taxes on labour, to enable or accelerate certain cultural changes within the water boards. Most importantly, the typology of organisational elements within a water board is addressed as barrier, wherein the literature this typology has not been identified.

4 THE MATERIAL CHAIN AND ITS ACTORS

This chapter provides an answer to the third sub-question of this research, which has been formulated as:

- How do the chains of concrete and steel as a building material look like, which (type of) actors are present within that chain and what do they need to implement circularity?

This chapter focuses on the current chain of materials used within the construction sector in the Netherlands. Section 4.1 dives deeply into the concrete industry. Section 4.2 does the same for steel. The chosen assessment method CMM, which states circularity is something one can use to overcome one or more problems, will be used to evaluate both chains by assessing their needs for:

- Protecting material streams;
- Protecting environment;
- Protecting or creating value.

. Thereafter, Section 4.3 addresses the market of materials and shows the actors which are involved, showing their position and need changes due to the transition.

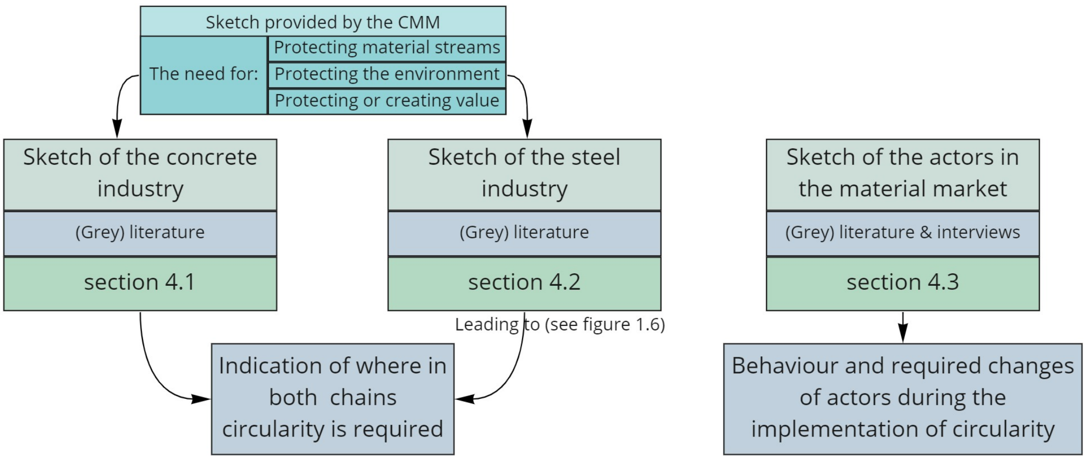


Figure 4.1: Chapter overview

4.1 THE CONCRETE INDUSTRY

In the past years, enormous studies have been done to the material chain of concrete. In Figure 4.2, an average chain for today's industry is outlined.

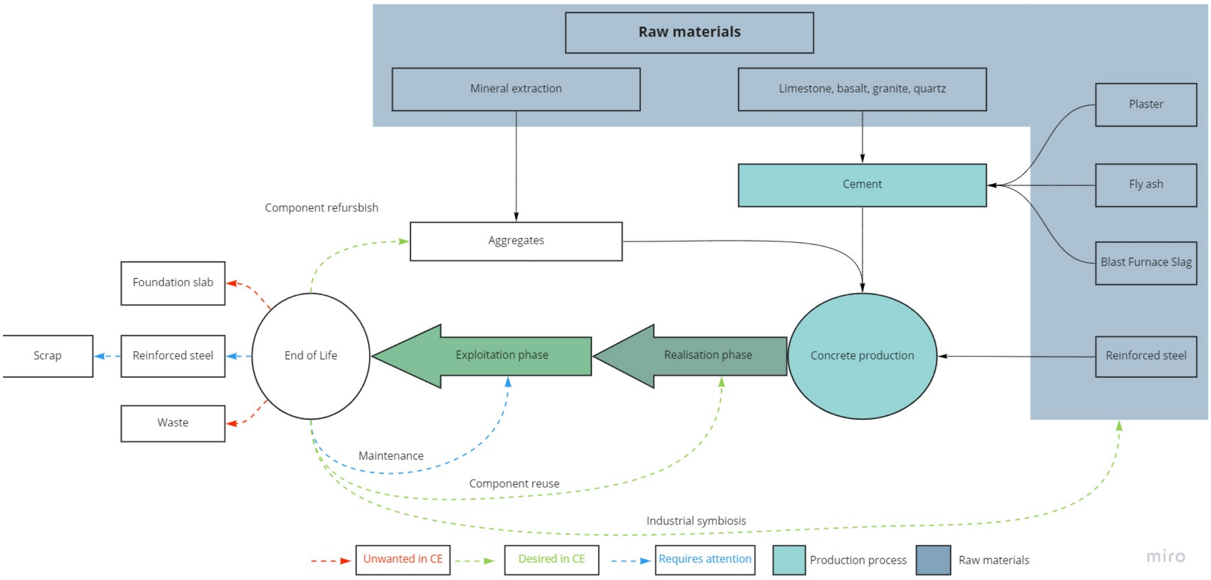


Figure 4.2: An average concrete chain in the Netherlands. (Own image, adapted from Wouters [2019])

4.1.1 Concrete composition

Concrete roughly consists of 2 types of substances; cement and aggregates.

4.1.1.A *Cement*

Cement is a binding component and reacts with water and hardens. The cement hardens equally well under and above water. Cement is made by burning limestone together and sand. Burning this mixture at high temperatures creates clinker. There are different cement types, designated CEM I to CEM V, with a smaller or higher content of Portland cement and blast furnace cement.

PROTECTING ENVIRONMENT The cement industry is viewed as a major shareholder in worldwide GHG emissions. Countless studies named numbers about the Co2 emissions, most often about 5% to 8% of all worlds emissions [Favier et al., 2018]. For GHG and other environmental indicators, Figure 4.3 shows that the clinker production process is the main contributor. Final production of cement and preparation of the materials do not have a significant impact on the environment compared to the production of clinker.

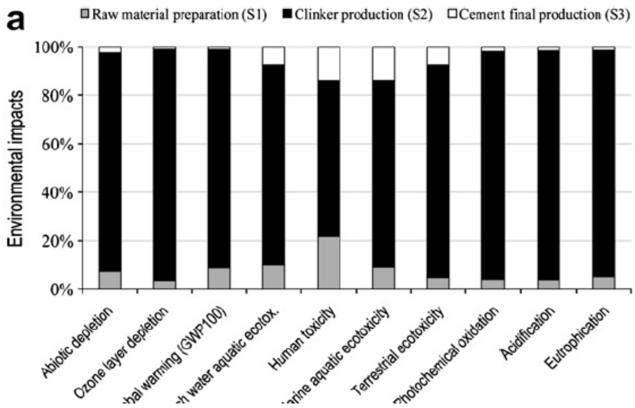


Figure 4.3: Environmental impact indicators
[Chen et al., 2010]

PROTECTING MATERIAL STREAMS As cement is not a unique product, it consists of various elements and is produced with different side materials. To judge whether or not all these materials are becoming scarce is out of scope, but from literature can be concluded that certain elements do actually harm the resources [Chen et al., 2010] [Miller, 2020].

PROTECTING OR CREATING VALUE Little or no attention is being paid to the value after a life cycle. Most of the concrete is being demolished into smaller parts and used as foundation layers for roads. However, this is downcycling and losing value, thus unwanted in a circular system.

4.1.1.b Aggregates

Aggregates consist of sand and gravel, but depending on the demands placed on the concrete and the availability of materials on-site, substances such as basalt, granite and rubble, slag are incorporated.

PROTECTING MATERIAL STREAMS Sand and grind are worldwide the most extracted raw materials. Although these materials look like they are widely available, the shortage of sand has already been foreseen and is subject of current debate [Bendixen et al., 2019]. Although almost 20% of the world's earth crust consists of sandy desert, sand is not inexhaustible. Not all sand can be used for construction purposes. Booming construction countries such as Qatar imported more than 6 million euro of sand [Gavriletea, 2017]. Sand can be found onshore and offshore. Onshore sources consist of sand deposits, rivers and floodplain alluvial deposits. According to Kowalska and Sobczyk [2014] the onshore deposits are located in environmentally valuable areas, such as mountains. Offshore deposits, potentially less harmful than onshore, is practice in more developed countries due to the cost of heavy equipment [Pereira, 2012]

PROTECTING ENVIRONMENT Besides the importance of resource protection, the mining industry for aggregates has major environmental consequences for the planet producing GHG [Gavriletea, 2017]. Within the damage to the environment, the construction industry in general attributes to this problem in multiple ways. Besides producing concrete, it is important to note that construction transport produces a significant amount of GHG in the material chain.

PROTECTING OR CREATING VALUE See the paragraph of cement.

4.1.2 Circular concrete

Within the concrete industry, the waste sources of concrete are maintenance and demolishing of different types of buildings, originating from different years and projects. This results in the concrete being of variable composition. The amount of concrete that is 'recycled' in the Dutch industry is about 95%.

However, 90% is downcycled to something like road slab and only 5% is of high-quality reuse. The amount of C&DW is expected to rise in the coming few years, as the construction works from the 50's is reaching its EoL status.

This provides the construction sector with various opportunities. The circular economy sees buildings EoL not as a demolishing project, but as a material bank. This development will be a continuous challenge to get the waste level or low-value re-use in the chain of materials to zero.

The needed changes in the concrete chain are visualised in Figure 4.2 by the colours green and blue. These material streams are desired and have to replace the red streams in the same figure. Waste should be avoided and whereas possible, primary input should be minimised. This circular concrete chain consists only of high-value reuse of materials. This is not only required to take steps towards declining raw material usage, but as the demand for raw material will someday reach an equivalent point of the secondary products, low-value reuse will result in waste again as the supply will be bigger than the demand.

4.2 THE STEEL INDUSTRY

Steel is an alloy consisting of iron, carbon and limestone. The steel industry is one of the biggest in the world. In 2017, worldwide 1700 million tons have been produced [Cramb and Amuda, 2017]. The industry is a highly competitive globalized industry in which actors are enormous. The industry relies heavily on international trade and manufacturing processes. This accounts for both raw materials as (semi) finished products. Almost 30% of the finished steel products have been transported after manufacturing [World steel association, 2018].

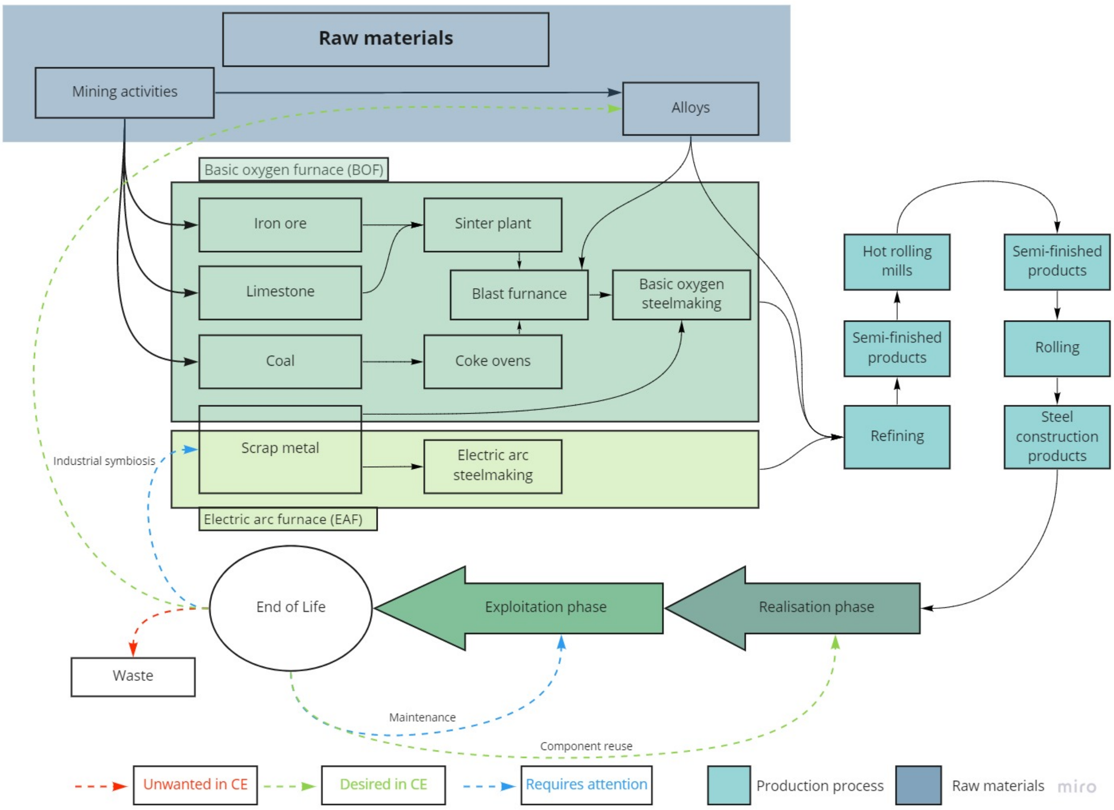


Figure 4.4: An average steel chain in the Netherlands (Own image)

4.2.1 Steel composition

In general, steel is composed of three main components; iron, carbon (coal) and alloys. The existing value of iron is kept relatively high compared to concrete. Steel always consists partly of recycled material. There are two types of production processes:

- BF process, the blast furnace process and basic oxygen steel process, where 20 to 30% scrap is mixed in.
- EAF process, the electric furnace process or electric steel process with almost 100%. Every steel product can be produced by this method.

On average 56% of all steel used in Europe is produced through EAF [Peschier, 2019] which can be considered as a high-quality reuse method. The challenge is to reuse steel without recycling since recycling still means energy input with possible Co2 emissions by production or transport.

4.2.1.a *Iron*

PROTECTING MATERIAL STREAMS With respect to iron, enough primary resources are available according to [World steel association, 2018]. With the growth of the worldwide economy and its inhabitants, it is expected that the BOF process will remain the primary production stream till 2050. The current supply of ferrous and scrap steel is not enough to fulfil the amounts of today's steel demands [Oda et al., 2013]. However, large quantities of scrap are not being used as input due to problems of separating and collecting small parts [van Maastrigt, 2019].

PROTECTING ENVIRONMENT The mining of iron has a relatively low impact on GHG in comparison with for example cement. Due to the widespread activities, however, it has a major contribution to worldwide GHG [IEA, 2020] with approximately 1.9 % - 5.1 % of worldwide GHG [Delevingne et al., 2020]. It must be noted that the transport which comes with the industry also seriously impacts the GHG of the iron.

PROTECTING OR CREATING VALUE Steel components cannot be degraded yet to a level in which the basic components can be regained. However, EAF processes can reform amounts of steel to complete new objects, even with enhanced stiffness capacities. However, sometimes new alloys need to be added.

4.2.1.b *Carbon*

PROTECTING MATERIAL STREAMS The raw material stock is just as iron enough for the coming years [World steel association, 2018]. In line with iron, it is expected that the primary raw material demand will grow [Oda et al., 2013].

PROTECTING ENVIRONMENT The production of carbon is highly polluting as are most of the mining activities. On top of that, the reaction of carbon with iron oxide produces GHG as well. Within this production, different research projects are ongoing to investigate the possibilities to replace carbon with hydrogen which would cause only water vapour. However, these technologies require about 5 times more energy.

PROTECTING OR CREATING VALUE See the paragraph of iron.

4.2.1.c *Alloys*

PROTECTING MATERIAL STREAMS Within the production of steel several smaller elements, known as alloys, can be added. These can be added in order to give the steel other capacities such as being stainless. As described before, the main components of steel are not very rare, however these extra materials are.

Figure 4.5: Expected stock of rare alloys processed in steel [van Maastrigt, 2019]

PROTECTING OR CREATING VALUE The prescribed recycle values do not apply to these materials which is a major problem. Used scrap in the EAF process is barely sorted for the applied alloys within it, so the renewal of these alloys out of the scrap is nearly impossible and therefore are lost [Björkman and Samuelsson, 2014]. This actually means that new alloys have to be added and therefore this is low-reuse. The global usage of these materials and the incapability's will eventually result in worldwide scarcity of these materials as depicted in Figure 4.5.

PROTECTING ENVIRONMENT Describing all specific alloys and their environmental pollution of CO2 is out of this scope, but generally it can be stated that the current production techniques of these alloys harm the environment as well [IPCC, 2016].

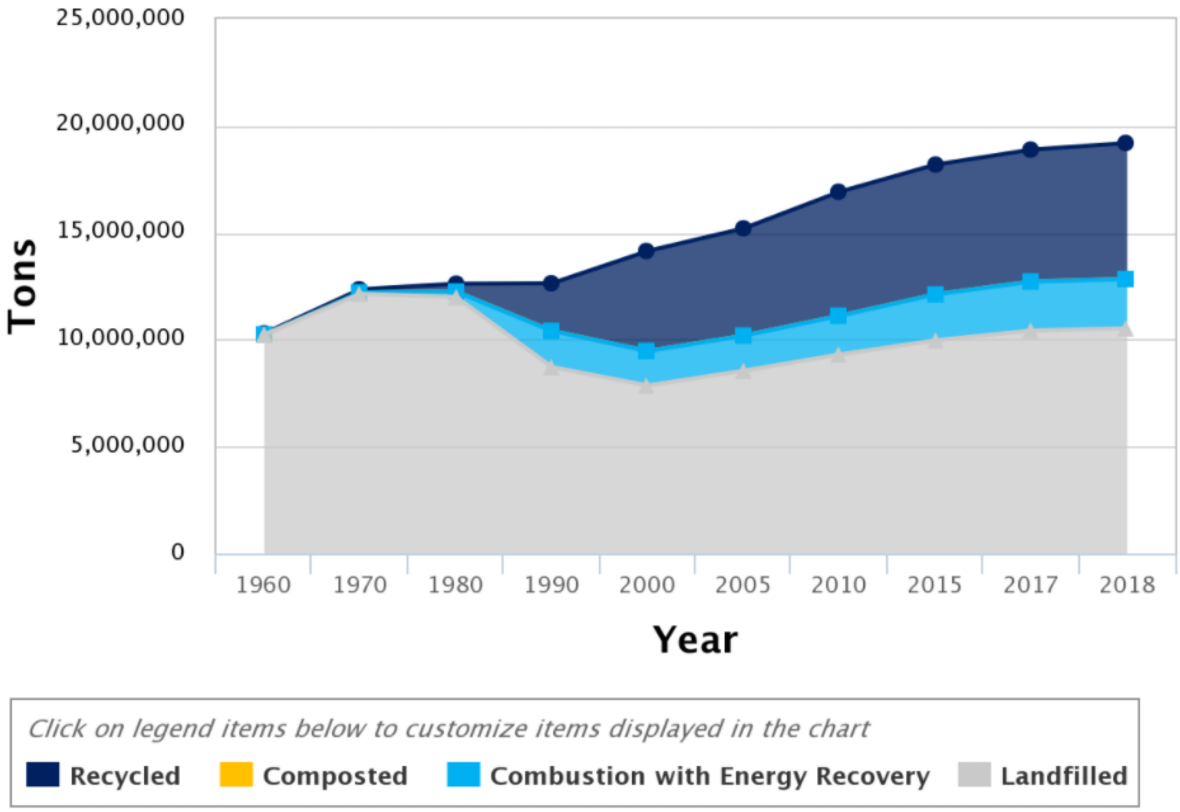


Figure 4.6: Ferrous Metals Waste Management
[EPA, 2021]

4.2.2 Circular steel

The needed changes in the steel chain are visualised in Figure 4.4 by the colours green and blue. These material streams are desired and have to replace the red streams in the same figure. Waste should be avoided and whereas possible, primary input should be minimised. It is important to note the difference between for example iron and alloys. As described, alloys have the need to be protected and resource depletion really is an issue. For iron however, resource depletion is less problematic, but the GHG of the primary production processes are a burden to this earth.

4.3 ACTORS IN THE MATERIAL MARKET

As described in the previous section, the chain of materials does contain a lot of processes that harm the goals of the CMM main pillars and therefore should be adjusted to make use of circularity. However, as the GHG produced by the sector are enormous in percentages, so is the industry itself. The industry is characterised by globalisation which makes huge changes almost impossible. Various interests of various stakeholders must be positively influenced in order to create incentives. Note: from this point, no distinguishing will be made between concrete and steel

An extended study of the current Dutch concrete chain, its actors and their responsibilities towards the transition has been carried out by Schraven et al. [2019]. In the next sections, this paper and its main findings will be treated as no other literature is available on this subject of matter. The actors identified by literature have been interviewed, in order to understand how these actors differ and what that means for the circular implementation of the water boards.

4.3.1 Actors typology

The paper claims that the actors within the Dutch concrete industry have had problems in addressing points of change for the industry. These representatives of the Dutch Stony materials supply chain (SMSC) have set up the fundamentals of the 'betonakkoord', a voluntary document that has been signed by a respective group of the industry. Different actors participate within the Dutch SMSC. This chain has different types of actors.

At first, demolishing companies demolish buildings when the construction is in its end of life period. These materials are up for sale. They try to sell their materials to recycling companies, but in the traditional market, it could happen that they pay for those materials instead of getting money for it in return. Currently, there is an incentive to do so, because landfill is prohibited and they can pass the costs to their client [Schraven et al., 2019]. The most favourable way is when the recycling companies are willing to pay for the materials, but they are only willing to do so if the complete composition and associated information of the material are available and the material has a certain degree of purity.

Secondly, the recycling companies sort and process the materials even further in order to sell them to traditional manufacturers. They are the buying party in this market and have a choice between primary products and secondary products. This means that primary aggregate producers operate in the same market as recycling companies. This fact may look like an unfair market since the steel and concrete manufacturers are enormous companies that have a lot of power within the market and see their business threatened by the recycling companies. The manufacturers can operate well in the linear market when it is about certificates and the purity of the materials they sell. At last, the traditional manufacturers produce materials and sell them to contractors.

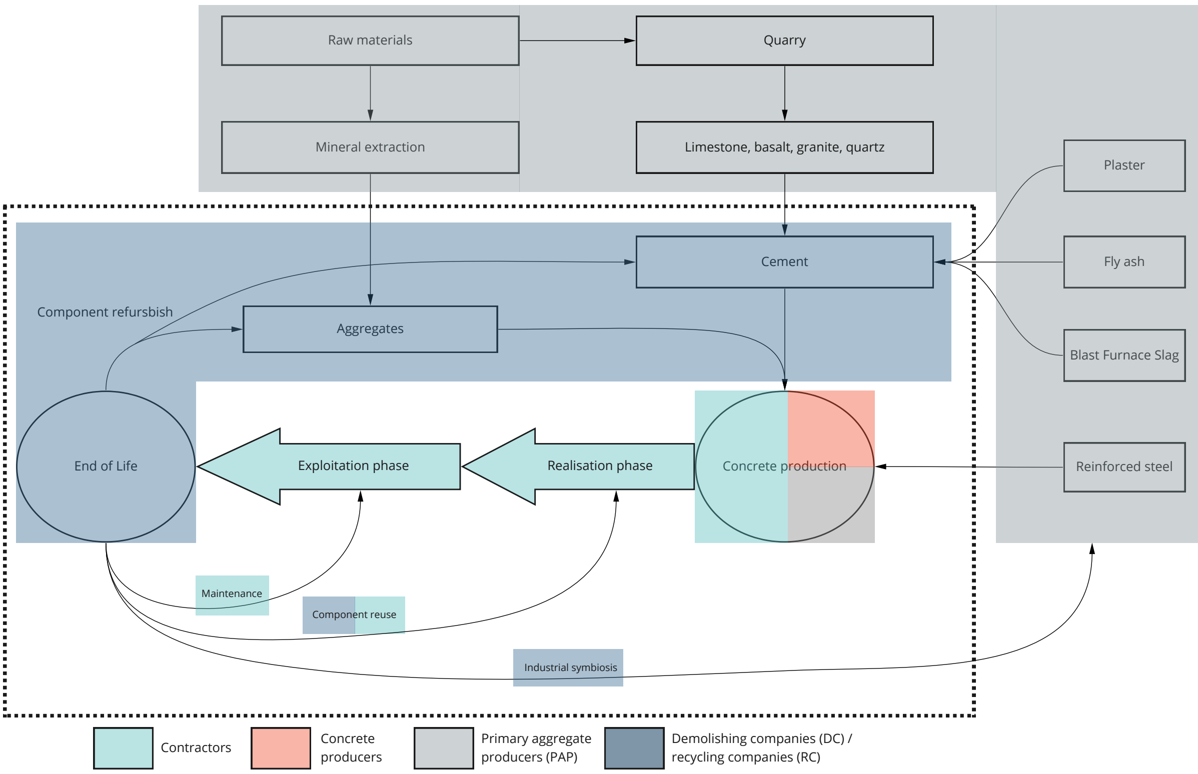


Figure 4.7: Actors visualised in concrete chain

4.3.2 Circular transition of the chain by actors

4.3.2.a *Literature Review on the Circular transition of Actors*

In order to transform the chain to a circular chain, Schraven et al. [2019] conducted research on the involved actors. The paper investigates needed changes according to the actors and other stakeholders. The research shows 40 different changes proposed by the participants which are needed to make this transformation of which only 6 were named double. This indicates that each actor has its own stakes but also a diffusion of responsibility. Furthermore, traditional manufacturers only named changes applicable to their own branch while demolishing / recycling companies named more fundamental changes which indicates that they see more need to change than the traditional manufacturers. The 6 changes that were named more than once:

- New ways of appraising value;
- Formulating circular economy;
- Real cost of transport;
- Integration of the supply chain;
- Raising awareness;
- Adequate pricing for demolition companies.

To the question of who should lead the various changes, it is remarkable that only 25% of the proposed changes by the stakeholders are assigned to themselves. This indicates that the parties involved do not think they are responsible for the transition to the circular economy. Schraven et al. [2019] concludes as well that in the variety of changes, no clear assignments or responsibilities can be found amongst the involved stakeholders. There is however one actor of which most of the interviewees think that it is responsible; the government. More inclusive; clients and investors. The government accounts almost for 50% of the proposed changes. A last remarkable note is about traditional manufacturers, they are not responsible for any changes which might indicate that they don't play a part in the future chain.

Schraven et al. [2019] states that there are two main contributors to the transition; a systemic role of government and a resource-oriented approach of supply chain actors. It advises the government to take a strong position as an early adaptor as the market of materials have bilateral dependencies which unlikely will result in a smooth transition. The actors shift the responsibilities to one another, partly to protect their own business case.

4.3.2.b *Interview Review on the Circular transition of Actors*

Interviews have been conducted with the actors named in Figure 1.4 respectively, material suppliers, recycling company, contractors and clients. Through these interviews, insight is provided into the changes in the material chain because of the transition.

MATERIAL SUPPLIERS At first, two traditional manufacturers of concrete and steel and the recycling company define circularity as a closure of the material streams only (interview 1, 2 & 3). This implies the end of the primary production chain. However, all manufacturers (interview 1, 2 & 3). are aware of the fact that in the coming decades the supply of secondary materials will not be enough to fulfil the material demands of the economy. This is the area in which the manufacturers of concrete and steel identify their future business cases. (Interview 2 & 3) are extensively busy with the reduction of GHG and emphasises the possibilities of maintaining the value of the material.

However, manufacturers of concrete and steel use different strategies for the future. Manufacturers of concrete and recycling companies focus on hybrid delivery options (interview 1 & 2). with second-hand materials and primary materials, while manufacturers of steel (interview 3) do not focus on production processes aimed at the use of second-hand materials, due to the globalised steel industry which makes it very expensive to change production processes. Besides their core activities, manufacturers of concrete and steel and recycling companies understand the need for change and acknowledge that the market + clients has difficulties implementing new material solutions. Therefore, manufacturers of concrete and steel and recycling companies extensively share knowledge and measurement methods (interview 1, 2 & 3) by connecting through branch organisations, participating in partner networks with specific knowledge about certain materials. This had led to more opportunities for the use of other materials (interview 1 & 3).

Manufacturers of concrete and steel and recycling companies see that the need for building materials will not disappear in the coming few decades (interview 1, 2 & 3). However, the focus on reducing primary resources is a risk for them, especially for the steel manufacturers who cannot combine primary and secondary material production processes (interview 3). Therefore, it is in the interest of steel manufacturers to focus on GHG reduction when producing materials and make sure materials keep their value in their life cycle (interview 1 & 3). However, they may have an uncertain business case in the coming decades.

Recycling companies experience risks when implementing new solutions in a linear system (interview 2). Certification often is mentioned as a risk for not being able to use new solutions in a project, which makes investments risky and unprofitable. This comes together with the current thought: 'Ordered today, delivered tomorrow. The circular material market works in another way and requires a different approach. Therefore, it is in their interest to make clients aware of this and use partnerships to speed up knowledge sharing and certifications of materials (interview 2). To the question of who should lead the change, the material suppliers all included themselves (interview 1, 2 & 3).

CONTRACTORS The contractors come up with circular ideas, however they are drawn back by procurement systems used wrongly by the clients (interview 9). Fulfilling life time specifications or certifications most often is a hard requirement in a linear material system, which implies they cannot use re-used materials (interview 8 & 9).

When offering circular ideas, contractors come up with a larger variety of solutions than in a normal situation, cause the solutions depend on the availability of secondary materials. Although the contractors agree this is the risk and challenge of the contractor, they experience a reluctance within the clients (interview 9).

According to the contractors, their circular innovations are not dependent from material suppliers. Instead, the contractors think material suppliers are the most innovative partner in the chain (interview 9). Contractors think that current material suppliers will stay in the market but need to accept urban mining ideas and keep reducing GHG (interview 8 & 9).

The risk position of the contractors is dependent from the type of contract that will be used in the circular future. The contractors advocate more functional specifications within the contracts to create more room for circular solutions (interview 8 & 9). Contractors experience difference in the supply of material origin information. Some suppliers are front-runners, others are not. In the future, contractors only want to buy their materials from suppliers with complete information on all aspects of the object (interview 8).

Project-specific risks of contractors depend on the type of project contract. Contractors expect that in a circular economy they still will be carrying the main risks when it comes to used materials and that material producers won't extend their responsibility (interview 8 & 9). However, the contractors interviewed have the ambition to built circular as fast as possible, and therefore it is in their interest that clients offer a circular perspective on which they can prepare their future business case, with the given risks involved. To the question of who should lead the change, the contractors all included themselves (interview 8 & 9).

CLIENTS (WATER BOARDS) The water boards are organised in several layers. The advisors think that the organisation need to be aware of material possibilities the market offers instead of crossing out certain ideas in advance. On top of that, they think asset management does not know how circular they are today in terms of secondary materials. This awareness could take away cold feet for new materials (interview 6 & 7).

The water boards are split in the circular mindset. Advisors think that one should accept the chance that a solution, in the end, could fail, why the asset manager says: 'If a product does not meet the requirements, we cannot fulfil our function' (interview 4 & 6). In general, the water boards are organised in a way that new buildings are designed for a very long period with as little maintenance as possible. This hinders other materials to enter the market (interview 4 & 5). The asset management department is considered as not mature enough for circularity.

Due to recent reorganisations, asset management and their knowledge about applied materials in their portfolio fall short (interview 4). Asset management experiences a very diverse supply market. Regular concrete and steel products are not their main concern. The supply market of specific products, for example pumps or moving objects which are fish friendly, is very specific and small for the water boards. Innovative producers are scarce and therefore asset management is not willing to specify circularity, because they fear unsuitable products (interview 4, 5 & 6).

Water boards have the risk that they will end up having internal differences in the approach to a circular economy. Beyond circularity, the different types of layers have different interests (interview 4, 5, 6 & 7). Although they all somehow want a circular future, the strategy how to achieve so is not available and therefore the boards do not have an internal shared vision on which they can decide their actions (interview 4, 5 & 6). Therefore, it is in their interest to come towards a shared vision about what, when and how to change. To the question of who should lead the change, the water boards all included themselves (interview 4, 5, 6 & 7).

4.3.2.c *Analysis of literature and interview data*

From the interview review, it can be derived that the given definition of circularity of the suppliers is in contrast with the circular 'actions' the traditional suppliers take. While their given definition of circularity all stated closing material streams would mean the absence of need for suppliers, the actions of the suppliers include them into a circular future. This mainly is based on the lack of secondary materials. This is also the biggest contradiction between the literature review and the interview review. The literature review indicated no responsibilities for the traditional manufacturers, while the interview review showed they are likely to have a circular future business case and thus are responsible for a solution to the problems. Moreover, it can be concluded that the change proposed by literature *'Formulating a circular economy'* is recognised by interviews.

The future business cases of traditional manufacturers marginally involve material streams. Instead, they incorporate GHG reduction within circularity and undertake actions to reduce GHG in their current primary material production. From the interviews, the researcher argues a clear difference can be seen between the steel and concrete chain. The concrete market is a more flexible market than the steel market because there are far fewer steel producers worldwide than concrete producers. Steel production processes are complex and require extensive investments to change marginal things in the production processes. Moreover, a steel company cannot change between the EAF / BOF processes, which makes the distinction between primary and secondary materials. The market is structured in such a way that some manufacturers use EAF techniques and others use BOF. This is in balance with the supply of scrap. Concrete supply chain a more local chain with shorter lines, flexibility, less complex processes and therefore more laborious.

Circular material suppliers have set foot in the market of traditional manufacturers. The key to success in this entry was the focus for knowledge sharing, focusing on certain material streams and hybrid delivery options. With the hybrid delivery options, they became a stable supplier for their customers. With certain material streams, they make themselves available to a lot of contractors by providing the most used materials in a circular manner. At last, they assigned knowledge sharing as the key factor to set foot in a huge market. Collaborating with partners creates synergy.

Regarding the contractors, it immediately can be derived some circular solutions are not being applied yet, due to various reasons. They indicate that water boards are not yet in a position to assess circular ideas and therefore do not value ideas, thus supporting the change proposed by literature *'New ways of appraising value'*. Contractors themselves have the power to buy at certain material suppliers, given the ambition for a circular transition. They indicate they might exclude some suppliers if they don't provide full information of the materials. However, nowadays that is not yet the case as they indicate material suppliers are the front runners of the transition.

Regarding the water boards, it can be concluded that the way they are organised influence the internal approach to the material chain. The way in which materials are chosen relies heavily on the long lifespan approach of the waterboards objects. Circular strategies for using re-used concrete or steel in maintenance are likely to fail, as the asset management wants to stick to the current approach because they do not have the manpower and money to experiment with designs that require a higher effort of the asset management. The advisors want the organisation to focus on the current knowledge of circular materials, which might result in less fear for bad operations. For example, EAF steel is being used quite often, while some people still are afraid of the performance issues of re-used steel beams. It can thus be concluded that the change proposed by literature *'Raising awareness'* is recognised by interviews and needed in the boards. On top of that, a certain difference in the approach of the circular material chain has to be made into which objects are common (e.g. concrete floors) and waterboard specific objects (e.g. fish-friendly steel pumps).

Regarding the responsibility of the change, the literature review mainly appointed the government. Meanwhile, the interview review shows that in the intervening years this is changed which indicates that everyone is aware of the need for the transition.

4.4 LEARNED LESSONS AND CONCLUSIONS FROM SQ3

This chapter offers insight into the material chains of concrete and steel. The chain of concrete in is addressed in Section 4.1 and steel in Section 4.2. The differences between these materials on the different CMM pillars show that is important to look beyond circularity. The various parts of the chain require different approaches to use circularity. This is important for the water boards, as they have the power to influence the chain and have to use this power effectively. **Circularity should not be the goal**. It is important to see where in a material chain circularity is required. Actors need to have and provide insight into the real climate and material problems and use circularity as a tool to effectively counteract these problems. The CMM helps to identify this needs through its three main pillars. This shows for example that focusing on material streams for iron might not be the most problematic issue, because there is still plenty of it. Meanwhile, alloys do have short-term problems with respect to availability in the earth's crust. GHG are a problem in relation to iron. Regarding concrete; GHG appears to be a bigger issue than the availability of the cement and aggregates. In reality, awareness of this seems absent. Preventing the usage of iron might seem circular, however it is the question whether that is effective. Focusing on the reduction of alloy usage certainly is effective. It can be argued that circularity is treated as a goal on its own.

The actors in the chain are identified and discussed in Section 4.3. They are aware of the fact that the demand for primary materials is not likely to disappear in the coming decades, given the economic growth and corresponding material demand. With respect to this subject, a gap can be spotted between the interview and literature analysis in Section 4.3. Literature concluded no specific task or future is relevant for current material producers, while interviews conducted appoint the opposite. This means that primary material producers need to be included in circular strategies. Moreover, a difference can be observed between the concrete and steel chain. The concrete market is a more flexible market than the steel market because of various reasons (e.g. globalisation of the steel market), which the water boards need to take into account when determining circular strategies for these specific materials. Moreover, the water boards need to create space for recycling companies in their material portfolio. They can do so by accepting hybrid delivery options. It is up to the water boards to create incentives, thus supporting these initiatives. It is remarkable to see that actors interviewed define circularity in a multiple ways. Together with the fact that some circular actions are not in accordance with the given definition, it can be concluded that circularity is not unambiguously defined in the chain.

In specific, the water boards mainly need to provide incentives in three topics, which have been identified in both literature and interviews as widely supported requirements for the implementation of circularity:

- *Formulating a circular economy*
- *New ways of appraising value*
- *Raising awareness*

This needed changes strengthen the earlier selected approach of the CMM, which clearly frames circularity with respect to underlying climate change topics, thus formulating a circular economy and offering a method to assess circular ideas and design.

5 CIRCULAR DESIGN CRITERIA AND IMPLEMENTATION STRATEGIES

This chapter provides an answer to the fourth sub-question of this research, which has been formulated as:

- Which ambitions and different circular strategies can be defined for civil structures, and how can these be combined towards a circular implementation tool for the water boards?

This chapter starts with introducing key elements for circularity and water boards in Section 5.1, which thus need to be included in the implementation tool. Thereafter, practicalities of such a tool are addressed in Section 5.2, in order to understand how water boards can use this tool. Not only today but also towards the future. Section 5.3 Determines and explains circular strategies suitable for the water boards are determined and connects them to an LCA approach. Section 5.4 brings all of this together, by showing and explaining the implementation tool.

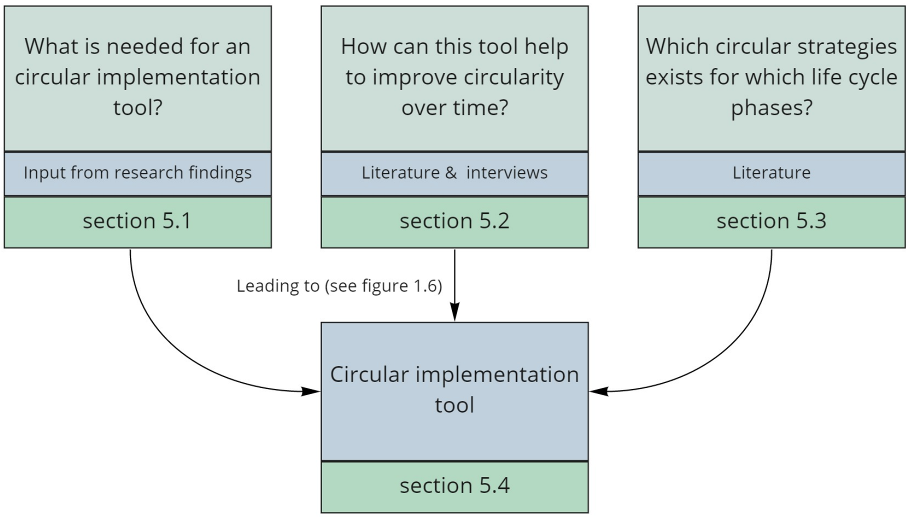


Figure 5.1: Chapter overview

5.1 REQUIREMENTS FOR AN IMPLEMENTATION TOOL

This research presented several items which where argued to be successful for the water boards and therefore should be included in the implementation of circularity for the water boards:

- The need to formulate circularity in a systematic approach (mentioned in Section 2.2.2 and Section 4.3.2.c)
  This is achieved in Section 5.1.1
- A method to assess the value of an asset differently (mentioned in Section 4.3.2.c).
  This is achieved in Section 5.1.2 and Section 5.3.2.
- The inclusion of primary material manufacturers in circular strategies (mentioned in Section 2.1.1 and Section 4.3.2.c).
  This is achieved in Section 5.3.2.

For each of these requirements, this section explains how they are incorporated in the design of the implementation tool or advise is given for the water boards on how to treat this item besides the tool to make the tool a success.

5.1.1 A systematic approach

In order to understand how circularity can be implemented in a systematic approach, this thesis discovered some specific systematic points in Section 3.2.1 which have been successful in the past for implementing innovations in the water boards.

- The use of overarching programs;
- The use of an LCA based method;
- Circular strategies which concern both asset management and realisation.

These strategies should help the water boards to overcome the identified barriers which can be experienced when implementing circularity.

OVERARCHING PROGRAMS It is recommended to set up overarching programs for circularity as water boards. Within these programs, the water boards, preferably all together, should adopt a systematic definition of circularity and set circular ambitions accordingly. These programs are identified as a success factor for innovations in water boards earlier in this research. When circularity and according to ambitions are clearly defined, these programs can help to execute circular ambitions in multiple projects, which creates the potential for developing circular solutions between those projects. Moreover, these overarching programs helped the water boards to execute certain strategies in the maintenance phases as well. Due to long-term arrangements, the contractors also knew on beforehand which developments would be appreciated and therefore could investing in these things.

LCA The use of an LCA based approach is achieved by the use of the CMM based approach in the implementation tool, which is discussed in Section 2.4.2. Moreover, the circular strategies are connected to a certain life cycle stage, in order to show which strategies can be used in which life cycle stage.

CIRCULAR STRATEGIES Circular strategies are elaborated in Section 5.3. In this section, it is explained what these strategies are and for which phase of an asset they might be used.

5.1.2 Circular assessment / ambitions

In order to fulfil the need to assess the value of an asset differently in this implementation tool, the CMM is used. It is recommended to use the CMM criteria as these ambitions so that it is possible to focus on the problems that are located in the different pillars of the CMM. For example, water boards can have as an ambition to focus on the CMM indicator 2.1 for alloys, to solve the problem of resource depletion. The CMM provides circular value criteria that can be used to assess different designs which claim they incorporate circularity. Moreover, these criteria can serve as ambitions for a water board. For example, water boards can have as an ambition to focus on the CMM indicator 2.1 for alloys, to solve the problem of resource depletion. This section presents CMM criteria that the water boards can use to assess to which extend the designs comply with the principles of circular building.

The criteria covers the three goals of the CMM in which circularity can be used as mentioned in Section 2.4.2, which are:

- Protecting material streams;
- Protecting environment;
- Protecting or creating value;

The choice of this method has been argued in Section 2.6. With the chosen themes it is expected that an integrated assessment of the circularity of a building is possible. In order to assess these themes, the CMM is summarized in figures. In total, the CMM delivers 7 indicators which in total deliver a circularity score of an object. An indicator can have multiple output numbers. In the visual representation, these can be seen through the used colours in the title numbers.

5.1.2.a *'Protecting material streams'*

For the theme 'Protecting material streams' indicators 1 - 3 are assigned, visualised in Figure 5.2.

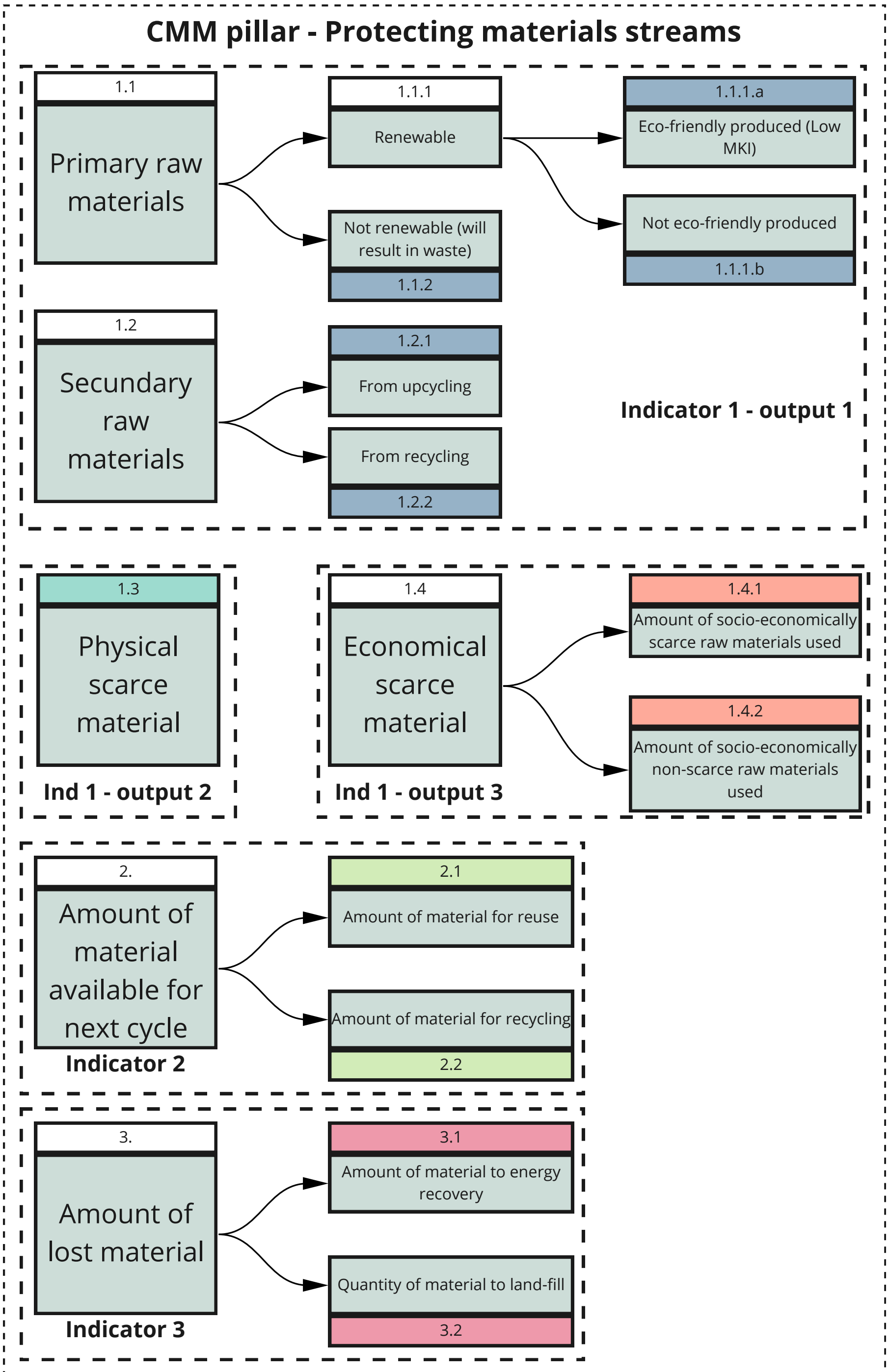


Figure 5.2: CMM indicator 1 - 3 (containing 5 output numbers)

5.1.2.b *'Protecting environment'*

For the theme 'Protecting environment' indicator 4 is assigned and is visualised in Figure 5.3. Please note that number 11 of the original MKI has been removed due to an overlapping theme in indicator 1. Moreover, the CMM adapts the MKI or MPG method as leading for indicator 4, meaning that this part has already been practised by several parties.

CMM pillar - Protecting environment

Indicator 4, output 1 - 18

4.1	4.7	4.14
Climate change – overall	Eutrophication - freshwater	Emission of particulate matter
4.2	4.8	4.15
Climate change – fossil	Eutrophication - seawater	Ionising radiation
4.3	4.9	4.16
Climate change – biogenic	Over-fertilisation - soil	Ecotoxicity (freshwater)
4.4	4.10	4.17
Climate change – use of land and changes in use of land	Occurrence of smog	Human toxicity, carcinogenic
4.5	4.12	4.18
Ozone depletion	Depletion of abiotic materials – fossil energy carriers	Human toxicity, noncarcinogenic
4.6	4.13	4.19
Acidification	Use of water	Impact/Soil quality related to the use of land

Figure 5.3: CMM indicator 4, containing 18 output numbers

Note: as argued in the scope of this research, biodiversity themes will not be treated. Therefore, this indicator will be treated as one, thus no distinguishing is made between the 18 sub-indicators in further the implementation tool.

5.1.2.c *'Protecting or creating value'*

For the theme 'Protecting or creating values' indicators 5, 6 and 7 are assigned and are visualised in Figure 5.4.

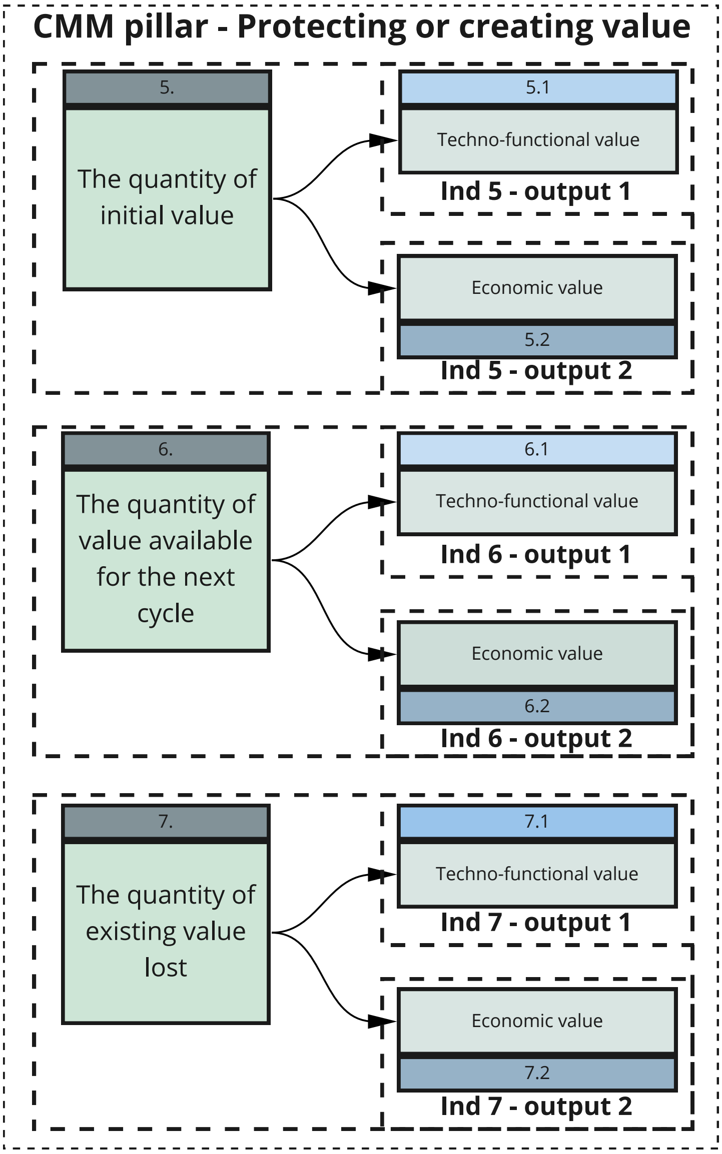


Figure 5.4: CMM indicator 5, 6 and 7, containing 6 output numbers

5.2 USING AN IMPLEMENTATION TOOL

The topic of circularity is about a transition. In a transition, actors can use various strategies in order to get the transition going. In order to use an implementation tool with certain strategies, actions need to be carried out. Using circularity at a project level can be characterized as an **intervention** [Górecki et al., 2019]. This section elaborates on the definition of interventions, and uses literature and interview data to do so, and what that means in a systematic approach.

5.2.1 Types of interventions

A transition is illustrated by several developments on interventions [Górecki et al., 2019]. According to Górecki et al. [2019], it is essential to work together towards new interventions but also note which developments exists.

This is acknowledged by the actors involved in the development of the water boards. New initiatives are very hard to launch on your own. A company can do something, but the subject should be launched regional to make it to success (Interview 2, 3, 6, 7, 8 & 9). This indeed creates a transition on different levels and speeds (interview 7), which implies synchronisation on a circular level is difficult to achieve within one specific project.

Therefore, it can be argued that interventions can roughly be divided into:

- Existing interventions;
- New interventions;

EXISTING INTERVENTIONS This type of intervention is considered to have a direct impact, it is something a water board department immediately can do today without any dependencies from the system. No certain big issues are expected. Moreover, the material chain and the market are ready to apply these interventions within the projects of the water board. **Example: wooden quay walls**

NEW INTERVENTIONS This type of intervention is considered to have an indirect impact, it is an intervention that makes an impact on the given situation but cannot be done without an adjustment in the system or collaboration with other actors and still needs to be developed over time. This adjustment to the system can be needed within the water boards themselves or with other actors in the chain. Regulation issues might need to be adopted by the government, or external organisations not mentioned in the material chain, such as building standard platforms. **Example: marketplace for second-hand iron quay walls**

5.2.2 Intervention development

Górecki et al. [2019] described the need to develop interventions to stimulate the transition which needs to take place in a systematic approach. This is a process in which the market works together to enable new interventions. However, the current market is a linear market, which has been identified as a barrier, in which companies are not willing to share their expertise. In interviews, this tension is addressed, in order to provide insight into how to tackle this.

In order to make new interventions possible, key is knowledge sharing (interview 2, 3, 4, 5, 6, 7, 8 & 9). One of the arguments against knowledge sharing is losing your business case (interview 2, 8, & 9). As a material supplier, this can be avoided by sharing knowledge through partnerships, in which companies with different expertise can overcome different problems, such as certification issues (interview 2 & 6). Moreover, together they speed up the transition and are a more stable partner for a client (interview 2) . Moreover, certain suppliers actively see the need for change and already extensively share their knowledge at for example universities (interview 3).

Water boards can achieve this knowledge sharing through communication with other boards. Although this initiated by the UVW, this is not sufficient (interview 4 & 5). Within the interviews held by (interview 4 & 5), people involved were not aware of the developments of each others board. This is a pity because the subject involved the same objects within the same transition. Moreover, water boards also indicated that internal knowledge-sharing sessions are now far too non-committal and are the first to be removed from the agenda (interview 4).

Together, the water boards can make a stand towards certifications instances and building standard instances (interview 4 & 6) which was identified as a barrier as well, to speed up those revisions which will make some solutions possible over time. The water boards can obtain their knowledge for this internally (interview 5) or engineering firms (interview 4 & 5), however contractors think that water boards can learn a lot from them which improves the joint stand even further (interview 8).

The evaluation and knowledge sharing part are therefore important in making new interventions a success. Summarized, this can be achieved by knowledge sharing or partner-shipping. These processes will enable the transformation of new interventions into an existing intervention. This process should be strict with a high priority, as the interview data showed this is the first item to be removed from the calendar. The figure of the evaluation process Figure 5.5 shows the process of intervention developments. Within multiple projects, attention needs to be paid to new interventions which might not make an impact in the current project, but it increase the change of being transformed into an existing intervention, thus deployable in a new project.

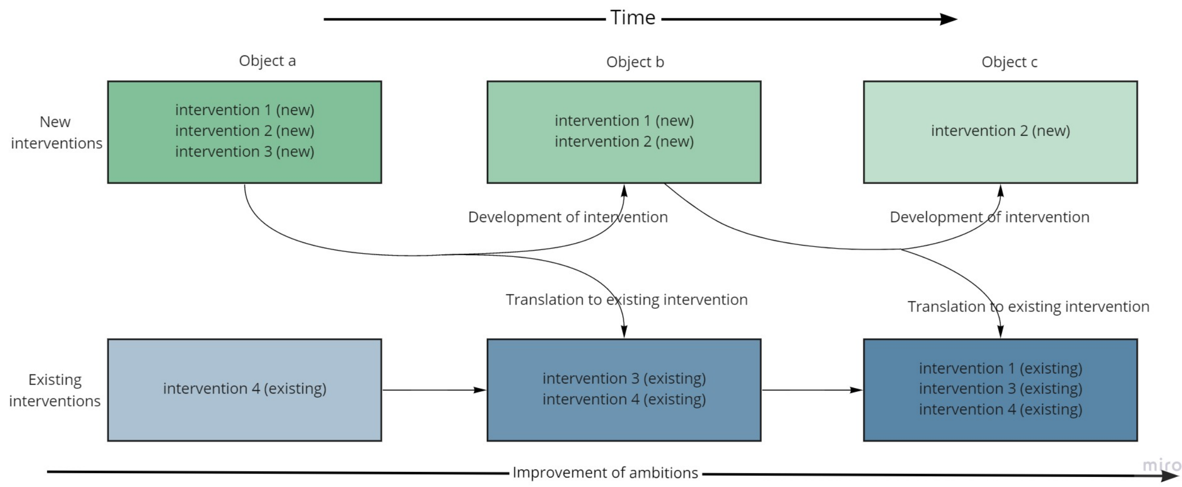


Figure 5.5: Developments of interventions over time (own image)

5.3 LIFE CYCLE PHASES AND CIRCULAR STRATEGIES

In this section, the life cycle stages identified in the theoretical background of this thesis once again are showed. These phases are used in the implementation tool and connected to circular strategies, as the research turned out an LCA method fits a systematic approach. Moreover, it provides the water boards with circular strategies to incorporate in the asset management.

5.3.1 Life cycle analysis phases

Within the circular economy, products, objects and substances are used as long as possible, thus extending its lifetime or enhancing its quality in every phase. This thesis has been pushing for a systematic circular approach, which means that circular strategies should be used in all of the life cycle phases. In Figure 2.4 (again showed in Figure 5.6) these life cycle stages are showed.

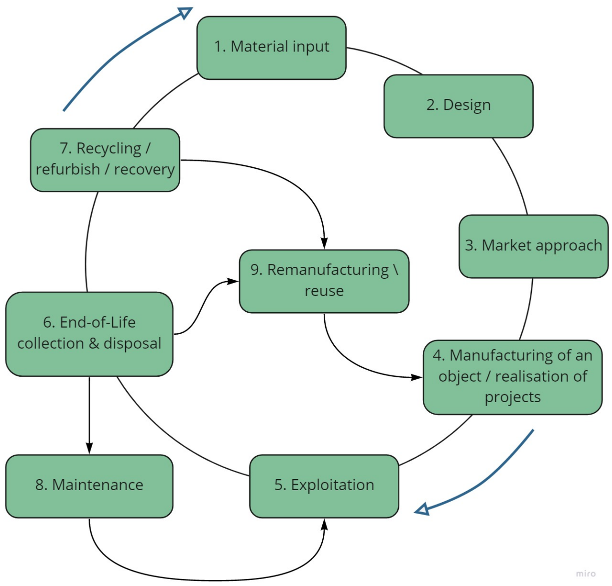


Figure 5.6: Circular value chain of an object

5.3.2 CE strategies

The correct use of the strategies provides circular improvement within the construction industry. In order to assign different circular strategies towards life cycle steps, a literature review has been executed. Various strategies are published by Leising et al. [2017], Moreno et al. [2016], Kalmykova et al. [2018] and Salvador et al. [2021], which carried out research towards theoretical approaches, strategies and implementation cases in general. These strategies are thoroughly studied, in order to assess the suitability for the implementation tool of the water boards. A suitable strategy should:

- be applicable in the construction industry;
- be applicable for multiple issues/materials;
- contributes to one of the three pillars of the CMM.

Subsequently, the strategies are assigned to one of the 9 life cycle value chain steps in Figure 5.6. The suitable strategies are presented in Table 5.1 and Table 5.2.

1. Material input		
[1]	Bio based materials	Input from bio-based resources which last longer than their own production time (e.g. wood 30 years) and can be regenerated
[2]	Aggregates & scrap materials from secondary objects	Input from the end of the circle in which raw materials are re-obtained
[3]	Re-using parts from EoL objects	Input from predecessor object, some parts might still be sufficient
[4]	Secondary parts from marketplaces	Input from secondary material marketplaces
[5]	Middle course	Use primary materials in exchange for funds for circular research / CO2 reduction
2. Design		
[6]	Design for disassembly	A design that takes into account the need for disassembly for - repair, refurbishment or re-use.
[7]	Design for modularity	Products composed of functional modules so that the products can be upgraded with newer features and/or functionalities. The modules can be individually repaired or replaced, thereby increasing the longevity of the product core. Make a consideration between: - adjustable - versatile - refitable - convertible - scalable - movable
[8]	Eco Design	A product which design is focused on its environmental impacts during the whole lifecycle and construction period (MKI)
[9]	Reduction	A design in which the use of (harmful) materials are reduced to a minimum
[10]	Data based design	A design focuses on the completeness of data, such as a materialpassport and monitoring during lifetime
[11]	Overdimensioning	Overdimensioning of objects might be fruitful for future use to extend the lifetime and therefore LCA value
3. Procurement		
[12]	Taxation	Punish activities that are associated with negative externalities
[13]	Tax credits and subsidies	Reduce tax on resource and extra labour needed for circular activities
[14]	Green procurement	Steering on circular demands and specifications instead of costs
[15]	Life Cycle assessment	LCA is a structured, comprehensive and internationally standardized method. It quantifies all relevant emissions and resources consumed and the related environmental and health impacts.
[16]	System-based approach	Approach with a focus on extra value for the environment, such as combining WKO
[17]	Project-bundled approach	Multiple (similar) projects within 1 procurement which creates opportunities for contractors
4. Manufacturing		
[18]	Reproducible & adaptable	A transparent and scalable manufacturing technology that can be replicated elsewhere using indigenous resources and skills.
[19]	Energy efficiency	Providing the required services with reduced energy input, which can be achieved by reduced consumption and energy-efficient processes.
[20]	Optimisation for life-cycle length	Avoid the materials with a low lifespan

Table 5.1: Circular strategies per life cycle part 1

5. Exploitation		
[21]	Community involvement	The voluntary involvement of different stakeholders in organizing sharing platforms and providing guidance on product repair and replacement.
[22]	Product as a service	Such as Pay per use, rental - buy / rebuy - leasing. Not all models are circular, therefore EPR is needed (Extended producer responsibility)
[23]	Product labelling and measurement	Availability of data for a certain object. Contains its origins, GHG, materials, details, etc. Aims to privide information for a lower MKI during exploitation
[24]	Sharing	Shared use/access/ownership of for example space and products and sharing platforms enabling shared use. Multi-purpose space which therefore reduces the need for more.
[25]	Stewardship	In contract with EPR. Demands responsibility from stakeholders without incentives
[26]	Virtualize	Dematerialization. For example use of telecommunication to decrease use of office space and travel
[27]	Reduce energy usage	Focus on energy efficieny operations and embodied energy
[28]	Supply of energy	Focus on renewable energy sources

6. End-of-life collection & disposal		
[29]	Extended producer responsibility	Extended Producer Responsibility is an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle in order
[30]	Incentivized re-use	A method for rewarding consistent and repeated recycling of recyclable materials, for example a deposit refund
[31]	Logistics / Infrastructure building	Facilitate areas needed for industrial symbiosis, marketplaces etc. Solutions that render optimum collection.
[32]	Seperation	The biological constituents should be separated from the technical or man-made/inorganic constituents. The technical nutrients ought to be used for remanufacture and the biological
[33]	Take-back and trade-in systems	Efficient take-back systems ensure that the products are recovered from the consumer after end of life and proceed to be

7. Recycling and recovery		
[34]	By-products use	Byproducts from other manufacturing processes and their corresponding value chains are used as raw materials for manufacturing new products.
[35]	Element/substance recovery	The process of recovering metals, non-metals and other re-usable substances from a material waste stream
[36]	Type something Functional recycling	Process of recovering materials for the original purpose or for other purposes, excluding energy recovery
[37]	High-quality recycling	The recovery of materials in pure-form without contamination, to serve as secondary raw materials for subsequent production of the same or similar quality products.
[38]	Composting	Process where biological nutrients are returned to the soil after break-down by micro-organisms andother species.

8. Maintenance		
[39]	Upgrading, repair	The most efficient way to retain or restore equipment to the desired level of performance is maintained. Moreover, service aftersales is considered key for competitive advantage and business opportunity. Maintenance is also carried out in the form of repair. To eradicate product
[40]	Monitoring	Instead of certification, monitoring can provide contractual terms for products. By specific monitoring, one can measure the performance of an object and predict its value

9. Remanufacture		
[41]	Refurbishment	Replacing defective components by reusable ones
[42]	Re-use	Using components from an EoL object in another object

Table 5.2: Circular strategies per life cycle part 2

5.4 IMPLEMENTATION TOOL

5.4.1 Strategies to intervene in certain circular ambitions

The implementation tool for implementing circularity is showed in Table 5.3. The presented circular design criteria / ambitions of Section 5.1.2 are placed on the x - axis. At the same time, the circular strategies of Section 5.3 are placed on the y-axis. The interaction of every ambitions and strategy shows a color, indicating the type of intervention (see Section 5.2) or whether a strategy does not fit a certain ambition. The insights of all interviews, literature study's and other knowledge have been used to draw this matrix.

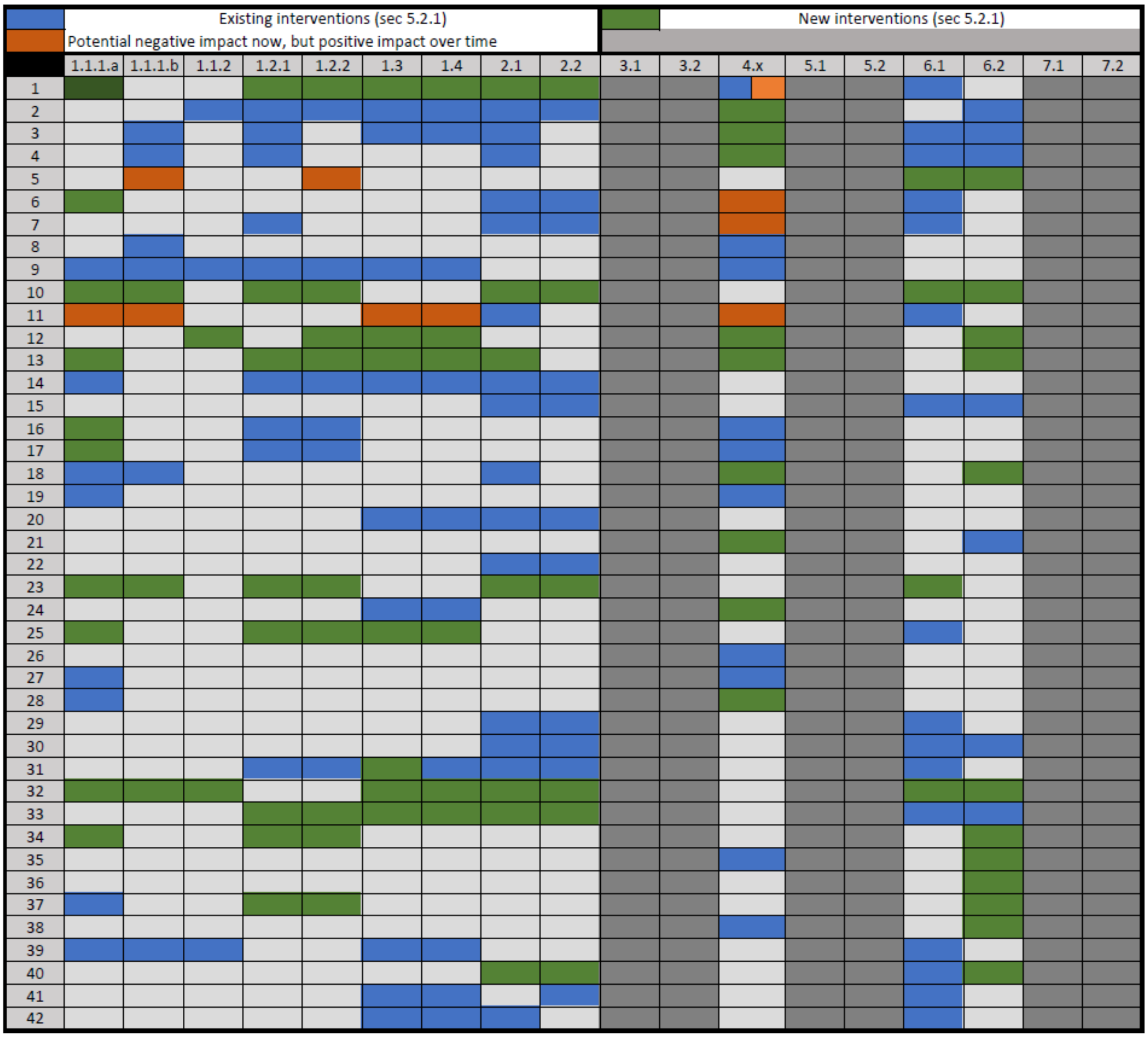


Table 5.3: Circular strategies in relation to CMM (authors interpretation)

Trough this matrix, the water boards are provided with insight in which circular strategies can contribute to certain CMM pillars, either now or in the future. It must be noted that indicators [3, 5, 7] are not connected to strategies. This is because they work together with other indicators. For example, indicator 2 measures the amount of reuse and recycling. If a material is not being reused or recycled, the material will be assigned to either 3.1 or 3.2 which are not desired in a circular economy. Strategies aiming for indicator 2, therefore, aim to lower indicator 3.

An simple example of identifying strategies is made in Figure 5.7. It should be noted, in line with the conclusions of Chapter 5, the need for particular ambitions for a material must be thoroughly explored.

Examples Table 5.3		
Specific ambition for a water board	Strategies	
CMM 1.2.1 Secondary raw materials from upcycling	Existing interventions	New interventions
	2 - Aggregates & scrap materials from secondary objects 7 - Design for modularity	13 - Tax credits and subsidies 33 - Take-back and trade-in systems

Figure 5.7: Example of identifying strategies for a certain ambition related to a material

5.4.2 Analysis of circular strategies

In a systematic approach, strategies can have interaction with each other. These interactions can create synergy but can also create potential conflicts. In order to determine which strategies are applicable and can be used alongside each other with the optimal result, an analysis is carried out. On the x and y-axis, all strategies are placed. The corresponding boxes in the matrix indicate the type of interaction by a colour and a letter + number combinations. A clarification of the possible interactions can be found in Appendix A, which elaborates on all the letter + number combinations. The numbers within the matrix correspond with the numbers in the Appendix. This analysis was carried out by the researcher and therefore prone to observers error and bias, caused by the subjective view and potential misinterpretations of the researcher. The results are visible in Table 5.4. Both this matrix and Table 5.3 are to be used, evaluated and validated by the water boards and is out of scope for this research.

Synergie   Potential conflict   Dependancy

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
1								S1		D1	C11	S26	S26	D7						C12			S11																			
2								S10				S26	S26	D7									D6																			
3						S2	S13	S10		D4		S26	S26	D8									D6								D13											
4						S2	S13	S10		S8		S26	S26	D8									D6				S4															
5									C2																		S4															
6			S2	S2			S12		C4	D3		S26	S26	S15		S32		S23				D14						S20							S14	S14	S14					S23
7			S13	S13		S12			C4	D11		S26	S26	S15		S22			C9			D14					C9	S20							S14	S14	S14					S23
8	S1	S1	S1	S1					C1	D11				S17						C12			S5				C5	C5														S23
9					C2	C4	C4	C1			C4			S18	D5				C3				S9	S29		S7	S6	C6														
10	D1		S4	S8		D3	D11	D11						D12									S31				D2								D11	D11	D11		D11	D11	D11	D11
11	C11								C4					D9																												
12	S26	S26	S26	S26		S26	S26																							S26												
13	S26	S26	S26	S26		S26	S26																							S26												
14	D7	D7	D8	D8		S3	S3	S17	S18	D12	D9																		S19	S19			S19		S19	S19	S19					
15									D5											S30								S20														
16						S32	S22				S28							S22					D10				S20	S22				S32										
17																											C8	C8														
18						S23										S22																										
19							C9		C3													C10																				
20	C12							C12							S30																											
21																						C10			S28																	
22						D14	D14												C10		C10				C10		C10	C10	S27	S27		S27	S27		S27	S27	S27		S27	S27	S27	S27
23	S11	D6	D6	D6				S5	S9	S31						D10																										
24									S29																																	
25															S30						S28	C10					S24															
26									S7																		S24															
27				S4	S4		C9	C5	S6	D2						S20	C8					C10			S24	S24		S21							C7	C7	C7				C7	C7
28						S20	S20	C5	C6						S20	S22	C8					C10					S21								C7	C7	C7				C7	S25
29														S19								S27													S19	S19	S19					
30												S26	S26	S19								S27													S19	S19	S19					
31			D13																																							D13
32																S32						S27																				
33														S19								S27													S19	S19	S19					
34																																										
35						S14	S14			D11				S19								S27					C7	C7	S19	S19			S19									
36						S14	S14			D11				S19								S27					C7	C7	S19	S19			S19									
37						S14	S14			D11				S19								S27					C7	C7	S19	S19			S19									
38																																										
39										D11												S27																				
40										D11												S27																				
41										D11												S27					C7	C7														
42						S23	S23		S23	D11												S27					C7	S25			D13											

Table 5.4: Internal relations of strategies

5.5 LEARNED LESSONS AND CONCLUSIONS FROM SQ4

This chapter uses key developments from the literature study and combines them in an implementation tool. The requirements for an implementation tool are discussed in Section 5.1, which are mentioned as:

- The need to formulate circularity in a systematic approach;
- A method to assess the value of an asset differently;
- The inclusion of primary material manufacturers in circular strategies;

The way in which a systematic approach can be included is being explained by earlier findings of this research, thus arguing the inclusion of an LCA based method, the creation of an overarching program for the inclusion of the circularity and circular strategies which concern both asset management and realisation. The CMM fulfills these demands partly, and therefore it is argued to use the three pillars and its design criteria as ambitions, in order to systematically improve these ambitions.

Section 5.2 describes the possible outcomes of the implementation tool; opportunities for interventions. It introduces the concept and need of interventions and explains the difference between new and existing interventions. Thereafter, the need for intervention development is described, which should take care of a better use of circularity in the future. This enables clients as the water boards to be able to counteract various problems more effectively in the future.

LCA and the its phases addressed earlier in this research are showed again in Section 5.3. It shows 9 phases of an asset, which do not only include the realisation phase, but also the asset management, thus creating possibilities of using circularity in multiple phases of an asset, not being restricted to the realisation. Circular strategies are identified and discussed as well in this section, showing strategies for each of the 9 life cycle phases.

Section 5.4 shows the results of this chapter with the design of an implementation tool. It combines the CMM indicators with circular strategies. Water boards, or preferably the UVW, can use the indicators to define circular ambitions over time for each of the materials within their assets. With this tool, they can connect these ambitions with strategies, in order to determine which strategy is suitable. Moreover, insight is provided into whether a strategy can be used as an intervention now or in the future and whether it creates synergy or conflict when used in parallel with other strategies.

The results of this chapter can be used as an implementation tool by water Boards for their assets. Long term ambitions have to be set by a water board or, more preferably, the UVW, signed by all the water boards. This implementation tool can be used twofold. At first, they determined ambitions can be presented to the market. Through this, the market knows which developments will be likely to happen and can adjust their business case and associated investments accordingly. Secondly, within the internal organisation, the ambitions and strategies can be translated into the asset management strategy of the water board and give direction to the implementation of circularity at the various intervention moments. The presented implementation form is a base and acts as a starting point, continuously evaluating and adjustments through a principle necessary as this subject is new to all actors involved and considered as learning on the job.

6 IMPLEMENTATION EXAMPLE: PUMPING STATION

This chapter functions as an implementation example of this research, thus incorporating the results of this research and explaining the developed implementation example. This is done with the example of a pumping station, one of the important assets of the water boards. It is a device for moving water from a lower to a higher level. It brings or keeps water in a water level at a certain level, which is a major challenge in The Netherlands.

6.1 THE USE OF THE IMPLEMENTATION TOOL

The implementation tool can be used to define circular ambitions over time for certain levels. With respect to the **strategic level**, preferably the UVW prescribes the ambitions for certain materials such as concrete and steel, after research to the material chain of all water boards, thus providing insight which material has the need for which ambition. Thereafter, the individual water boards could use this on a **tactical level** with an analysis for each type of its assets, thus identifying opportunities for certain strategies. It is of course not possible/needed to use all strategies at once. On a **operational level**, the water boards could apply a strategy to a certain material during a maintenance period, in accordance with the set ambitions and opportunities on the tactical and operational level.

The interpretation of the strategic level is addressed in Section 6.2. The tactical level is skipped in this example as this does not immediately contribute to the clarity of this example, thus moving on to the results of the tactical level on the operational level for a water board, considering a pumping station in Section 6.3.

6.2 AMBITIONS IN OVERARCHING PROGRAMS – STRATEGIC LEVEL

In Chapter 3 it is mentioned that circularity should not be the goal. It is important to have insight into where in the chain circularity is required. This insight is provided in Chapter 4 for the materials concrete and steel, two of the most important and polluting materials in the construction industry and in the design of pumping stations. In Chapter 5 the implementation of circularity is discussed and it is argued to use overarching programs for the implementation of circularity in which ambitions for circularity per material are set. These ambitions could be defined by using CMM indicator.

The asset management departments of water boards are not mature, compared to the department of realisation. However, circularity should be used in all phases of an asset. Therefore, interventions for the different phases must arise from joint ambitions, which requires the asset management to be organised differently in terms of maturity in order to execute the joint strategy.

For this implementation example of pumping stations, the ambitions for circularity are defined. These ambitions should be included in an overarching program. The material section of Chapter 4 gave the current state of the materials framed in this research, concrete and steel. Based on the current state of those materials, the CMM indicators showed in Figure 6.1 are labelled as urgent. In order to execute these strategies, the water boards need to determine their overarching program. This is needed since a systematic approach requires something that ensures continuity along with multiple projects.

nr		Raw Material	CMM indicator as ambition			
1	Steel	Iron & Carbon	A	4 - Protecting environment	B	1.3 & 1.4 Physical / economical scarcity
2	Steel	Alloys	C	2.1 - Amount of material for reuse	D	1.1.1 - Renewable produced
3	Concrete	Aggregates	E	6.1 - Functional value available for next cycle	F	1.2.1 - From upcycling
4	Concrete	Cement	G	4 - Protecting environment	H	6.1 - Functional value available for next cycle

Figure 6.1: Possible ambitions for a water board

Figure 6.1 shows the ambitions set for the materials concrete and steel for a pumping station on a strategic level, thus not specified for a certain project. Steel and concrete are split in the same way as in Chapter 4, thus iron & carbon, alloys, aggregates and cement. For each of these substances, two ambitions are being determined a water board should focus on for that substance in all of their assets. These are indicated by A - H, with a CMM indicator such as (4 - Protecting environment) functioning as ambition. Two of the set ambitions are addressed in more detail below:

With respect to steel, Chapter 4 mentions that most of the scrap already is being re-used and it is hard to improve that due to a shortage of scrap materials. Currently, the environmental damage is considered as most at the fingertips of the producers, thus setting the ambition for this material for the water boards. Through this ambition, different strategies can be used to lower the environmental impact of the iron and carbon usage of the water boards.

With respect to alloys, Chapter 4 concluded that current possibilities of regaining alloys are limited. This chapter concluded that alloys are at risk. Within the coming years, price rises are expected. These can be observed already today. Some of them will be unavailable within a few decades. Therefore, the ambition set to be able to regain these materials is of the utmost importance. Through this ambition, different strategies can be used to lower the environmental impact of the iron and carbon usage of the water boards.

Figure 6.2: Render of a pumping station
[HHDelfland & Kragten, 2021]

6.3 CIRCULAR STRATEGIES AND INTERVENTIONS FOR A PUMPING STATION – OPERATIONAL LEVEL

Chapter 3 concluded that it's obvious for the water boards to apply circularity in the realisation of new assets. However, it is mentioned that in order to fully profit from circularity, it should be used in all life cycle phases. For an operational level, this means that the strategic ambitions set earlier in this example, are translated to specific operational interventions for a pumping station. In this example of a pumping station, interventions for different life cycle phases will be highlighted.

At first, attention is drawn to the life cycle (8 - maintenance / re-use and 9 - exploitation) which prevent the water boards to go towards replacement / new realisation of a pumping station. If these cycles can be used, this most likely immediately results in a reduction and refusal of new materials. Moreover, most of the assets already exist and newly built asset mainly arise from a replacement program due to a lack of re-use possibilities.

Secondly, attention will be drawn to the life cycles regarding realisation (2 - Design, 3 - Procurement and 4 - manufacturing). Although the use of circularity will decrease the need for new assets, it is important to use circular strategies in new assets to decrease this even more.

6.3.1 Maintenance and re-use

Within the life cycle phases of maintenance and re-use and the given ambitions of Figure 6.1, the following strategies are identified for a pumping station using the implementation tool, thus using and implementing circularity on an operational level. It must be emphasized that these are just a selection of possible strategies. Moreover, the interactions named are just a selection as well, since the interaction matrix Table 5.4 displays a various range of interactions for each strategy. The numbers A - H in front of every intervention correspond with the strategic ambitions mentioned in Figure 6.1.

Ambition		Strategy number + intervention	Example of possible interaction (Table 5.4)	Synergy / conflict / dependancy
Ambition 4	A	27 - Reduce total energy usage by applying solar panels	**Strategy - 7** **Interaction C9**	One might be able to not disassemble solar panels, which would create waste. Demand DfD solar panels.
Ambition 1.3	B	31 - Facilitate areas for a marketplace with other water boards for second-hand quay walls	**Strategy - 3** **Interaction D13**	Available spaces will increase the chance of storing parts, which are replaced during exploitation and refurbished, which can be of later use in a new project instead of being landfill.
Ambition 2.1	C	23 - Trough selecting materials with product labelling a client can select on materials which contribute towards regaining alloys	**Strategy - 2** **Interaction D2**	Regaining alloys will result in the possibility of re-using alloys instead of adding new ones.
Ambition 1.1	D	27 - Focussing on reduction of total used energy during maintenance may reduce total GHG emissions needed for production	**Strategy - 15** **Interaction S20**	Focussing on reduction of energy during maintenance may require large invesments from contractors which they can you more often, therefore contributing to the system.
Ambition 6.1	E	23 Product measurement says something about the current state in the exploitation phase. When a replacement is needed in the exploitation phase, measurement may generate information beneficial for reuse.	**Strategy - 10** **Interaction S31**	A data driven design may result in information which can say something on beforehand about when to replace something and how it thereafter can be re-used.
Ambition 1.2	F	10. Monitoring instead of building standards may take away the fear for using second-hand materials, or reusing for example foundation piles on the same spot.	**Strategy - 35/37** **Interaction D11**	Monitoring of an object is required to make a proper decision on element or substance recovery.
Ambition 4	G	28. Ensuring the production of cement takes place with green energy improves the production process with respect to GHG.	**Strategy - 22** **Interaction S22**	Focussing on reduction of energy during maintenance may require large invesments from contractors which they can you more often, therefore contributing to the system.
Ambition 6.1	H	32. When during exploitation concrete is removed or replaced, seperation may result in cement being re-used.	**Strategy - 27** **Interaction S27**	Seperation opens possibilities for high - quality recycling.

Existing intervention   New intervention

Figure 6.3: Strategies and intervention for life cycle 8 and 9 of a pumping station (own image)

Two of the mentioned interventions are explained in more detail below

EXISTING INTERVENTION: Existing interventions displayed in Figure 6.3 in green can be the use of solar panels, focusing on energy usage during the maintenance by for example mobile windmills or applying monitoring systems during the performance. These can be immediately applied.

NEW INTERVENTION: new interventions displayed in Figure 6.3 in blue for the water boards can be to facilitate areas needed to store quay walls with other water boards, as this is something the range of a single water board moat likely is too small for.

6.3.2 Realisation

Within the life cycle of (2 - Design, 3 - Procurement and 4 - manufacturing) and the given ambitions of Figure 6.1 for the materials, the following opportunities for a pumping station are identified using the implementation tool. It must be emphasized that these are just a selection of opportunities. Moreover, the interactions named are just a selection as well, since the interaction matrix Table 5.4 displays a various range of interactions for each strategy. The numbers A - H in front of every intervention correspond with the strategic ambitions mentioned in Figure 6.1.

Ambition		Strategy number + intervention	Example of possible interaction (Table 5.4)	Synergy / conflict / dependancy
Ambition 4	A	1 / 8 - Redesign the steel quay walls by certified wooden quay walls	**Strategy - 9** **Interaction C1**	Eco design (wood) may require more materials to obtain the same specifications. Moreover, wood requires land use. Find a balance between the two.
			Strategy - 12 **Interaction S26**	Additional, new taxation models might be needed to create a business case. Wood needs more labor, which is highly taxed.
Ambition 1.3	B	2/3 - If steel is required, prohibit new produced ones	**Strategy - 14** **Interaction D8**	It requires green procurement criteria to put this on the market.
Ambition 2.1	C	6 / 7 - Offer the pump market a vision on your ambitions of pumps. This means separable parts of pumps and maybe pumps as a service.	**Strategy 22** **Interaction D14**	Separable pumps require a special market in which standardization is required. This opens up for product as a service, as the producer becomes the expert
		6 / 7 / 10 / 11 - Aim for standardisation in pumping stations	**Strategy 42** **Interaction S23**	Standardisation incorporates principles that could enhance and complement the theoretical resuability of compontents and the quality of the materials after disassembly
Ambition 1.1	D	6/32 - Only permit applications in which alloys can be restracted, or suppliers who demonstrably invest in those techniques.	**Strat 16** **Interaction S32**	This will make improve direct interventions on reuse of substances in the future
Ambition 6.1	E	3 / 4 - Demand use or involvement of producers into HAS / ADR techniques.	**Strategy 10** **Interaction S4/8**	By striving for a high proportion of secondary materials, monitoring the object can improve the current culture of secondary materials, in which fear plays a major role
Ambition 1.2	F	2 - Demand concrete with maximum amount of concrete granulate	**Strategy 23** **Interaction D6**	It is required to use labelled concrete or measure the concrete capacities in order to use it within the project
Ambition 4	G	1 - Demand partly use of geo-polymers + involvement of producer in building standards	**Strategy 13** **Interaction S26**	Taxation or credits and subsidies can create more space for a viable business case with circular materials
Ambition 6.1 (H)	H	1 - Redesign the concrete foundation piles with wooden piles	**Strategy 20** **Interaction C12**	Bio-based materials may have a less longer life span than normal concrete. A balance between the two is needed

Existing intervention   New intervention

Figure 6.4: Implementation possibilities within realisation phase

Two of the mentioned interventions are explained in more detail below

EXISTING INTERVENTION: Existing interventions displayed in Figure 6.4 in green name various existing interventions which could be applied in the realisation phase of a pumping station. Some of the ambitions already are implemented in reality.

NEW INTERVENTION: New interventions displayed in Figure 6.4 in blue mention amongst others modularity (Strat 7). Although executed in practice by now, standardization is absent (Interview 4). This means that using the modularity concept in the future becomes difficult, as there is no vision behind the modularity concept about whether the pumping station needs to be adjustable, versatile etc. Standardization is a basic need for successful modularity. An existing intervention of modularity now has the chance to become worthless in the future. A more systematic approach to this new intervention is needed in order to create a successful existing intervention.

6.3.3 Intervention development

Besides the application of certain circular interventions, Section 5.2.2 mentioned also to focus on the development of certain new interventions, which can be developed towards an existing intervention, thus usable in projects. This can be illustrated with strategy (G) of Figure 6.4. A good example of an intervention that was new and became usable through intervention development is the use of geopolymers as a replacement for cement. This has been in development for quite some time, but through knowledge sharing the start-up phase with accompanying fears for the product have been passed and now is being used more frequently. The European certification system in particular was a barrier. The trick was to use the so-called performance certification. They are therefore not working on a product certificate, nor on a process certificate, but on a performance certificate. This is not obtained on the basis of testing against a standard or assessment guideline, because there is no such thing, but on the basis of a validated performance. It is based on experiences, projects and research elsewhere in combination with current field trials.

This eventually has led that a new intervention became an existing intervention. With this, SCS expects to convince all construction parties, including insurers, of the possibilities to use this product [Tissink, 2021].

Figure 6.5: Photograph of a pumping station
[WDOD, 2021]

7 CONCLUSION

This research addresses the topic of circularity. More specific, it places the subject in the context of climate change and conscious public commissioning. The research focuses on the water boards in the Netherlands and outlines the necessity and possibilities for the use of circularity for this specific public client. By doing so, the research answers the main question through its sub-questions:

- **1. What is circularity, and what are current developments and bottlenecks within the Dutch construction sector regarding this theme?**

Circularity should be seen as a method, which can be used to overcome the problems of resource depletion, GHG and related problems. Circularity should be defined in a systematic manner, which means the water board should assess and implement circularity not in one project, but on multiple projects over time. Within this definition, multiple developments are appointed, with the CMM as an outstanding development. The CMM fits the set criteria for assessing circularity in a systematic approach using an LCA, thus being suitable for this research. Bottlenecks regarding circularity have been addressed and a typology is drawn. Based on the literature, barriers can be expected in Technological, Legal, Micro-Market, Macro-Market and Regulatory aspects.

- **2. What are current innovation enablers and bottlenecks within the Dutch water boards with respect to the implementation of circularity?**

The water boards are closely connected to nature, as most of their assets have as a core task controlling the behaviour of nature, for example, water level differences. The characterization of a water board is not unambiguous. The history of the water boards causes them to differ quite a lot in asset management levels, the status of assets etc. Nowadays, water boards differ to those topics between themselves, but within a single waterboard, these topics differ as well. This results in having different ideas about what circularity is and how to use or implement this. This research argued that these kinds of issues can be overcome by the use of overarching programs and life cycle approaches. Examples such as the HWBP show that these programs are a success factor for innovations in both the realisation and asset management phases. Circularity is a systematic approach which means that water boards should implement circularity in all life cycle phases of an asset. This research showed that the asset management department requires more attention to increase its maturity when it comes to these innovative circular ideas. Nowadays, innovations tend to happen only in the realisation of water boards. Besides the fact this restricts innovations possibilities, it won't allow circularity to function properly, as circular strategies are connected throughout all life cycles. Moreover, the differences in time and budget between the realisation phase and asset management is one of the reasons the asset management department is anxious for circular innovations as it might be a threat to their core business. Therefore it is necessary to get asset management on the same level as the realisation in the water boards.

- **3. How do the chains of concrete and steel as a building material look like, which (type of) actors are present within that chain and what do they need to implement circularity?**

Both of the chains are characterised as a chain with multiple phases. A difference can be observed between the concrete and steel chains. The concrete market is a more flexible market than the steel market because of various reasons (e.g. globalisation of the steel market). The differences between these materials on the different CMM pillars show that is important to look beyond circularity. The various parts of the chain require different approaches to use circularity. Circularity should not be the goal. It is important to see where in a material chain circularity is required. This is important for the water boards, as they have the power to influence the chain and have to use this power effectively.

This research showed that over the years the actors in the chain have all become aware of the need for change, even the primary material producers, which do have a future business case. This means that primary material producers need to be included in circular strategies. The actors in the chain indicated to require three specific changes: *'Formulating a circular economy'*, *'new ways of appraising value'* and *'raising awareness'*.

- **4. Which ambitions and different circular strategies can be defined for civil structures, and how can these be combined towards a circular implementation tool for the water boards?**

This answer is being given by using key developments from the literature study and combining them in an implementation tool. It is argued to use the CMM indicators as ambitions for each material. It is advised to agree on those ambitions in overarching programs, thus by multiple water boards together, preferably all of them. 42 circular strategies are presented, connected throughout 9 LCA phases. These strategies are connected to the CMM indicators with the implementation tool. This tool shows which strategies can contribute to which indicators and thus help the water boards to **use** circularity as a solution for a certain problem in a material chain. Moreover, the chapter explains the different types of interventions and explains that circularity is a method that should be **implemented** over time. This process will enable to develop new interventions. If attention is being paid to a new intervention now, it might be applicable overtime in the next project. The implementation tool shows the current state of interventions related to circular strategies and CMM indicators.

Through these sub-questions, the research can answer its main question:

- **How can water boards use and implement circularity and thus contribute to the prevention of resource depletion and counteract climate change?**

The water boards should understand what circularity exactly is. They should realise that treating circularity as a goal on its own will not have the desired results in 2030. A joint definition of what circularity is will enable water boards to use circularity successful by identifying opportunities and tackling barriers. This research presented an implementation tool according to a systematic definition. It places circularity in the context of a systematic approach, rather than a project-based approach. This systematic approach emphasises that implementing a CE requires a fundamental shift rather than an incremental shift of the current system. Currently, the prevailing thought is to treat circularity as an 'extra item' in program requirements. This might lead to some positive results at first, but will very likely not contribute to intervention development, let alone a successful integrated approach to the real problems of resource depletion and climate change.

The water boards can implement circularity by means of the developed tool, which guides the development of interventions over time. Circularity therefore can not be implemented at once but in a systematic way. In order to use this tool, the water boards should have a clear insight into what the actual problems related to resource depletion and climate change are and how these problems can be related to materials such as concrete and steel. If this is well understood, the implementation tool can ensure the correct use of circularity to the solution of these problems. The water boards altogether should set clear strategic ambitions for the materials in their assets, and use interventions on an operational level to use circularity effectively.

8 DISCUSSION

8.1 DISCUSSION OF THE RESEARCH DESIGN

A mixed-method approach was used to execute the research. The executed interviews, research to grey literature and scientific literature study is a qualitative method discussed in the introduction of this research. The validity of this research is discussed below.

8.1.1 Scientific literature

Regarding the use of scientific literature, it has been concluded that the term 'circularity' has many different interpretations. This has resulted in a very extensive literature review and the need to include grey literature in order to define how circularity actually is defined in the Dutch construction sector. Combined, this has led to an extensive elaboration on the chosen definition of circularity in this thesis; a systematic definition, which came forward in the scientific literature and is validated in grey literature. This result provides the input for the choice in this research for a suitable measurement method – and thus connects this graduation research to the existing body of literature.

Moreover, literature on the practical implications of circularity in the water boards was barely present. This resulted in the contribution of scientific research not prevailing in answering the sub-questions but that it together with the collected data, led to the conclusions. This means that literature with clear conclusions was usually not available, leading to interpretations of the author, with pitfalls such as the selection bias of the author, and the included literature not being individually appraised on validity.

8.1.2 Grey literature

This research uses grey literature, for example, policy documents, in order to gain insight into what the actual goals of the Dutch government are with respect to circularity and which problems exist in current material chains. These documents, therefore, provide, in combination with scientific literature, the input for the problem statement, objectives and research questions – and thus connects this research to the existing body of grey literature. Furthermore, grey literature gave further substance to the systematic approach that followed from the literature study, by choosing the CMM as a suitable approach and measurement method to use circularity in the construction sector, thus connecting the research again to existing grey literature.

However, the use of grey literature is not without consequences. Although broadening the possible sources of the research, it is a challenge to remain the quality at a constant level. As this research was about exploring new concepts, the amount of scientific research is limited. The research topic, however, is booming, resulting in a high amount of grey literature being produced and has therefore a high potential for subjectivity. Adams et al. [2017] states that grey literature may be of use in research aiming for guidance in practice. However, it also mentions the fact that there is no evidence for this resulting in better outcomes. It recommends evaluating the outcomes after a certain period, and at the same time combine it with other research methods.

8.1.3 Interviews

In order to substantiate and validate the research with actual data and practical insights, interviews have been held. The interviews were executed in a semi-structured manner, through an interview protocol. This protocol was prepared with the information and data from the literature study. This type of interview offers the possibility of steering the themes of the interview, but at the same time offering space to the interviewee to introduce relevant aspects not addressed at first in the protocol, thus providing new insights.

The interview data substantiated the description of the water boards as an organisation, thus providing insight into barriers and opportunities for circularity in the construction industry. The same has been achieved for the material chains, which provides insight into how involved actors respond to the implementation of circularity. Moreover, the interviews substantiated the choice for a systematic approach, which therefore indicates that data from the interviews is in line with the earlier results from the (grey) literature and thus connects the interview data to this research.

Regarding the set boundaries for this research, limitations have been encountered for this method. This research mentioned the huge differences between the 21 water boards and their internal departments. This has been encountered by organising duo-interviews, with people from the same departments but from different water boards. However, results might differ when more or different boards were included. The argument holds for the material suppliers as well. Only 3 interviews are conducted with 3 different organisations in the material chain, while the material suppliers are widespread across the world and therefore it is expected they differ quite a lot. Moreover, as this topic is social in the sense that the behaviour of people highly influences the choices being made, it must be noted that most of the people involved were strong supporters of the circular economy and therefore it is plausible that they look at the subject unambiguously. More attention towards the more negative or less involved persons could result in other insights.

8.2 QUALITY AND LIMITATIONS OF THE RESEARCH

As discussed in the introduction, the research aims to provide quality research throughout the concepts of credibility, transfer-ability and consistency [Lincoln and Guba, 1985]. In this section, first, the quality of the methods is discussed. Furthermore, the research outcomes are discussed.

8.2.1 Quality and limitations of the research methods

Credibility is achieved by using the concept of triangulation, to overcome the problems mentioned above, thus comparing literature with grey literature and interview data. As mentioned, within the set time and scope constraints, the interviews were held with a variety of people. This was achieved by interviewing multiple departments of different water boards.

The transferability is cared for two-fold. Firstly, the concepts bespoken are described in detail, with plenty of guidance to provide clarity and structure. Even a whole chapter is dedicated to an example. Secondly, the presented implementation tool incorporates strategies which can be used for all type of assets within a water board and is not restricted to a pumping station. Although the described implementation tool is designed for concrete and steel and applied at a pumping station, the recommendations and the tool are wide applicable amongst the assets of water boards.

The consistency of the research can be observed by the fact that triangulation is applied. Only the first question is answered by literature, subsequent questions are answered by multiple sources. Moreover, consistency and clarity are achieved by closing every chapter with a summary of the chapter and starting every new chapter by explaining which concepts of previous chapters are used.

In conclusion, it can be argued that the three elements are treated within the possibilities of the research has. Time constraints and the fact that semi-structured interviews require a lot of work, both in scheduling and analysing, limited the number of interviews. On top of that, the CMM still is in development and therefore this research should be adopted after the revision of the CMM. Therefore, room for improvement on the quality of this research is certainly possible – although the quality could be labelled satisfactory.

8.2.2 Quality and limitations of the research outcomes

Regarding the quality of the research outcomes, the research plan mentioned three scientific outcomes in Section 1.8.1. The quality and limitations of these outcomes are discussed in this section.

- Providing insight on which areas barriers are experienced and which changes are therefore needed to close the cycle of materials in practice. This is done for the construction sector, material chain and the water boards in particular;

The research provided a literature overview of the expected barriers by means of a literature study. Therefore, these results adopt the characteristics of a literature study. In this case, that implies that the credibility of the sources is quite high, however, the transferability was in danger since the literature conducted to specific the Dutch construction market in relation to circularity is very limited. Nothing was to be found on the water boards. At the same time, literature conducted on the material suppliers was enormous, as this is a globalised industry and they are under a magnifying glass everywhere. By means of triangulation, this transferability has been enhanced. Specific attention and more time have been spent on water boards in the interviews and new emerging parties. However, due to the earlier described potential bias, the results of this overview could be not fully complete or correct. The same accounts for the proposed changes within the water boards or the chain of materials.

This research focussed on circularity as a systematic approach, thus including problems like resource depletion, GHG etc. The water boards however do not only deal with civil structures and related problems but have to deal with biodiversity as well. Biodiversity explicitly was not part of this research, but is an important part of the asset management of the water boards and is represented in the CMM as well (indicator 4). Therefore, indicator 4 is treated as one indicator, whereas in reality, 18 indicators take place within this indicator, all relating to different sub-problems and therefore will need different strategies to be tackled whereby in this study these sub-indicators are all lumped together.

Moreover, the material chain studied in this research did not incorporate the mining activities/strategies of primary or secondary materials. It is likely that different methods of mining have pros and cons, and can be translated into extra strategies for the implementation tool.

- Providing the core principles of circularity and what that implies for the current project-based approach of Water boards;

The core principles have been identified by literature, leading to a distinction between a systematic approach of the R-frameworks. (Grey) literature regarding this topic quite often addressed this. Therefore, the shift to a systematic approach has been argued and tested as a hypothesis in the interviews. This results in the high credibility of this research outcome. As this core principle automatically includes the bigger picture of the whole sector, this makes the results transferable to other sectors as well. Moreover, this perspective runs like a thread through the research, making the implications of this choice clearly outlined.

The core principle of circularity has as a starting point the infinite amount of available green energy. This energy is needed to execute a lot of the mentioned strategies in this research. However, this infinite amount is far from reality. It is therefore advised to be somewhat cautious with circular strategies that require a lot of energy, and at the same time remain active with the development of green energy and usage reduction. Until the moment green energy is widely accessible and available, this is a major limitation to the outcomes of this research.

- It provides an implementation tool that incorporates existing measurement tools that focus on materials in the Dutch construction sector, such that it can be used for multiple assets of the waterboard.

After the given definition of circularity as a systematic approach, the research provided a clear measurement method of circularity, by the introduction of the CMM. It is explained how this method can contribute to the successful use of circularity and which steps a water board should make in order to achieve this. This method, therefore, is an important base for the results of this thesis. The method is existing and even incorporates other tools such as the MKI, therefore perfectly suiting this objective.

The implementation tool in this research is built upon the CMM. This method has been established with input from various actors within the Dutch Construction industry. The credibility of this method, therefore, is quite high. Even though the CMM is widely supported within the Dutch construction sector, the construction sector has not yet selected this method as the main method for working/implementing circularity or made its use mandatory. This research argues this method is suitable and should be adopted by the actors in the chain. Although assessed suitable, case studies could not be executed as the first projects with this method just start. Therefore, validating this approach was not possible, thus making the method and this research prone to errors. Moreover, validation of this research is not something that can be done through usual validation tools, such as validation interviews. Validation and evaluation is part of the process and therefore this research should be treated as learning on the job. It can therefore be considered as a base for the transition, rather than being a rigid approach. On top of that, after the CMM is finished, the presented implementation tool should be adjusted towards the revision of the CMM.

The implementation tool further uses circular strategies. These strategies come from various sources, thus enhancing credibility. Coupling the strategies to the CMM method has been done by the author, discussing the choices with the direct mentors only. Validation was, as mentioned before, not possible and the implications of these results are so big that multiple years of research should be conducted to validate the developed tool. This means that the credibility of the method is not fully delineated. By adopting this tool and fully describing it, including an implementation example, the transferability has been covered and the outcomes of this research can be used for other materials and assets than described in this research.

The used method for the implementation tool, the CMM, still is at its design phase and currently is being evaluated. It is a widely supported method in the Dutch construction sector but also restricted to the Dutch construction sector. However, this research has not been involved in the evaluation process the developer of CB'23 has set up, therefore potentially missing pitfalls this method has. A new version is to be presented in July 2021 and the theory of this research should be changed accordingly.

For all of these research outcomes, the consistency of the problems has been covered by the application of triangulation, earlier described. This means that themes in the scientific literature have been compared with grey literature, and are addressed in interviews.

8.3 RECOMMENDATIONS FOR FUTURE RESEARCH

Generally, scientific research has scope restrictions or recommendations that arise from the discussions. The recommendations following from this research are mentioned in this section.

Firstly, it is recommended to investigate the differences between the used version of the CMM and the new version to be published in 2021. The indicators and the three main pillars might be adjusted, thus having consequences for the presented implementation tool.

Secondly, in order to guide the water boards further towards successful use of circularity, it is suggested to conduct research on all material streams ongoing in the water boards. This research scope set the constraints towards steel and concrete, but it showed that the place in which circularity should be used can differ quite a lot. In order to determine which changes in a material change are required to change resource depletion, GHG and related problems, research towards all the material chains and their real problems could be beneficial for the water boards in order to use the presented implementation tool for other materials too.

Thirdly, within the scope of this research, it is advised to investigate which interfaces the theme of biodiversity has with the results of this research. Biodiversity is something influenced by resource depletion and GHG. Biodiversity is very closely related to water boards. However, biodiversity cannot only be viewed from a construction perspective, so the question is whether the CMM method is the right method for determining and guiding the water boards to successful use of circularity within the theme of biodiversity. If this is not the case, there is a risk that the CMM will not comply with the systematic approach of circularity.

Fourthly, the transferability of the research could be enhanced, by performing cross-case research into whether the presented theories can also be applied to other public clients, and to which extend the observations and barriers presented for the water boards are comparable. This concerns on the one end the organisational aspects, but on the other hand the differences in the types of assets and services that these organizations manage.

Fifthly, it is recommended to investigate how circularity is treated abroad and the existence of measurement methods in other countries. Scientific literature in this research is not restricted to The Netherlands, but the grey literature is. Therefore, international methods comparable to the CMM have not been made clear. Perhaps comparable methods can be found, perhaps not. If such methods exist, comparing those methods and spotting important differences in research is not only fruitful for this research or the water boards, but for the successful use and implementation of circularity across the globe.

Sixthly, the interview data from this research showed that a potential research gap can be found in the procurement tools of the water boards. Procurement is an important tool of the water boards in order to steer the market, as the water boards cannot realise the ambitions to overcome resource depletion and climate change on their own. Appendix G shows a preview of potential research topics. Research to expertise development, the question of who should be the expert in a project with circular ambitions and transferring knowledge of circularity to other projects, while at the same time protecting circular business cases can improve the market to implement and use circularity.

BIBLIOGRAPHY

Adams, R. J., Smart, P., and Huff, A. S. (2017). Shades of Grey: Guidelines for Working with the Grey Literature in Systematic Reviews for Management and Organizational Studies. *International Journal of Management Reviews*, 19(4):432–454.

Afshari, A. and Górecki, J. (2019). Circular economy in construction sector. Department of Industrial Engineering, Shirvan Branch, Islamic Azad University, Shirvan, Iran 2 UTP University of Science and Technology, Bydgoszcz, Poland.

Arnoldussen, J., Roemers, G Errami, S., Blok, M., Semenov, R., Kamps, M., and Faes, K. (2020). Materiaalstromen,milieu-impact en energieverbruik in de woning- en utiliteitsbouw, uitgangssituatie en doorkijk naar 2030.

Ashokkumar, A. B. (2020). Implementing the design for disassembly principle in the public procurement process of buildings in the Netherlands. MSc. Thesis, TU Delft.

Bendixen, M., Best, J., Hackney, C., and Iversen, L. (2019). Time is running out for sand. *Nature 571, pages 29–31*.

Beumer, M. (2020). 13 tools waarmee je de circulariteit van producten en organisaties kan meten. https://www.circulairondernemen.nl/bibliotheek/11-tools-waarmee-je-de-circulariteit-van-producten-en-organisaties-kan-meten. Den Haag.

Binnekamp, R. (2020). Cie4030 cme addendum reader. www.brightspace.tudelft.nl. TU Delft.

Björkman, B. and Samuelsson, C. (2014). Recycling of steel. *Handbook of Recycling: State-of-the-art for Practitioners, Analysts, and Scientists*, pages 65–83.

Bourguignon, D. (2018). Material use in the european union, towards a circular approach. *European Parliament Think Tank*. EU.

Bouwagenda (2020). Vrijgekomen en verwerking van afval per doelgroep, 1990-2012. http://www.compendiumvoordeleefomgeving.nl/indicatoren/nl0206-Vrijkomen-en-verwerking-van-afval-per-doelgroep.html?i=1-4. Den Haag.

Burger, J., Ter Haar, F., and Leclercq, E. (2020). Maar hoe dan? een evaluatie van circulaire projecten bij (semi) publieke opdrachtgevers. *Opdrachtgeversforum, Werkgroep circulaire bouweconomie*.

Carles, J. (2019). Cleaning up steel is key to tackling climate change. *Financial Times*. London.

Castelein, L. (2018). Circulair contracteren in de bouwsector. Master's thesis, Technische Universiteit Delft.

CB23 (2020a). Leidraad: Meten van circulariteit, werkafspraken voor een circulaire bouw v2.0. Platform '23, Den Haag.

CB23 (2020b). Leidraad: Paspoorten voor de bouw, werkafspraken voor een circulaire bouw v2.0. Platform '23, Den Haag.

Chen, C., Habert, G., Bouzidi, Y., and Jullien, A. (2010). Environmental impact of cement production: detail of the different processes and cement plant variability evaluation. *Journal of Cleaner Production*, 18(5):478–485.

Chen, T.-L., Kim, H., Pan, S.-Y., Tseng, P.-C., Lin, Y.-P., and Chiang, P.-C. (2020). Implementation of green chemistry principles in circular economy system towards sustainable development goals: Challenges and perspectives. *Science of The Total Environment*, 716:136998.

Compendium voor de Leefomgeving (2015). Wat is circulair bouwen? https://circulairebouweconomie.nl/. Den Haag.

Corona, B., Shen, L., Reike, D., Rosales Carreón, J., and Worrell, E. (2019). Towards sustainable development through the circular economy—a review and critical assessment on current circularity metrics. *Resources, Conservation and Recycling*, 151:104498.

Coste, L. (2019). The role of municipal policy in the circular economy. Goldschmeding Foundation.

Cramb, A. and Amuda, M. (2017). *Steel Production and Refining*.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage.

De Groot, F. (2019). Circulair bouwen wordt minder vrijblijvend. Bouwtotaal.

de Jesus, A. and Mendonça, S. (2018). Lost in transition? drivers and barriers in the eco-innovation road to the circular economy. *Ecological Economics*, 145:75–89.

De Leeuw, M. (2020a). Duurzaam bouwen, op weg naar een hoger niveau in 2021. *Cobouw*.

De Leeuw, M. (2020b). Materialenpaspoort nog lang niet uniform in gww-sector. *Cobouw*.

De Saar, N. (2021). Waterschap doet bijzondere bruggenaanbesteding in groningen. *CoBouw*.

De Valk, E. and Quik, J. (2017). Eenduidig bepalen van circulariteit in de bouwsector. Ministerie van Volksgezondheid Welzijn en Sport, Den Haag.

De Vries, F., Van Schijndel, H., Van Bezu, K., and Blekemolen, M. (2018). Onderzoek over de transitie naar de circulaire utiliteits-, grond-, weg- en waterbouw op zoek naar hefbomen vanuit een inkoop- en aanbestedingsoogpunt. TwynstraGudde.

Delevingne, L., Glazener, W., Grégoir, L., and Henderson, K. (2020). Climate risk and decarbonization: What every mining ceo needs to know. building a climate strategy won't be quick or easy—but waiting is not an option. McKinsey & Company.

Dew, K. (2007). A health researcher's guide to qualitative methodologies. *Australian and New Zealand Journal of Public Health*, 31(5):433–437.

Dijksma, A. and Kamp, H. (2016). Nederland circulair in 2050, rijksbreed programma circulaire economie. Den Haag.

Ellen MacArthur Foundation (2017). What is the circular economy. https://www.ellenmacarthurfoundation.org/circular-economy/what-is-the-circular-economy.

Emmelot, J. (2021). Circular housing envelope elements from residual materials. MSc. Thesis, TU Delft.

EPA (2021). Ferrous metals: Material-specific data. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/ferrous-metals-material-specific-data.

EU (2019). Sustainable buildings for europe's climate-neutral future. https://ec.europa.eu/easme/en/news/sustainable-buildings-europe-s-climate-neutral-future.

European Commission (2008). Waste and repealing certain directives. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008.

European Commission (2020). A new circular economy action plan. European Parliament Think Tank.

Favier, A., De Wolf, C., Scrivener, K., and Haber, G. (2018). A sustainable future for the european cement and concrete industry, technology assessment for full decarbonisation. ETH Zurich, Ecole polytechnique federale de Lausanne.

Fusch, P. and Ness, L. (2015). Are we there yet? data saturation in qualitative research. *Qualitative Report*, 20:1408–1416.

Gavriletea, M. (2017). Environmental impacts of sand exploitation. analysis of sand market. *Sustainability*, 9(7).

Geissdoerfer, M., Savaget, P., Bocken, N., and Hultink, E. (2017). The circular economy – a new sustainability paradigm? *Journal of Cleaner Production*, 143:757–768.

Geldermans, R. (2016). *Design for change and circularity – accommodating circular material & product flows in construction*. Energy Procedia. pag.301 – 311.

Ghaffar, S. H., Burman, M., and Braimah, N. (2020). Pathways to circular construction: An integrated management of construction and demolition waste for resource recovery. *Journal of Cleaner Production*, 244:118710.

Ghisellini, P., Cialani, C., and Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, 114:11–32. Towards Post Fossil Carbon Societies: Regenerative and Preventative Eco-Industrial Development.

Gioia, D., Corley, K., and Hamilton, A. (2013). Seeking qualitative rigor in inductive research. *Organizational Research Methods*, 16:15–31.

Groot, P. and Visser, N. (2016). Evaluatie marktvisie waterschappen, ervaringen tot nu toe en bouwstenen voor vernieuwing. *EIB*. Amsterdam.

Górecki, J., Núñez-Cacho, P., Corpas-Iglesias, F., and Molina-Moreno, V. (2019). How to convince players in construction market? strategies for effective implementation of circular economy in construction sector. *Cogent Engineering*, 6.

Hanemaaijer, A., Kishna, M. Kooke, M., Brink, H., Koch, J. Prins, A., and Rood, T. (2019). Circulaire economie in kaart. Planbureau voor de leefomgeving, Den Haag.

Hanemaaijer, A., Kishna, M. Kooke, M., Brink, H., Koch, J. Prins, A., and Rood, T. (2021). Integrale circulaire economie rapportage. Planbureau voor de leefomgeving, Den Haag.

Hermans, M. (2014). 'is a little more alright?'. Delft University of Technology.

Hermans, M. (2020). TU Delft course slides AR2R036 Public construction clients. https://brightspace.tudelft.nl/d2l/le/content/193704/viewContent/1614138/View.

HHDelfland & Kragten (2021). Render gemaal. https://www.hhdelfland.nl/. Internal design document.

Hillege, L. (2019). Milieukostenindicator mki – overzicht. Ecochain articles.

IEA (2020). Iron and steel. https://www.iea.org/reports/iron-and-steel. Paris.

IenW (2020). Uitvoeringsprogramma circulaire economie 2020-2023. Den Haag.

IPCC (2016). *Guidelines for National Greenhouse Gas Inventories, metal industry emissions*.

ISO (2006). Iso 14044:2006(en) environmental management — life cycle assessment — requirements and guidelines. https://www.iso.org/obp/ui/#iso:std:iso:14044:ed-1:v1:en. Genève, Swiss.

Jackson, M., Lederwasch, A., and Giurco, D. (2014). Transitions in theory and practice: Managing metals in the circular economy. *Resources*, 3(3):516–543.

Jawahir, I. and Bradley, R. (2016). Technological elements of circular economy and the principles of 6r-based closed-loop material flow in sustainable manufacturing. *Procedia CIRP*, 40:103–108. 13th Global Conference on Sustainable Manufacturing – Decoupling Growth from Resource Use.

Jeltya, F. (2016). Amsterdam opent circulair gebouw voor rechtbank. https://www.duurzaambedrijfsleven.nl/infra/19003/amsterdam-opent-circulair-gebouw-voor-rechtbank.

Jongeneel, C. (2020). Circulair bouwen worstelt met bestaande normen. *Techniek en wetenschap in perspectief*.

Kakabadse, N. and Steane, P. (2010). Meaning and interpretation: Insights and discourse. *Journal of Management History*, 16.

Kalmykova, Y., Sadagopan, M., and Rosado, L. (2018). Circular economy – from review of theories and practices to development of implementation tools. *Resources, Conservation and Recycling*, 135:190–201. Sustainable Resource Management and the Circular Economy.

Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., and Hekkert, M. (2018). Barriers to the circular economy: Evidence from the european union (eu). *Ecological Economics*, 150:264–272.

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

Koenen, I. (2013). Innovatie blijft nog beperkt tot wat koplopers en individuen. Cobouw.

Koops, R. (2020). Waar blijft die circulaire uitvraag. *Binnenlands bestuur*. Sweco.

Kowalska, A. and Sobczyk, W. (2014). Negative and positive effects of the exploitation of gravel-sand. *In˙zynieria Miner*, 15:105–'09.

Kramer, W. (2020). Betonmarkt in nederland. https://betonhuis.nl/cement/betonmarkt-nederland.

Kuijpers, M. (2020). Staal is onmisbaar én supervervuilend. hoe ziet een duurzame ijzertijd eruit? *De Correspondent*. Amsterdam.

Leising, E., Quist, J., and Bocken, N. (2017). *Circular Economy in the building sector: Three cases and a collaboration tool*. Journal of Cleaner Production. nr: 176, pag.976 – 989.

Liebsch, T. (2019). Levenscyclusanalyse (lca) – een volledig overzicht voor beginners. https://ecochain.com/nl/knowledge/levenscyclusanalyse-life-cycle-assessment-lca-complete-beginners-guide/. EcoChain.

Lincoln, Y. and Guba, E. (1985). *Naturalistic inquiry*. SAGE publications.

MacArthur, D., Zumwinkel, K., and Stuchtey, M. (2015). Growth within: a circular economy vision for a competitive europe. McKinsey Center for Business and Environment.

Manickam, P. and Duraisamy, G. (2019). *4 - 3Rs and circular economy*. The Textile Institute Book Series. Woodhead Publishing.

Matthews, T. K. R., Wilby, R. L., and Murphy, C. (2017). Communicating the deadly consequences of global warming. Columbia University press.

Medina, E. and Fu, F. (2021). A new circular economy framework for construction projects. *Proceedings of the Institute of Civil Engineers: Engineering Sustainability*.

Meijdam, H., van Ardenne-van der Hoeven, J., Demmers, M., Dykstra, E., Frissen, L., de Graeff, J.J.and Hooimeijer, P., Koeman, N., van Lier Lels, M., Meester, G., Nijhof, A., and Vanstiphout, W. (2015). Circulaire economie, van wens naar uitvoering.

Mentink (2014). Circular business model innovation: A process framework and a tool for business model innovation in a circular economy. MSc. Thesis, Technische Universiteit Delft.

Milin (2017). Circulair bouwen met milin bv. https://www.milin.nl/blog/circulair-bouwen-met-milin-b-v/.

Miller, S. A. (2020). The role of cement service-life on the efficient use of resources. *Environmental Research Letters*, 15(2):024004.

Min. EZK (2016). Handreiking bij stap één in lca: Doel & scope. Ministerie van Economische zaken, Klimaat en Innovatie, Den Haag.

Moreno, M., Rios, C., Rowe, Z., and Charnley, F. (2016). A conceptual framework for circular design. *Sustainability*, 8:937.

Moss, K. (2019). Here's what could go wrong with the circular economy—and how to keep it on track. *World economic forum*.

Mutsaers, M. (2019). Kansen voor circulair bouwen in de aanbestedingswet 2012. Nysingh, Utrecht.

Oda, J., Akimoto, K., and Tomoda, T. (2013). Long-term global availability of steel scrap. *Resources, Conservation and Recycling*, 81:81–91.

Oostdijk, A., Dreef, S., and Schellekens, J. (2019). Evaluatie stelsel nationale milieudatabase en milieuprestatie gebouwen en gww-werken. Berenschot.

Overmars, A. (2019). Hulpmiddelen circulair bouwen. https://www.hevo.nl/actueel/blog-circulair-aanbesteden-deel-2.

Overmars, A. (2020). Hulpmiddelen circulair bouwen. https://www.hevo.nl/actueel/blog-circulair-aanbesteden-deel-3.

Pachauri, R. and Meyer, L. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC.

Pereira, K. (2012). Sand mining, the 'high volume–low value' paradox. King's College, London.

Peschier, M. (2019). Handvat duurzaam materiaalgebruik voor bouw- en infrabedrijven praktische tips en voorbeelden. *Stimular, de werkplaats voor duurzaam ondernemen*.

PIANOo (2019a). Dialoog met de markt essentieel voor creatieve oplossingen circulareit. Marktontmoeting GWW, Den Haag.

PIANOo (2019b). Meten en monitoren van circulair en klimaatneutraal aanbesteden voor de gww-sector. Leernetwerk GWW, Den Haag.

PIANOo (2021a). Keuze gunningscriterum en opstellen (sub)gunningscriteria. https://www.pianoo.nl/nl/inkoopproces/fase-1-voorbereiden/keuze-gunningscriterum-en-opstellen-subgunningscriteria. Den Haag.

PIANOo (2021b). Selectiecriteria. https://www.pianoo.nl/nl/metrokaart/selectiecriteria. Den Haag.

Ploeger, H., Prins, M., Straub, A., and van den Brink, R. (2017). Circular economy and real estate: alternatives for operational lease. *Journal of the International Research Conference 2017: Shaping tomorrow's built environment*.

Potemans, A. (2017). Modular building in a circular economy: An exploratory research. MSc. Thesis, Technische Universiteit Delft.

Pots, J. (2018). The stimulation of circular economy in the dutch construction industry : how procurement processes can realize a transition arena that is required in order to stimulate the transition to a circular economy. MSc. Thesis, Universiteit Twente.

Potting, J., Hekkert, M., Worrell, E., and Hanemaaijer, A. (2017). Circular economy: Measuring innovation in the product chain. Planbureau voor de leefomgeving, Den Haag.

Prieto-Sandoval, V., Jaca, C., and Ormazabal, M. (2018). Towards a consensus on the circular economy. *Journal of Cleaner Production*, 179:605 – 615.

RecyclingNL (2021). Ladder van lansink - de afvalhiërarchie. http://www.recycling.nl/ladder-van-lansink-2-0.html.

Reike, D., Vermeulen, W. J., and Witjes, S. (2018). The circular economy: New or refurbished as ce 3.0? — exploring controversies in the conceptualization of the circular economy through a focus on history and resource value retention options. *Resources, Conservation and Recycling*, 135:246–264. Sustainable Resource Management and the Circular Economy.

Rijksdienst voor ondernemend Nederland (2019). Hulpmiddelen circulair bouwen. https://www.rvo.nl/onderwerpen/duurzaam-ondernemen/circulaire-economie/circulair-bouwen/hulpmiddelen.

Rijksoverheid (2018). Circular construction economy. Ecochain articles.

Rijksoverheid (2019). Dubocalc. https://www.rijkswaterstaat.nl/zakelijk/zakendoen-met-rijkswaterstaat/inkoopbeleid/duurzaam-inkopen/dubocalc/index.aspx.

Rijkswaterstaat (2019). Prototype circulair viaduct. Rijkwaterstaat rapportendatabank.

Ritchie, H. (2017). How long before we run out of fossil fuels? https://ourworldindata.org/how-long-before-we-run-out-of-fossil-fuels.

RIVM (2011). Wat is lca? https://www.rivm.nl/life-cycle-assessment-lca/wat-is-lca. Den Haag.

Rotmans, J. (2021). 4 jaar green deal dgww 2.0. https://www.onlineseminar.nl/rotterdamahoy/webinar/6f9369af-127b-4bf2-8321-20fcfa1f7b44/4-jaar-green-deal-dgww-20/. Online webinar.

RWS (2018). Platform cb'23 gaat circulair bouwen concreet maken. https://www.rijkswaterstaat.nl/nieuws/2018/01/platform-cb23-gaat-circulair-bouwen-concreet-maken.aspx. Den Haag.

Salvador, R., Barros, M. V., Freire, F., Halog, A., Piekarski, C. M., and De Francisco, A. C. (2021). Circular economy strategies on business modelling: Identifying the greatest influences. *Journal of Cleaner Production*, 299:126918.

Schraven, D., Bukvić, U., Di Maio, F., and Hertogh, M. (2019). Circular transition: Changes and responsibilities in the dutch stony material supply chain. *Resources, Conservation and Recycling*, 150:104359.

Schut, E., Machiel, C., and Mesman, M. (2015). Circular economy in the dutch construction sector a perspective for the market and government. Ministerie van Infrastructuur en Waterstaat, Den Haag.

Shafiee, S. and Topal, E. (2009). When will fossil fuel reserves be diminished? *Energy Policy*, 37(1):181 – 189.

SKAO (2017). Evaluatie co2-prestatieladder voor waterbouwers stimulans voor samenwerking. https://www.skao.nl/nl/news-item/Evaluatie-CO2-Prestatieladder-voor-Waterbouwers-stimulans-voor-samenwerking.

Stegeman, H. (2015). The potential of the circular economy. Rabobank Publications.

Struker, A., Uijterlinde, C., De Jong, A., Van Esch, R., and Peeters, R. (2020). Stip op de horizon, circulair water 2050. WiCE.

Sönnichsen, S. and Clement, J. (2019). Review of green and sustainable public procurement: Towards circular public procurement. *Journal of Cleaner Production*, 245:118901.

Tissink, A. (2021). Via de achterdeur van de eurocodes bereidt scs de weg voor geopolymeerbeton. *CoBouw*.

TNO (2013). Kansen voor de circular economie. *TNO R10864*. TNO Delft.

Tsolis, N. (2017). Enhancing circularity in the building industry. MSc. Thesis. Technische Universiteit Delft.

UVW (2016a). De waterschapsmarkt van de toekomst, bouwstenen voor vernieuwing. Den Haag.

UVW (2016b). Inkoop- en aanbestedingsbeleid. https://www.uvw.nl/publicatie/inkoop-en-aanbestedingsbeleid-waterschappen/.

UVW (2021). Unie van waterschappen - thema's. https://www.uvw.nl/. Online publications, Den Haag.

van Boerdonk, P., Krikke, H., and Lambrechts, W. (2021). New business models in circular economy: A multiple case study into touch points creating customer values in health care. *Journal of Cleaner Production*, 282:125375.

Van de Vondervoort, S. (2019). Circulariteit in de bouw juridisch bezien. *Tilburg University publications*. Masterscriptie Rechtsgeleerdheid.

van Maastrigt, J. (2019). Quantifying Life Cycle Environmental Benefits of Circular Steel Building Designs, development of an environmental assessment tool for reuse of steel members in building designs for the Netherlands. Master's thesis, Technische Universiteit Delft.

Vos, N. (2018). Bouwen aan een circulaire toekomst een onderzoek naar de betekenisgeving en implementatiemogelijkheden van circulariteit binnen de bouwkolom van bam renovatie concepten. Masterthesis Organisatie, Verandering en Management, Universiteit Utrecht.

WDO Delta (2019). Vernieuwen van 60 gemalen en stuwen. https://www.wdodelta.nl/gemalen-en-stuwen-en-waterbergingen. Waterschap Drents en Overijsselse Delta projecten.

WDOD (2021). Foto gemaal. https://www.wdod.nl/. Internal design document.

World steel association (2018). Fact sheet: Steel and raw materials. Brussels.

Wouters, P. (2019). Ketenanalyse gmb beton. Het toepassen van alternatieve- en gerecyclede materialen in beton.

Wuestman, E. and Bakker, K. (2021). Rapid circular contracting, innovatiegericht circulair inkopen. *Stichting Circulaire Economie*. Den Haag.

A CLARIFICATION OF SYNERGIES, DEPENDENCIES AND POTENTIAL CONFLICTS

S1 Using bio-based materials may have a positive influence on the Eco Design and the other way around.

S2 DfD incorporates principles that could enhance and complement the theoretical reusability of components and the quality of the materials after disassembly.

S3 Design for disassembly and policy on circular contracting: Design for disassembly implies no circular contracts (such as take-back contracts), but both do increase the or safeguard the potential for reuse.

S4 Use of secondary materials of the building process and embodied energy of materials used: By striving for a high proportion of secondary materials, the embodied energy could also decline (provided by the dismantling and transport process is not excessively energy - intensive) and thus produce a more favourable effect, and vice versa

S5 Product labelling will result in a more detailed overview about the capacities of materials. This might result in possibilities in reduction

S6 Material use of the lifespan and embodied energy: By striving for less material use, the total embodied energy could also be more favourable, and vice versa.

S7 Environmental impact of materials used and energy efficiency of buildings including systems and technologies: striving for optimal efficiency

S8 Use of secondary materials for the building process and certification of materials: secondary materials have no supply chain from the extraction or production location (where a large part of the impact generally occurs), which could make certification less urgent.

S9 Product labeling may result in less risks by reducing the amount of material. Performance can be predicted more accurate due to better information data and the other way around.

S10 Using scrap materials, re-used parts from objects or marketplaces may have a positive influence on the Eco Design and the other way around.

S11 By striving for the use of bio-based materials, the incentive to provide product labels is present. Vice versa, by aiming for product labelling bio-based materials may act as an example for other materials

S12 By striving for design for disassembly, the modularity of a building could also increase which might result in synenergy

S13 By striving for reused materials from EoL objects and parts from marketplaces, modular building and DfD could be viable design options because building bricks are available. vice versa, modular building and DfD could create a demand for certain materials

S14 By striving for DfD and modular building the theoretical possibilities for substance recovery, functional recycling and high-quality recycling are improved.

S15 In a traditional sector, incentives need to be created in order to create space for circular design ambitions. Therefore, the green procurement should demand ideas for preventing waste after lifetime, which could stimulate modularity and DfD

miro

Figure A.1: Clarification of synergies

S16 By striving for a Data-based design, the degree of eco design could be improved due to eco materials mostly have a better information base which can take for examples material passports to a higher level

S17 By striving to use circular procurement, the contract could also include demands for eco-labelling and thus produce a more favourable end result and vice versa

S18 By striving to use circular procurement, the contract could also include demands for reduction on current design demands and thus produce a more favourable end result and vice versa

S19 Circular procurement may create incentives for the EoL status of an object, which is an incentive for trade back systems or EPR and which benefit the re-use status of EoL objects

S20 Reduce dependancy on external energy streams and LCA approach in combination with a system based approach. By striving to be independant of external energy streams, the adaptivity to future transition scenario's could also be more favourable and vice versa

S21 Reducing dependence on external energy sources , energy efficiency and renewalble energy will already be considered for achieving this goal and the result of these strategies will be positive two fold.

S22 By striving for better integration in existing and future urban development plans, the flexibility of the building could also increase and vice versa, since a buildings flexibility already contributes to its integration in future urban development plans.

S22 By striving for better integration in existing and future urban development plans, the object itself may share its energy production or may profit from existing energy structure, which benefits its energy usage

S23 DfD incorporates principles that could enhance and complement the theoretical resuability of compontents and the quality of the materials after disassembly

S24 Providing feedback to resdident can result in lower energy consumption through increased awareness of the energy performance and so yield further efficiency during the use phase

S25 The re-use of objects will most likely result in a lower energy consumption because the production stage of a certain object needs more energy than re-use of a little adaptations

S26 Taxation or credits and subsidies can create more space for a viable business case with circular materials

S27 Product as a service has an automatic incentive to reuse objects or recycle it in a high quality manner

S28 If users have a connection with the object in use which make them feel responsible, this might have positive impact on several properties of the objec

S29 Sharing of functionalities's might reduce the need for certain objects

S30 Selecting materials on life span might benefit LCA

S31 A data driven design may result in information which can say something on beforehand about when to replace something and how it thereafter can be re-used

S32 Striving for certain improvements in processes which cannot be achieved within 1 project benefit the system in the end, since it provides a better solution in the future for the whole system

Figure A.2: Clarification of synergies

D1 Bio-based building, bio-based materials requires a form of documentation of the origins of the bio-based origin. A material passport could be likely or possible solution within a data-based design

D2 Material passport and embodied energy: embodied energy requires a form of documentation and evidence that the material passport could provide.

D3 Design for disassembly and material passport: Design for disassembly requires a form of documentation of materials and joints; a material passport could be a likely or possible solution.

D4 Theoretical reusability of materials or components at equivalent level of quality and material passport: demonstrating the theoretical reusability requires a form of documentation that a material passport provides.

D5 Striving for reduction in a design might be positive at the start of a objects life cycle. However, a LCA might provide insight that this is not the case.

D6 Product labeling is required in order to use certain objects more than once. Information about it's origin, strength etc.

D7 In a traditional sector, incentives need to be created in order to create space for circular design ambitions. Therefore, the green procurement should leave space in its demands and program requirements for other refursbished materials

D8 In a traditional sector, incentives need to be created in order to create space for circular design ambitions. Therefore, the green procurement should leave space in its demands and program requirements for other secondary objects or reused parts.

D9 Overdimensioning need circular procurement because overdimensiong will not be better in a linear system but may be more suitable for a long term approach of the objects life cycle

D10 By striving for better integration in existing and future urban development plans, data based design is required in order to have the right information over time which supports the future development

D11 Design for disassembly or modular buiilding or recycling steps with re-use in the end of the life cycle requires a form of documentation which provide information about materials and building structure. A data based design is needed.

D12 Data based design is dependant from the way of contracting. It should be obliged in the contracting phase

D13 Facilitation of areas is needed to create possibilities of re-using parts in a later stage

D14 Modular systems require a special market in which standardization is required. This opens up for

Figure A.3: Clarification of dependencies

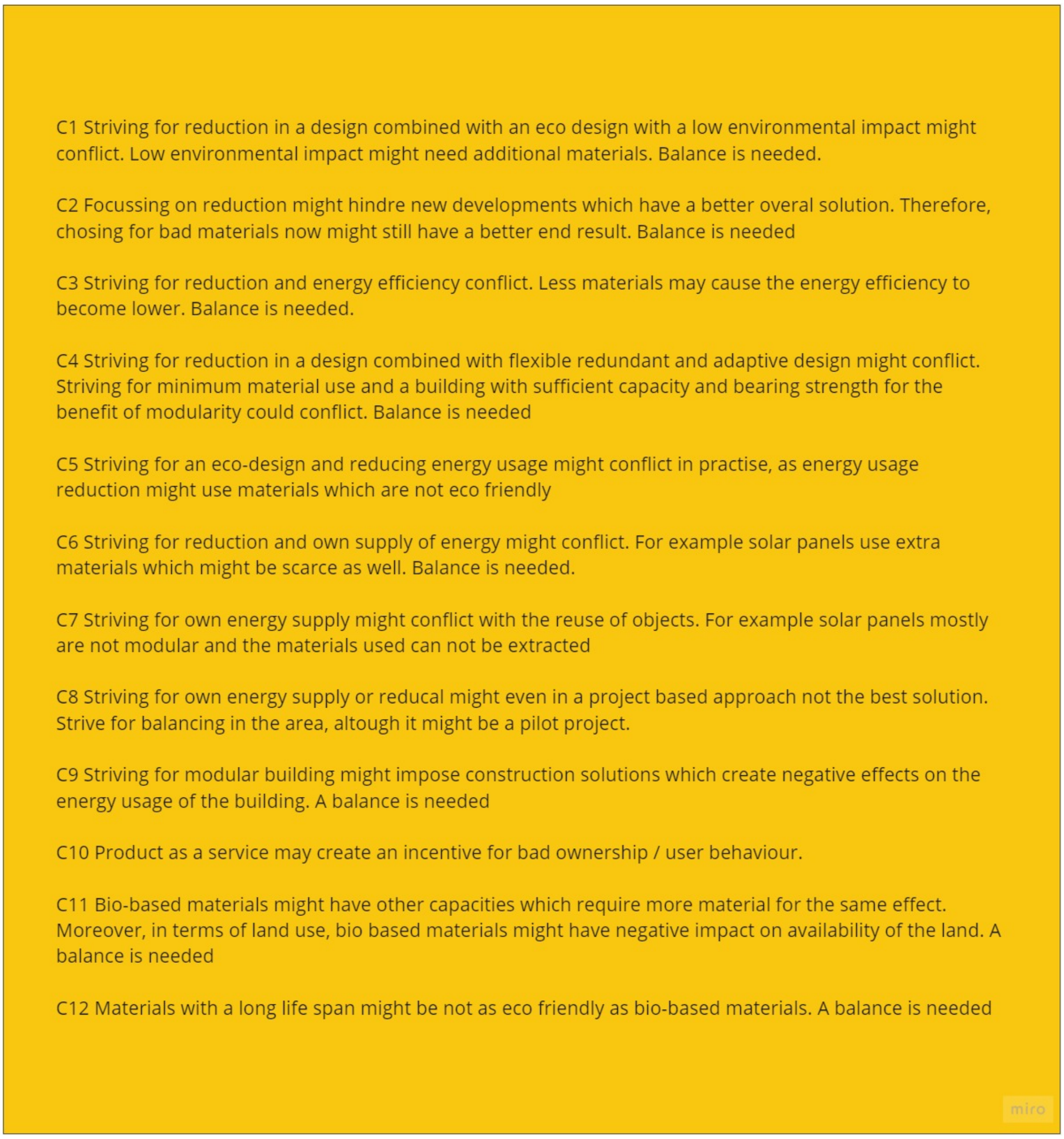


Figure A.4: Clarification of potential conflicts

B INTERVIEW PROTOCOL

Name interviewee
Organisation
Role and experience
Date

Ask permission for recording

Acquaintance

- Student;
- Research;
- Interviewee.

Underlying topics are part of all interviews. However, depending on the knowledge of a interviewee, a interview may head a certain direction and therefore skip themes.

b.1 GENERAL TOPICS

- What defines circularity - systems perspective vs project approach;
- Barriers for implementing circularity in your project portfolio;
- Lessons learned from past experience of embedding circularity in projects;
- Low-hanging fruit vs High-hanging fruit for implementing circularity;
- Key developments and factors for 2030;

b.2 TOPICS SQ3

- Internal/external drive to implement circularity;
- Current developments within circular concrete and steel;
- Material solutions without a business case;
- Supply and demand of secondary materials - changes in position of the chain related to power position related to unwillingness of parties;
- Role of marketplaces and future for material suppliers;
- Buyer - seller guidance within the chain;

- Market forces which prevent circular solutions to embed;
- Certification of adjusted materials.
- Technical or data challenge?
- Which responsibilities do the clients have towards data management?
- Align current initiatives about Co2 emissions and energy usage with circularity?;
- Linear juridical system;

b.3 TOPICS SQ5

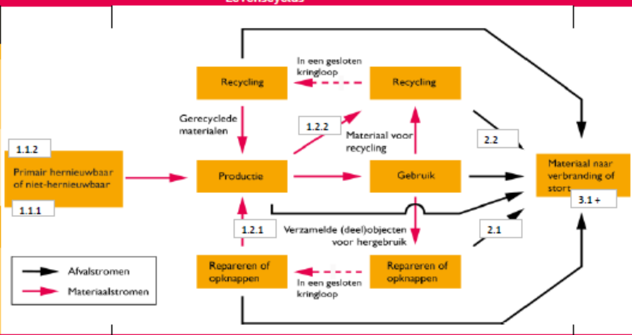
- Current initiatives within circular concrete and steel;
- Which role does you organisation play in the transition;
- Transition from a linear to circular market approach;
- Circular business case;
- Circular building standards and laws;
- Measuring, defining and performance (lifespan) circular modified concrete and steel;
- Which changes do you expect from a client in the project demands the coming years, in terms of specification / approach and asset management?
- Procurement strategies for implementing circularity and new actors such as Marketplaces;
- Current contracts applicable, such as RAW or UAV-GC;
- Barriers in current market encountered by client / contractor / material suppliers

C MEASURING CIRCULARITY - EXAMPLE FORMAT CB'23

MATERIAAL INPUT

Nummer	Indicator	kg	%
1	Totaal input	12	100%
1.1	Primair	1	8,33%
1.1.1	Niet-hernieuwbaar	1	8,33%
1.1.2	Hernieuwbaar	0	0,00%
1.1.2a	Duurzaam geproduceerd hernieuwbaar		0,00%
1.1.2.b	Niet-duurzaam geproduceerd hernieuwbaar		0,00%
1.2	Secundair	11	91,67%
1.2.1	Secundair uit hergebruik	5	41,67%
1.2.2	Secundair uit recycling	6	50,000%

Levenscyclus



MATERIAAL OUTPUT

Nummer	Indicator	kg	%
	Totaal output	10	100%
3	Totaal verloren	3	30,00%
3.1	Energieterugwinning	1	10,00%
3.2	Stort	2	20,00%
2	Totaal 'gered'	7	70,00%
2.1	Beschikbaar voor hergebruik	3	30,00%
2.2	Beschikbaar voor recycling	4	40,00%

MILIEU-IMPACT VOLGENS NEDERLANDSE BEPALINGSMETHODE

Nummer	Milieu-effectcategorie	Indicator	Eenheid	Resultaat
4.1	Klimaatverandering - totaal	GWP- totaal	kg CO2-eq.	
4.2	Klimaatverandering - fossiel	GWP- fossiel	kg CO2-eq.	
4.3	Klimaatverandering - biogeen	GWP - biogeen	kg CO2-eq.	
4.4	Klimaatverandering - landgebruik en	GWP- luluc	kg CO2-eq.	
4.5	Ozonlaagaantasting	ODP	kg CFC11- eq.	
4.6	Verzuring	AP	mol H+ eq.	
4.7	Vermesting zoetwater	EP- zoetwater	kg PO4- eq.	
4.8	Vermesting zeewater	EP - zeewater	kg N-eq.	
4.9	Vermesting land	EP- land	mol N-eq.	
4.10	Smogvorming	POCP	kg NMVOC-eq.	
4.11	Uitputting van abiotische grondstoffen - Mineralen en metalen	ADP- mineralen & metalen	kg SB-eq.	
4.12	Uitputting van abiotische grondstoffen - fossiele brandstoffen	ADP- Fossiel	MJ, net cal.val.	
4.13	Watergebruik	WDP	m^3 wolds eq. deprived	
4.14	Fijnstof emissie	Ziekte door PM	Ziekte-incidentie	
4.15	Ioniserende straling	Humane bloodstelling	kBq U235-eq.	
4.16	Ecotoxiciteit (zoetwater)	CTU ecosysteem	CTUe	
4.17	Humane toxixiteit, carcinogeen	CTU humaan	CTUh	
4.18	Humane toxiciteit, non- carcinogeen	CTU humaan	CTUh	
4.19	Landgebruik gerelareerde impact/ bodemkwaliteit	Bodemkwaliteits-index	dimensieloos	

Een deel van deze indicatoren treedt per 1 jan 2021 in werking

WAARDEBEHOUD

Nummer	Indicator	%
5	Hoeveelheid initiële waarde (input)	
5.1	Technisch-functionele waarde	
5.2	Economische waarde	
6	Hoeveelheid beschikbare waarde voor	
6.1	Technisch-functionele waarde	
6.2	Economische waarde	
7	Hoeveelheid verloren bestaande waarde	
7.1	Technisch-functionele waarde	
7.2	Economische waarde	

SCHAARSTE

Nummer	Indicator	kg	%
1.3	Fysieke schaarste (kg SB-eq.)		-
	Socio-economische schaarste	-	-
1.4.1	Socio-economisch schaarse grondstoffen		
1.4.2	Socio-economisch niet-schaarse grondstoffen		

Figure C.1: Example of communication format

[CB23, 2020a]

D LIFE CYCLE ANALYSIS

An Life Cycle Assessment (LCA) is a method of mapping the impact of products and human activities on the environment. Special calculation models are used for this. In LCA, the entire life cycle of a product or material is taken into account. The LCA is used globally and in The Netherlands for comparable calculation methods and worldwide defined by ISO [2006]. An LCA may be used in procurement processes, if designed according to the ISO standard Min. EZK [2016]. Within that standard, four stages are being defined.

1. Goal and scope definition
2. Inventory analysis
3. Impact assessment
4. Interpretation

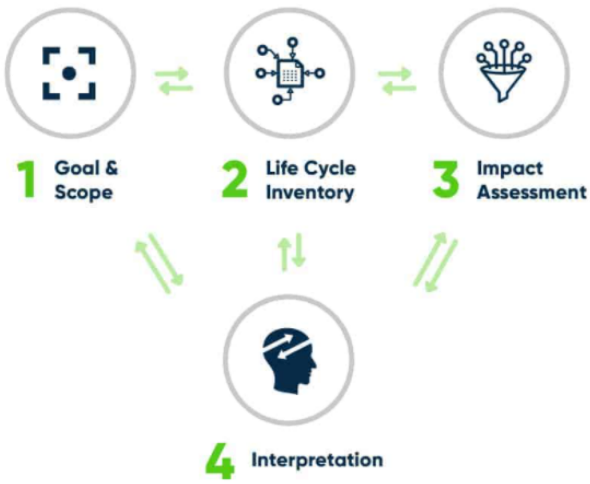


Figure D.1: LCA - model
[Liebsch, 2019]

PHASE 1: GOAL AND SCOPE In this phase, it is being determined what is going to be analysed, in which way it will be analysed, and till what detail level the analysis will reach.

1. What will be assessed? Is it a product? If so, which part of the product will we assess (the functional unit)? For LCA studies on cradle-to-gate (Boundary type) bulk materials, the functional unit can be mass or volume can be a product; for example 1 ton of iron ore.
2. What system will be used for the assessment?
3. What are is not going to be assessed? The value chain can go very deep. However, reaching a certain depth may not be of interest to the analysis. For example, one may conclude that the details of the preforms of our raw materials wont be thoroughly analysed. These are also known as the cut-off criteria

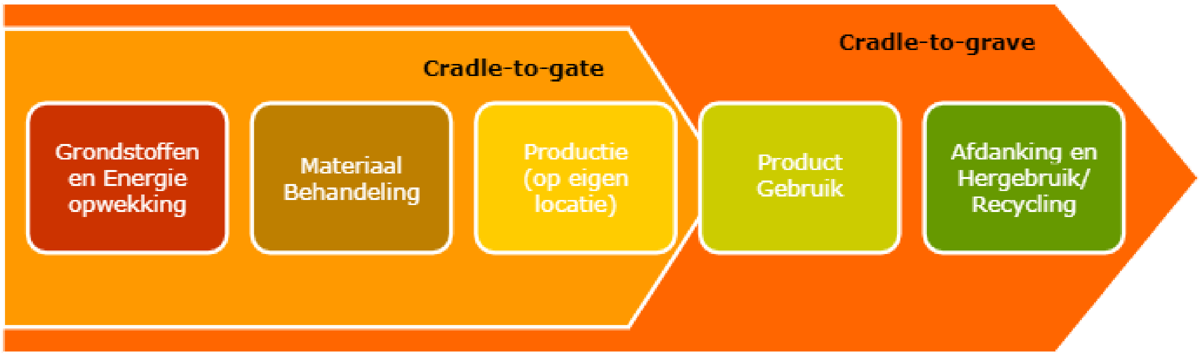


Figure D.2: Cradle-to-gate and Cradle-to-grave approach LCA
[Min. EZK, 2016]

PHASE 2: INVENTORY PHASE The Life Cycle Inventory (LCI) is the methodological step of identifying the input and output streams of a product system. These flows include the supply of water, energy and raw materials as well as emissions to air, land and water. This data can be based on historical literature findings.

Figure D.3: Life cycle inventory - Flow model
[Liebsch, 2019]

PHASE 3: IMPACT ASSESSMENT With the information from the beforehand phases, and impact assessment can be made. This assessment shows the severity of the environmental impacts that occur in within the object.

- The first step within this assessment is the classification has to be carried out. Uses resources can be assigned towards impact categories. An example of this can be abiotic depletion.
- Thereafter, characterisation has to take place. This means converting the results into the reference unit of the corresponding impact categories. This could for example be a *kg CO2-eq*

PHASE 4: INTERPRETATION In the last phase, results are being intrepreted

E MEASUREMENT UNITS OF THE CMM

The CMM describes a way of measuring circularity. Although maybe not relevant for this thesis, the reader may ask which starting points and boundaries the CMM has [CB23, 2020a].

- *The life cycle of the object is the starting point* which means that if parts should be replaced before the life cycle ends, this replacement has to be included.
- *Impact of users is not included* such as old paper, waste of a restaurant etc.
- *Materials that do not end up in the object or sub-object do not count for indicators 1 to 3* Materials that are consumed but do not end up in the object or sub-object and are not production waste, do not yet have to be counted as used material stock (indicators 1 to 3 including partial indicators) .30 They do count as the impact of the production process on the environment (indicator 4 including sub-indicators). This concerns, for example, (fossil) energy carriers, water and packaging material.
- *Measurement unit is mass in kg*

The required information for a specific object can be obtained in the following manner.

- For the materials used (in object parts) in all life phases, with the following information per material;
  - quantity in kilos;
  - scarce / non-scarce32 in the list of Critical Raw Materials (CRM, see European Commission, 2017);
  - physically scarce / physically non-scarce determined according to NEN-EN 15804: 2012 + A2: 2019 (abiotic depletion potential, ADP);
  - primary / secondary;
    * as secondary: reuse / recycling;
    * as primary: sustainably renewable33 / non-sustainably renewable;
  - most likely end-of-life treatment: available for next cycle / unavailable for next cycle;
    * as available for the following cycle: reuse34 / recycling;
    * if not available for the following cycle: energy production / landfill;
- materials that are consumed but do not end up in the object or sub-object and are not production waste (see section 5.1) for the calculation of the environmental impact35;
- emissions to soil, air and water for calculating the environmental impact;
- costs and benefits per phase in the life cycle, for GWW (partial) objects according to the Standard System for Cost Estimates (SKK) and for B&U (partial) objects according to NEN 2699 or NEN-ISO 15686-5;
- information about the adaptive capacity of the structure, including information about the detachability of partial objects (see section 6.4.2 for details);
- estimated useful life of objects or sub-objects (per object sub-object). The SBK determination method (Stichting Bouw Kwaliteit, 2019: 37) can be used for construction works. It is also possible to work with a substantiated design lifespan.

In everyday practice, the detail-level of used materials can differ quite a lot. A conceptual design will not contain a lot of information about the resource of a specific element. Therefore, the CMM uses four different levels of detail, which explain which data may be used to assess the circularity of an object. These levels are:

- Level 1: Material is known (for e.g. concrete)
- Level 2: Product is known (for e.g. concrete beam)
- Level 3: Product is known in detail (for e.g. C30/C37 beam of 20x20x300) with a coating.
- Level 4: Product is known in detail, including data from manufacturing and resources.

This data can be obtained trough various methods.

- For specific data:
  - The Environmental Product Declarations (EPD) on the base of NEN-EN 15804
  - Specific for the Dutch Market: MRPI database;
  - Manufacturer specific information;
- For generic input data:
  - Dutch Nationale Milieu database with 3 products cards;
  - In the process database of the NMD and EcoInvent44, generic data can be searched at raw material or material level;
  - For Europe, the generic dataset from the Product Environmental Footprint Pilot Guidance (PEF) can be used.
- For generic output data:
  - SBK-method appendix V;
  - For Europe, the generic dataset from the Product Environmental Footprint Pilot Guidance (PEF) can be used;

  For further elaboration on the calculations of the CMM and the manner in which the end result is composed, see chapter 5 of [CB23, 2020a]. This document describes the above-mentioned points as well, with additional information on how to integrate this method into an existing LCA. An example of how a circularity calculation result can look like is added in Appendix C.

F | MATERIAL-PASSPORT FRAMEWORK CB-23

Regarding the re-usage of materials, two main problems can be identified within the Dutch construction sector [CB23, 2020b]:

1. Too little information is available about existing used materials and constructions. As a result, the risks using re-use materials are quite big;
2. Matching the supply and demand of available materials - in time, location and quality between different parties in the chain is insufficient possible.

Shortly, when designing a structure, information about the what and when of available materials is missing in the design phase of a project. A data system is suggested as a solution to overcome this [De Valk and Quik, 2017]. The 'material-passport' is a product from the 'transitieagenda' in order to implement circularity within the Dutch Construction Industry. The Rijksoverheid [2018] defines the passport as:

> *A materials passport for a structure provides insight into which materials were used in the construction and how they were used have been processed. That makes the reuse and recovery of materials during demolition or dismantling a lot simpler and gives buildings more value.*
> (Rijksoverheid, 2018, p. 20).

There is not and most likely won't be one method for such a passport, just as with the MKI. Different concepts already exist, such as Madaster and ReNtry. However, as early chapters have shown, defining circularity is difficult and in order to measure circularity, data should be comparable. Therefore, it is of uttermost importance that different passports include homogeneous data output which can be compared. To realise this homogeneity, the organisation CB'23 [RWS, 2018] developed a document 'Paspoorten voor de bouw' which include arrangements (no standards) for a circular future in order ensure this homogeneity. This is further elaborated in the Lemma.

Lemma 1: Paspoorten voor de bouw - Circulair Bouwen 2023

This lemma will shortly introduce the 'Paspoorten voor de bouw'. At first, it is advised to split the passport into different categories, because the determination and management of data sets must be in line with the usual scales in the sector. These levels run from resource to area and will result in a passport for:

- construction work or management object;
- element, building part or component;
- or construction product (the most detailed object level);
- material;
- raw material.

A passport for a building or a road uses the passports established at lower scale levels. The passports are merged at a higher level in order to complete the passport of a certain object. This distinction is made on an earlier treated division named in Section 2.3, in which a distinction is made within the physical space and object.

As the transition is a gradual process, so is this passport. Therefore, a complete passport is difficult to obtain. The accuracy of a certain passport can be determined or influenced by:

1. the stage of life of a building, coupled with the effort (and therefore financial investment) it takes to obtain and record the correct data;
2. the value that can be created with this data, which depends on the quality and quantity of the data;
3. the degree to which the passport is kept accurately during the use phase;
4. the extent to which the government imposes an obligation;
5. the scale level on which the passport is drawn up.

Furthermore, the document includes existing standards such as the NEN-EN 15804 and EPD certificates, and fits the document 'Meten van circulariteit' [CB23, 2020a] substantiated with LCA's with the same life cycles. The information which can be included sometimes already is available or can be made available easily by fitting these systems within a passport, such as BIM, Kadaster, Decomposition NEN and manufacturing information when ordering a product

All the information within this lemma is substantiated by CB23 [2020b]

This passport is not yet obliged to use or to develop during a project. The minister postponed this decision towards 2022, but different initiatives and documents conclude that a certain passport is inevitable to reach 2030's goals.

G EXERTING PURCHASING POWER THROUGH EXISTING PROCUREMENT TOOLS

This appendix shows a preview of research gaps which exist in the purchasing power of the water boards. The water boards cannot effectively use circularity without other actors in the chain, and have to use their power trough purchasing, which need to be done by procurement. Within this research, this subject is touched upon briefly, but not detailed enough to draw hard conclusions. This appendix aims to show which elements are touched, to elaborate on the recommendation mentioned in Section 8.3.

The purchasing power of the water boards and the degree to which they can steer is reflected in different elements [PIANOo, 2021a] [UVW, 2016b]. In this appendix, the following topics of this process are briefly addressed.

1. Selecting of the tenderers
2. Specification of the object
3. Award criteria
4. Collaboration forms

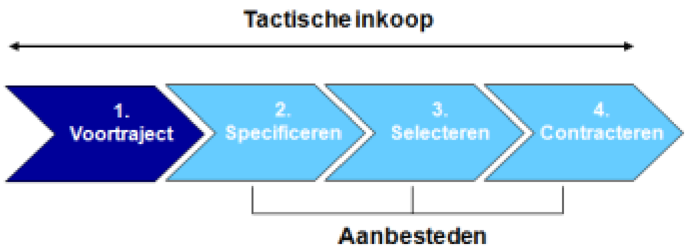


Figure G.1: Water boards purchasing plan

Connecting themes such as tendering procedure are considered out of scope. The topics are discussed in up-following sections in order to mention which elements/methods can be used for a successful use of circularity. Identified topics such as the CMM are mentioned, in order to provide insight into where and why these tools can be used.

g.1 SELECTING OF THE TENDERERS (VOORTRAJECT)

In order to achieve circular results by purchasing, the water boards should aim to collaborate with parties who are willing to invest in these results. In this research, indirect interventions were introduced. It is needed that selected tenderers are involved in the developments of circularity by investing into indirect interventions, thus developing circular concepts over time. This selection can be made through either selection criteria or suitability criteria [PIANOo, 2021b]. These selection methods can be used by paying attention to, in addition to the usual requirements, the involvement of the tenderer in knowledge sharing branches and their expertise.

The preservation of knowledge is mentioned in Figure 5.5 and quite important. Ensuring the preservation of knowledge will enable other organisations and people to observe, learn and improve on certain indirect and direct interventions. The UVW could be an organisation to organise this preservation of knowledge, however, they already acknowledged that the subject of circularity is too big for them to cover all of the preservation of knowledge within the water boards (Interview 7). Therefore, the three elements which are highlighted in Chapter 6 are explained in more detail below, to elaborate on what requirements can be imposed on tenderers.

g.1.1 Partnerships

Partnerships can be found in many forms. Partnerships enable market parties to learn or use the expertise of other parties to overcome knowledge gaps when they apply for a tender. This can, for example, be achieved through a consortium when applying for a tender.

Within these partnerships, it is a challenge to convince market parties to share their expertise on certain levels. General and disinterested knowledge sharing may not always be possible, not everyone wants to give away the smith's secret. However, this research has shown that contractors who want to lead the transition do acknowledge the importance of this. Mutual agreements can be made in order to learn from each other and built upon long term trust.

Partnerships can also be formed by collaborating on the same project. Another benefit of this is that the client can collaborate as well. This client will have knowledge because of earlier projects done within the same ambitions, thus striving for the same developments within the interventions. Enough space should be embedded in the projects demands to fully profit from the knowledge of the client and tenderers.

g.1.2 Knowledge sharing

Knowledge sharing on certain interventions can happen through various instances. This research builds upon the CMM of CB'23, which has platforms to share knowledge, such as the 'Leernetwerk Bouw & GWW'. Another example, especially focused on the procurement part, is the 'PIANOo Vakgroep GWW en Bouw'. More specific, technical developments can be shared by organisations such as 'De betonvereniging' or 'bouwen met staal'. This research has shown that these kinds of platforms also emerge for the new urban mining markets and proved to be of great added value.

g.1.3 Governmental policies

Within a transition, there most likely will be leaders and laggards. The laggards can benefit from governmental policies or pilots in the form of building standards or NEN standards. These will very likely take away some of the risk involved during the process and therefore will be important to also include those who stayed behind in the transition.

Sectoral governmental policies can also include guidelines for public clients in which ambitions on knowledge are mentioned. Through these guidelines, specific requirements can be set when selecting tenderer through the selection criteria. For example, active contributions in the partnerships in developing techniques to separate concrete substances can be required to steer the development of certain ambitions. Another example is the CO_2-prestatieladder, in which tenderers are obliged to qualify on.

g.2 SPECIFICATION OF AN OBJECT

Within a project, a client wants to design the procurement process in such a way that there the best circular solution will be used in the project. The expert brings this solution to the table. A distinction can be made in terms of cooperation between the market and the water boards, where the difference is about which side acts as the expert. The expert should bring in the knowledge on various themes, such as knowledge sharing, interventions to be applied, developments of interventions aligning the ambitions. This can be divided into three situations:

- Client as an expert;
- Combination of experts;
- Tenderer as an expert.

Within projects, the expert normally is appointed on beforehand. However, it can be the question of whether throughout the whole process the same actor should act as an expert. It can be an option to assign different process steps to different experts, or even different scopes within the same process towards another expert. The tenderer can be an expert on, for example, implementation of a direct intervention, but the client, for example, on knowledge sharing. Moreover, the evaluation of indirect interventions can be a task for both of the actors, in which the tenderer has the technical know-how and the client the overview of what is going on for which ambition / strategy.

9.3 AWARD CRITERIA

To assess the different bidders, a client has to draw award criteria in order to assess which bidder gets the project. The award criteria need to be assessed based on quality / price ratio. [PIANOo, 2021a] cites:

> *The Procurement Act 2012 prescribes that you, as a contracting authority, in principle choose the best price-quality ratio (BPKV) when awarding contracts above the European tender threshold (and when applying the Tendering Regulations for Works 2016 below the threshold). The Proportionality Guide is also based on awarding based on BPKV. The lowest price or lowest costs may only be used as an award criterion if you justify this choice in your tender documents.*

It is not advised to only assess on price. This is only a viable option if the specifications only technical. The circularity of the given design can be assessed through various instruments. This research proposed to use certain ambitions for circularity and an assessment framework of the CMM (thus including the MKI). Multiple circular design criteria can be included, with different weights. The mentioned indicators in Section 5.1.2 perfectly fit as these award criteria and serve the set ambitions by the overarching program. [CB23, 2020a] proposed a framework for this, see Appendix C. This provides an opportunity to implement the example of Chapter 6 with different possibilities for the water board, to steer for example only on alloys, concrete or both of them.

9.4 COLLABORATION FORMS

Collaboration requires agreements. These agreements are laid down in a contract, which follows from a certain project delivery method, chosen by the client or an advisor. These PDM's describes how the responsibilities and arrangements are being drawn up Hermans [2020]. The contracts applied within these models can be tailor-made, but most often standard contracts are being used, specified for a project. In the Netherlands, usually, these contracts are traditional (e.g. DBB) with the UAV as general conditions, or integrated contracts with the UAV-GC as general conditions. Other types, such as an Alliance, Turnkey or Bouwteam are possible and used as well.

The contracts form an important part of the water boards tool. Although main procurement tools are used as a project-based approach, this research has opted for a systematic approach. Therefore, water boards should align ambitions along with multiple projects and use a programmatic approach in order to live up to the ambitions.

g.4.1 Current contracts

From interview data, it can be observed that the programmatic approach already is being used within the purchasing of the water boards. Setting up structures in which different parties work together over a longer period appears to play an important role in the field of knowledge sharing and the progress of innovations (Interview 4, 6). However, not every challenge can be tackled by a construction team. It was acknowledged that a shortage of work treated the work stock and therefore the continuity of the team (Interview 5). Not every challenge contains enough work and cash flow for a construction team. A framework contract could be an option but has its disadvantages as well, such as a less natural sharing of knowledge. It is therefore not possible to conclude that water boards must from now on implement everything in a construction team, or that a completely different form of cooperation must be initiated. When we talk about the systematic approach of maintenance, there is little or no experience apart from the use of some framework contracts (Interview 4).

g.4.2 Rapid Circular contracting

A new form of collaboration is the Rapid Circular contracting method (RCC), [Wuestman and Bakker, 2021]. It is more than a collaboration form, it includes the selection of contractors as well. The selection is not about the design, but about the vision and ideas. After selecting partners, the parties lay down the agreements in a collaboration and development contract, called the RCC commitment contract. Besides regular needs, ambitions to which the partners are committed are being described, therefore fitting this research results.

g.4.3 Transfer of ownership of an asset

Regarding ownership, a lot of strategies in Table 5.1 and Table 5.2 touch upon a change of the ownership of an object. Strategies such as product as a service or lease models influence this. A change of ownership would have a major impact on the water boards, in their organisation structure, asset management approach and culture.

Ownership can be divided into the ownership of the asset management and the legal ownership of the object. Despite the examples of Phillips, the interviewee of the boards are not very enthusiastic about replacing the legal ownership of their assets. It is considered as moving their main task to the market [6]. Moreover, recent events in history resulted in the desire to have full power over the instruments in order to provide water quality and safety (interview 4). The way of outsourcing does is considered as an option but for the far future (interview 4 & 6). Another specific reason for this is the long lead time of projects, compared to other Product as a Service model, such as cars or light.

All material suppliers indicate they do not have the intention to replace their business case by business case with some sort of ownership for them. They indicate that their current market with developments is so large that it is not an option to take up that challenge (interview 1, 2 & 3).

Contractors indicate they might see a shift in the legal ownership of the objects between different public clients. It is indicated that this is not desired as well, as the activities involved are core in the safety and prosperity of the country, which you do not want to be dependant on the mercy of the market (interview 9). Moreover, contractors see developments in the light of urban mining, rather than the transfer of ownership (interview 8).

However, water boards acknowledge that asset management could be procured as a service (interview 6). Doing this by yourself makes an organisation vulnerable to certain sunk costs. Moreover, specialities within the arsenal of objects could use the transfer of ownership as well, in order to improve certain specific developments. This could be the case for example pumps.

g.5 RECOMMENDATION

This appendix showed that a potential research gap can be found in the procurement tools of the water boards. Procurement is an important tool of the water boards in order to steer the market, as the water boards cannot realise the ambitions to overcome resource depletion and climate change on their own. Research to themes mentioned in this appendix, such as expertise development, CMM as award criteria, the question who should be the expert in a project with circular ambitions and transferring knowledge of circularity to other projects, while at the same time protecting circular business cases can improve the market to implement and use circularity. Moreover, it is interesting to investigate how project based procurement strategies can be transformed to the systematic approach needed for circularity.

H | INTERVIEW TRANSCRIPT 1

I | INTERVIEW TRANSCRIPT 2

J | INTERVIEW TRANSCRIPT 3

K | INTERVIEW TRANSCRIPT 4

L | INTERVIEW TRANSCRIPT 5

M | INTERVIEW TRANSCRIPT 6

N | INTERVIEW TRANSCRIPT 7

O | INTERVIEW TRANSCRIPT 8

P | INTERVIEW TRANSCRIPT 9

COLOPHON

This document was typeset using LaTeX. The document layout was generated using the arsclassica package by Lorenzo Pantieri, which is an adaption of the original classicthesis package from André Miede.