MASTER

Developing a framework for governments to achieve a circular transition with public procurements

Creating a framework for governments that improves the capabilities and knowledge to achieve a circular transition for newly built single-family homes with public procurements

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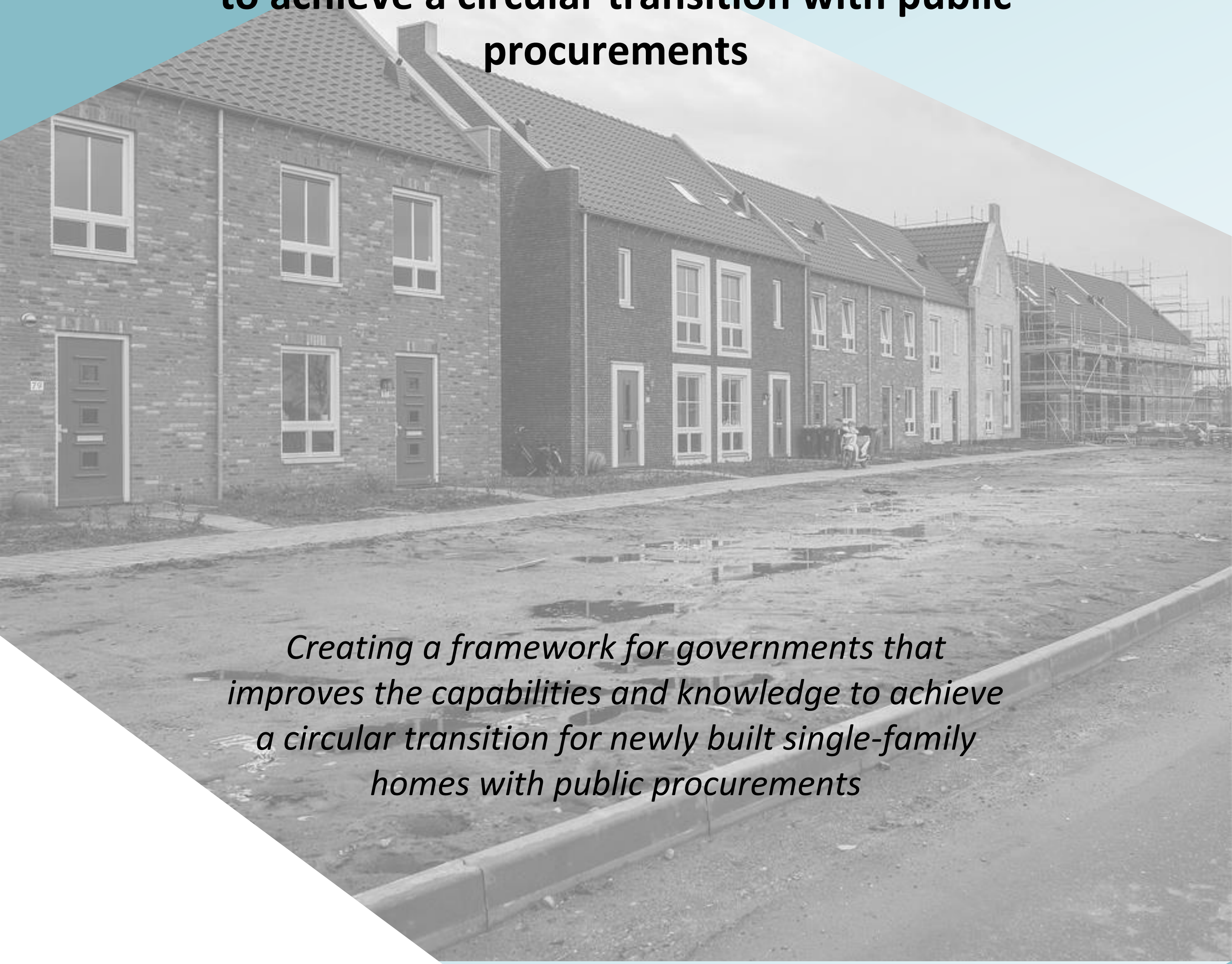

Creating a framework for governments that improves the capabilities and knowledge to achieve a circular transition for newly built single-family homes with public procurements

Graduation project

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Preface

Dear reader,

this master thesis is the result of my graduation project for the master programme Construction Management and Engineering at the Eindhoven University of Technology. My thesis provides information on how to improve the capabilities and knowledge of governments to achieve a circular transition for newly built single-family homes with public procurement.

During my master's studies, the circular economy and the transition to a circular economy caught my interest. It was clear that current construction methods need to change to reduce raw material consumption and waste production, thereby counteracting climate change, biodiversity loss and earth depletion, for the benefit of current and future generations. Therefore, I decided to focus my thesis topic on the circular economy. I hope that I can contribute to a circular transition in the construction sector with my thesis.

Various people have contributed directly or indirectly to this thesis. First, I would like to thank my supervisors at the university, Qi Han and Stephan Maussen, for their feedback and guidance during my graduation project. I would also like to thank my colleagues at Alba Concepts for their warm welcome, support, input, and feedback. I would especially like to thank Leonie Eggen for her time and feedback during my graduation project. In addition, I would like to thank all the experts for their valuable contribution to my research. Finally, I would like to thank my family and friends for their support, advice, and fun distractions during my graduation project.

I hope you enjoy reading it and that it inspires you to contribute to a circular transition.

Femke Oskamp
Eindhoven, July 2022

Table of Contents

Summary

Current construction methods deplete resources, pollute the environment, and negatively impact the climate. To counteract these negative effects, a transition is needed. Such a transition can be realized with the help of a circular economy. A circular economy reduces the consumption of raw materials and the production of waste, thus counteracting climate change, the loss of biodiversity and the depletion of the earth. Public procurement is an important tool for governments to stimulate and realize a circular transition. To do so, governments must have clear ambitions and formulate clear criteria for the circular economy. However, governments do not have sufficient knowledge about circular economy and circular criteria that can be applied in the procurement process. They need a tool to help them identify circular options and determine the practicality and value of these options. Therefore, this research aims to provide a tool and set boundaries for circularity by creating a framework for governments to help them identify circular options and determine the practicality and value of those options. In this research, the focus is on newly built single-family homes, as one million additional homes are needed by 2030, 70 percent of which will be single-family homes.

To help the governments identify circular options and determine the practicality and value of those options a system of metrics is needed that can guide government decision-making as they implement the circular economy. To guide government decision-making, the framework will consists of four steps. These steps are, in order:

- The project goals: indicate what a government wants to achieve with the project
- The circular strategies: a plan of action designed to achieve circular goals
- The circular economy criteria: criteria that can safeguard circularity in procurement
- The impacts of strategies: represent the effect of a circular strategy on a project

The steps must be followed in the given order because the outcome of one step determines the input to the other step. Following the steps in this order will provide governments with insight into circular options and the practicality and value of those options.

This leads to the research question of this research is: ‘How can a framework be designed and validated for governments to improve the capabilities and knowledge to achieve a circular transition for newly built single-family homes with public procurement?’

A design science research approach (DSR) is used to answer the research question. The DSR approach used in this research consists of four steps: exploration, synthesis, creation, and evaluation. In the exploration phase, information is collected through a literature study and expert interviews. In the synthesis phase, the results of the exploration phase are used to determine the project goals, circular strategies, CE-criteria, and the impact of circular strategies to consider for the framework. In the creation phase, the framework is created using the input from the synthesize phase. Finally, in the evaluation phase is examined whether the designed framework works.

In the exploration phase information is collected through a literature study and expert interviews. The results of the literature study are used to set the boundaries for this research and determine the factors to consider for the framework. The expert interviews are used to validate the findings of the literature study. The result of the exploration phase is a list of 18

project characteristics, 32 circular material strategies, and 25 impacts based on literature study and expert interviews to be considered for the framework.

The synthesize phase is used to translate the results of the exploration phase into meaningful project characteristics, circular material strategies, CE- criteria, and impacts for the framework. First, the Fuzzy Delphi Method is used to determine the factors to be considered for the project characteristics, circular material strategies, and impacts of the strategies. The factors to consider are:

- The project characteristics: Circular motives, ambition, willingness & acceptance, vision and budget.
- The circular materials strategies: Demountable, material efficiency, reuse, non-toxic materials and reduce.
- The impacts: Environmental impact, quality, lifespan, CO_2 emission and costs.

The second step is to determine CE- criteria for each circular material strategy. For the determination of the CE-criteria, the circular material strategy material efficiency is combined with the circular material strategy reduce, since these two circular material strategies are very similar. The result of determining the CE-criteria is a list of CE-criteria divided into three ambition levels that can be applied to the circular material strategies of reuse, demountable, reduce and non-toxic materials. The final step is to determine the impact of each circular material strategy. The result of determining the impact of each circular material strategies is an overview that provides information on the cost, quality, CO_2 emissions, lifespan and environmental impact of the circular material strategies of reuse, demountable, reduce and non-toxic materials. The overall result of the synthesize phase is a list of 5 project characteristics, 4 circular material strategies, and 5 impacts to consider for the framework. In addition, the CE-criteria for each circular material strategy are defined in three ambition levels and the impacts of each circular strategy are determined.

The creation phase is used to create the framework with the results of the synthesize phase. The content of the framework created in the synthesize phase and the sketches resulted in an infographic in A4 format. The framework presents the project characteristics, circular material strategies, circular economy criteria, and impact of strategies in the order to follow. In addition, each step is explained and additional information is provided on how to apply each step. The result of the creation phase is a framework in the form of an infographic that helps governments identify circular options and determine the practicality and value of those options.

In the evaluation phase, the framework is validated using expert interviews. In general, experts provided positive feedback on the framework. However, suggestions were also made to improve the framework. The framework is improved based on the experts' input from the interviews. The result of the evaluation phase is a validated framework that is supported by the market and governments.

By following the four steps of the Design Science Research methodology, a framework is designed and validated to improve the capabilities and knowledge of governments to achieve a circular transition for newly built single-family homes with public procurement.

Samenvatting

De huidige bouwmethoden putten hulpbronnen uit, vervuilen het milieu en hebben een negatieve invloed op het klimaat. Om deze negatieve effecten tegen te gaan is een transitie nodig. Een transitie kan worden gerealiseerd met een circulaire economie. Een circulaire economie vermindert het verbruik van grondstoffen en de productie van afval en gaat zo klimaatverandering, het verlies aan biodiversiteit en de uitputting van de aarde tegen. Aanbestedingen zijn voor overheden een belangrijk instrument om een circulaire transitie te stimuleren en realiseren. Overheden hebben echter onvoldoende kennis over de circulaire economie en circulaire criteria die in het aanbestedingsproces kunnen worden toegepast. Ze hebben een tool nodig om circulaire opties te identificeren en de bruikbaarheid en waarde van deze opties te bepalen. Daarom is het doel van dit onderzoek het bieden van een tool en het stellen van grenzen voor circulariteit door een raamwerk te creëren voor overheden om hen te helpen circulaire opties te identificeren en de bruikbaarheid en waarde van die opties te bepalen. In dit onderzoek ligt de focus op nieuwbouw eengezinswoningen, aangezien er in 2030 een miljoen extra woningen nodig zijn, waarvan 70 procent eengezinswoningen.

Om de overheden te helpen circulaire opties te identificeren en de bruikbaarheid en waarde van die opties te bepalen, is een systeem nodig dat de besluitvorming van de overheid kan sturen bij het implementeren van de circulaire economie. Om de besluitvorming van de overheid te sturen, bestaat het raamwerk uit vier stappen. Deze stappen zijn, in volgorde:

- De projectdoelen: geven aan wat een overheid wil bereiken met het project
- De circulaire strategieën: een plan van aanpak om circulaire doelen te bereiken
- Circulaire economie criteria: criteria die circulariteit bij aanbestedingen borgen
- Het effect van strategieën: representeren het effect van een circulaire strategie op een project

De stappen moeten in de gegeven volgorde worden gevolgd omdat de uitkomst van de ene stap de input voor de andere stap bepaalt. Door de stappen in deze volgorde te volgen, krijgen overheden inzicht in circulaire opties en de bruikbaarheid en waarde van die opties.

Dit leidt tot de onderzoeksvraag van dit onderzoek is: 'Hoe kan een raamwerk worden ontworpen en gevalideerd voor overheden om de capaciteiten en kennis te verbeteren om een circulaire transitie voor nieuwbouw eengezinswoningen te realiseren met openbare aanbestedingen?'

Een design science research approach (DSR) is gebruikt om de onderzoeksvraag te beantwoorden. De DSR-aanpak die in dit onderzoek is gebruikt, bestaat uit vier stappen: verkenning, synthese, creatie en evaluatie. In de verkenningsfase is informatie verzameld door middel van literatuuronderzoek en expertinterviews. In de synthesefase zijn de resultaten van de verkenningsfase gebruikt om de projectdoelen, circulaire strategieën, CE-criteria en het effect van circulaire strategieën voor het raamwerk te bepalen. In de creatiefase is het raamwerk gecreëerd met behulp van de input uit de synthesefase. Tot slot is in de evaluatiefase bekeken of het ontworpen raamwerk werkt.

In de verkenningsfase is informatie verzameld door middel van literatuuronderzoek en expertinterviews. De resultaten van het literatuuronderzoek zijn gebruikt om de grenzen voor

dit onderzoek te bepalen en de factoren te bepalen die moeten worden meegenomen in het raamwerk. De expertinterviews is gebruikt om de bevindingen van het literatuuronderzoek te valideren. Het resultaat van de verkenningsfase is een lijst van 18 projectkenmerken, 32 circulaire materiaalstrategieën en 25 effecten op basis van literatuuronderzoek en interviews met experts die in aanmerking komen voor het raamwerk.

De synthesefase is gebruikt om de resultaten van de verkenningsfase te vertalen naar zinvolle projectkenmerken, circulaire materiaalstrategieën, CE-criteria en effecten voor het raamwerk. Ten eerste is de Fuzzy Delphi-methode gebruikt om de factoren te bepalen die moeten worden meegenomen in het framework voor de projectkenmerken, circulaire materiaalstrategieën en effecten van de strategieën . De factoren om mee te nemen zijn:

- De projectkenmerken: Circulaire drijfveren, ambitie, bereidheid & acceptatie, visie en budget.
- De circulaire materiaalstrategieën: Losmaakbaarheid, materiaalefficiëntie, hergebruik, niet-giftige materialen en reduceren.
- De effecten: Milieu-impact, kwaliteit, levensduur, CO2-uitstoot en kosten.

De tweede stap is het bepalen van CE-criteria voor elke circulaire materiaalstrategie. Voor het bepalen van de CE-criteria is de circulaire materiaalstrategie materiaalefficiëntie gecombineerd met de circulaire materiaalstrategie reduceren, aangezien deze twee strategieën erg op elkaar lijken. Het resultaat van het bepalen van de CE-criteria is een lijst van CE-criteria onderverdeeld in drie ambitieniveaus die kunnen worden toegepast op de circulaire materiaalstrategieën hergebruik, losmaakbaarheid, reduceren en niet-toxische materialen. De laatste stap is het bepalen van de impact van elke circulaire materiaalstrategie. Het resultaat van het bepalen van de impact van elke circulaire materiaalstrategie is een overzicht dat informatie geeft over de kosten, kwaliteit, CO2-uitstoot, levensduur en milieu-impact voor de vier circulaire materiaalstrategieën. Het resultaat van de synthesefase is een lijst van 5 projectkenmerken, 4 circulaire materiaalstrategieën en 5 effecten die moeten worden meegenomen in het raamwerk. Daarnaast zijn de CE-criteria voor elke circulaire materialenstrategie vastgelegd in drie ambitieniveaus en zijn de effecten van elke circulaire strategie bepaald.

De creatiefase is gebruikt om het raamwerk te creëren met de resultaten van de synthesefase. De inhoud van de synthesefase en schetsen resulteerden in een infographic op A4-formaat. Hierin zijn, in de juiste volgorde, de projectkenmerken, circulaire materiaalstrategieën, circulaire economiecriteria en impact van strategieën gepresenteerd. Bovendien is elke stap uitgelegd en is er aanvullende informatie gegeven over het toepassen van een stap. Het resultaat van de creatiefase is een raamwerk in de vorm van een infographic dat overheden helpt circulaire opties te identificeren en de bruikbaarheid en waarde van die opties te bepalen.

In de evaluatiefase is het raamwerk gevalideerd aan de hand van expertinterviews. Experts gaven over het algemeen positieve feedback op het raamwerk. Er werden echter ook suggesties gedaan om het kader te verbeteren. Op basis van de suggesties uit de ineterviews is het raamwerk verbeterd. Het resultaat van de evaluatiefase is een gevalideerd raamwerk dat wordt gedragen door de markt en overheden.

Door de vier stappen van de DSR-methodologie is een raamwerk ontworpen en gevalideerd dat capaciteiten en kennis van overheden verbeterd om een circulaire transitie te realiseren voor nieuwbouw eengezinswoningen met openbare aanbestedingen.

Abstract

A circular economy (CE) can realize a transition by reducing the consumption of raw materials and the production of waste, thus counteracting climate change, the loss of biodiversity and the depletion of the earth. Public procurement is an important tool for governments to stimulate and realize a circular transition. However, governments do not have sufficient knowledge about circular economy and circular criteria that can be applied in the procurement process. They need a tool to help them identify circular options and determine the practicality and value of those options. This research provides a framework for governments to realize a circular transition in the public procurement of newly built single-family homes. To do so, using the four step of the design science research approach. In the first step, exploration, information is gathered through a literature study and expert interviews. In the second step, the synthesis, the results of the exploration phase are used to determine project characteristics, circular material strategies, circular economy criteria, and impacts for the framework. In the creation phase, the framework is developed into an infographic using the results of the synthesis phase. In the final step, the evaluation, the framework is validated by governments and market parties using expert interviews. By following the four steps of the Design Science Research methodology, a framework consisting of project characteristics, circular material strategies, circular economy criteria, and impacts is designed and validated to improve the capabilities and knowledge of governments to achieve a circular transition for newly built single-family homes with public procurement.

Keywords: Framework, circular economy, public procurement, project characteristics, circular material strategies, circular economy criteria and impacts

Glossary

Ambition	Striving for specific goals within a building project.
Budget	The total financial resources available to finance the project, from initiative to realization.
Circular economy criteria	Criteria that can safeguard circularity in procurements.
Circular material strategies	A plan of action to limit the amount of materials and use durable, reusable and recyclable materials.
Circular motives	The reasons why a person or company want to achieve certain circular goals. Examples of circular motives are image, finance, residual value, material scarcity, impact on climate and social motives.
Contamination	The application, combination or mixing of different materials and resources in a way that makes reuse difficult or impossible.
Costs	The total financial resources needed to finance the building, from initiation till realization.
CO2 emission	The total amount of CO2 produced during the realization of a building.
Demountable	Designing products or buildings of multiple parts that can be easily separated and reassembled
Environmental impact	The influence of a building on the natural environment and ecosystems of the planet, think of pollution, deforestation, and so on.
Framework	An overview that captures (new) ideas in an overall picture so that it is easy to remember and apply the (new) concept.
Impact of strategies	Impacts represent the effect of a circular material strategy on a project.
Lifespan	The period of time in which a product or building is used, from purchase till disposal.
Non-toxic materials	Replacing toxic and hazardous materials with regenerative sources.
Procurement	Is a method of purchasing in which the contract is put out to competing parties on the same time, terms, conditions and procedural rules.
Project characteristics	Features by which a project can be identified.
Purchasing	The acquiring of work, services or goods by paying for them.
Quality	The extent to which a building, and products within a building, meet established standards.
Reduce	Reducing the use of raw materials, water and energy and reducing the amount of waste generated.
Reuse	The reuse of products or components for the same function.

Reuse future	The percentage of materials that can be reused at another building after the end of life in the current building.
Reuse origin	The percentage of materials that is reused from another project, thus secondary materials.
Toxic materials	Materials that can be poisonous or cause health effects.
Vision	Your organization's view of the (future) world and the role of your organization in that world.
Willingness and acceptance	The benevolence of the client, contractor and consumer to implement and use circular measures.

List of Abbreviations

CE	Circular economy
CE-criteria	Circular economy criteria
CO2	Carbon dioxide
DfC	Design for circularity
DSR	Design science research
FDM	Fuzzy Delphi Method
MKI	Milieukostenindicator

List of figures

List of tables

1. Introduction

This chapter introduces the topic of the study by describing the research background, defining the research problem, formulating the research questions, presenting the research design, explaining the scientific and practical significance, and finally presenting the reading guide.

1.1 Research background

A transition is needed

Over the past decade, the demand for raw materials has increased and is expected to continue to increase due to the growing global population and increasing consumption (van Oppen et al., 2018; Rood & Hanemaaijer, 2016). This increasing demand for raw materials is negatively impacting the environment through a decline in biodiversity, an increase in greenhouse gas emissions and problems in the nitrogen cycle (Herczeg et al., 2014; Rood & Hanemaaijer, 2016).

One of the main contributors to the demand for raw materials is the construction industry. In the Netherlands, the construction industry is responsible for 50 percent of the raw materials consumption, 40 percent of the energy consumption, 30 percent of the water consumption and 40 percent of the total waste production (Meuffels & Hoppe, 2021; Transitieagenda Circulaire Economie, 2018). There is growing awareness that current construction methods need to change. Current, construction methods deplete resources, pollute the environment and negatively impact the climate. A transition is needed to counteract these negative impacts (Transitieagenda Circulaire Economie, 2018). Such a transition can be realized with the aid of a circular economy. A circular economy reduces raw material consumption and waste production, thereby counteracting climate change, biodiversity loss and earth depletion (Platform CB'23, 2020; Platform CB'23, 2021). In addition, a circular economy reduces dependence on new resources and provides economic benefits through value retention (Ellen MacArthur Foundation, 2013; Potting et al., 2018; Verberne, 2016).

To realize and stimulate a circular transition, the Dutch government has developed the program 'Nederland circulair in 2050'. In this program, the Dutch government has set the goal of achieving a fifty percent reduction in primary raw materials by 2030 and a one hundred percent circular economy by 2050 (Rijksoverheid, 2016; Rijksoverheid, n.d.-a). Within the program 'Nederland circulair in 2050', five sectors have been selected as priority sectors. These sectors are important for economic prosperity, but also have a negative impact on the environment. One priority sector is the construction sector, as the construction sector is responsible for 50 percent of the material consumption and most materials end up as demolition waste (Rijksoverheid, n.d.-a).

A transition through the purchasing process

The government, as a purchaser, can stimulate circular construction by requiring circularity (Bals et al., 2018; Ghisellini et al., 2016; Stimular, 2019). In this way, the purchasing and tendering process plays an important role (Scherpenisse et al., 2021). The purchasing power of public purchasers such as governments could accelerate the circular transition if circular tenders become their standard. Requiring circular economy in tenders could act as a catalyst for market parties to adopt and implement circularity in the construction sector (Scherpenisse et al., 2021). For this reason, the government is using the purchasing process for the

sustainable transition and as a tool to realize circular ambitions (Ollongren & Veldhoven-van der Meer, 2019; Platform CB'23, 2021).
Realizing circular ambitions in the purchasing process is done through public procurement. Public procurement is a specific part of the purchase of products, services and works by government organizations, as shown in Figure 1. It is a method of purchasing in which the contract is put out to competing parties on the same time, terms, conditions and procedural rules (IBR, 2020). In a tender, governments as contracting authorities are obliged to award tenders on the basis of the right price/quality ratio instead of the previously used lowest price, according to the Dutch Public Procurement Act 2012. The right price/performance ratio weights the economic component against a quality component (PIANOo, n.d.-a; IBR, 2020).
The study by Grandia and Meehan (2017) and Arrowsmith (2010) addresses the opportunities for public procurement to contribute to policy goals (Grandia and Meehan, 2017; Arrowsmith, 2010). At the European and national levels, procurement is seen as an important governmental tool to promote the circular economy, as it connects governments to physical products and enables the government to create a market for circular products (Circle Economy & Copper 8, 2018). In this context, several studies emphasize that procurement can act as a strategic tool to stimulate the circular economy (Platform CB'23, 2021; Lenderink et al., 2020; Climate-KIC, 2019; Ollongren & Veldhoven-van der Meer, 2019), or as a means to achieve sustainable ambitions (Klimaatverbond Nederland, 2020).

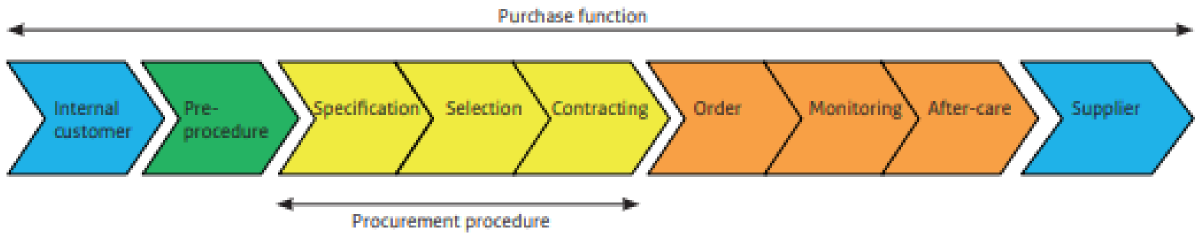

Figure 1; Purchasing process (IBR, 2020)

The transition to a circular construction sector

The literature points to the possibility of transitioning to a circular economy through public procurement. However, the transition to a circular economy has not yet been integrated into daily routines (Drijvers, 2019; Kubbinga et al., 2018; Leising et al., 2017; Tsolis, 2017). One reason for this is the slow implementation of innovations in the construction industry (Leising, et al., 2017). The study by Ebarhardt et al. (2019) and Leising et al. (2017) highlights the slow transition to a circular economy by pointing out that CE has already been applied in many other sectors using frameworks, but frameworks have not yet been developed for the complex problems in the construction sector. Frameworks are used to capture (new) ideas in an overall picture so that it is easy to remember and apply the (new) concept (Ebarhardt, et al., 2019; Leising, et al., 2017). The study by Metabolic (2019) also addresses the importance of a framework for circular and climate neutral indicators to measure the impact and effectiveness of circular procurement. The study by Acharya, et al. (2018) highlights the need for a multi-level policy framework to support the transition to a more circular built environment (Acharya et al., 2018). Finally, the study by Goodwin Brown, et al. (2021) addresses the need for organizational frameworks that make the concept of the circular economy more accessible (Goodwin Brown et al., 2021).

Another bottleneck that explains the slow transition to a circular economy is that while market parties are willing to build circularly, they need clients who specifically demand circular ambitions (Circular Economy & Copper8, 2018). Clients, such as governments, need to become familiar with CE and adapt their tender in the procurement process to the CE. In this way, governments can influence the market by adding specific CE criteria to the award and selection criteria (Castelein, 2018). CE-criteria that are effective are sufficiently ambitious and challenging to the market, but at the same time realistic to be met by leading market parties (PIANOo, n.d.-b). Other opportunities to implement CE perspectives in procurement are in the form of suitability requirements and contract terms (Climate-KIC, 2019).
A final bottleneck to the slow transition is that the goals of purchasers, in this case the government, in procurement are unclear or presented in vague terms (Climate-KIC, 2019). Cirkelstad's (2021) study highlights the importance of setting clear ambitions and interacting with the market. Simple and clear ambitions will help the market the most (Cirkelstad, 2021).

The transition to a circular housing market
Most of the existing building stock in the Netherlands consists of traditional construction methods and building materials. This means that most buildings are not demountable, the materials are mixed, and many low-quality materials have been used. It is virtually impossible to formulate circular principles for such buildings. Circular principles regarding the use of materials must be considered at the design stage of a project. This is the only way to provide guarantees for quality maintenance and material recovery (Geldermans & Jacobson, 2015). In the context of this research, it is therefore more relevant to focus on how circular principles can be integrated into the design of future construction.
Future construction in the Netherlands will require the realization of more than one million additional houses by 2030, of which 70 percent of the newly built houses should be single-family homes (de Zeeuw & Keers, 2020; Van Oppen & Bosch, 2020). Single-family homes consist of corner-, terraced-, semidetached- and detached houses (CBS, n.d.). According to the 'Transition Agenda Circular Building Economy', the transition to a sustainable housing stock and realization of one million additional houses must be done in a circular way. In doing so, the government requires circular products and services in public procurement (Ministry of Infrastructure and Water Management, 2019).
Due to the need for one million additional houses, the high demand for single-family homes, and the relevance of circular principles in the design phase, the scope of this research will be newly built single-family homes.

1.2 Problem definition

The preliminary research presented in the previous chapter suggests that public procurement is a key tool for governments to stimulate and realize a circular transition (Platform CB'23, 2021; Lenderink et al., 2020; Climate-KIC, 2019). To do so, governments need to have clear ambitions and formulate clear CE-criteria (Cirkelstad, 2021; Climate-KIC, 2019; Castelein, 2018; Ministerie van Infrastructuur en Milieu, 2015), preferably using a framework (Ebarhardt et al., 2019; Leising et al., 2017; Metabolic, 2019; Goodwin Brown et al., 2021). However, governments do not have sufficient knowledge of criteria that can be applied in the procurement process (Circular Economy & Copper8, 2018). In addition, the issue of the definition and knowledge of the circular economy is a constrain for organizations, including governments, to purchase in a circular manner (Neessen et al., 2021). The study by Lenderink et al. (2020) also suggests that purchasers lack the knowledge and resources to stimulate and access innovations such as the circular economy through public procurement to meet their needs and requirements (Neessen et al., 2021). This lack of knowledge and experience stands in the way of innovation and change toward a circular construction and results in a lack of circular procurement from the demand side (SGS Search, 2021).Organizations, including governments, are struggling with the complexity of circular procurement. They are searching for tools to help them identify circular options and determine the practicality and value of those options. On the other hand, organizations that are successful in implementing the circular economy have tools in place to discuss circularity (Neessen et al., 2021). In the current situation, the government does not know what the options are for CE (Cirkelstad, 2021). One solution is to set a minimum boundaries for circularity and provide a tool with circular options (Neessen et al., 2021; van Nunen, 2020). Therefore, this research aims to provide a tool and set boundaries for circularity by creating a framework for governments to help them find circular options and determine the practicality and value of those options. The framework will propose strategies and CE-criteria to integrate circularity into public procurements. The purpose of the framework is to achieve a circular transition in procurement.

The framework in this research is intended to help the governments identify circular options and determine the practicality and value of those options. To do this, governments need a system of metrics that can guide their decision-making as the implement the circular economy (WBSCD, 2020). To guide government decision-making, it is important to give substance to the objectives within a project, to be aware of the project specific features and impacts of decisions. To give substance to these issues, the framework will consists of four steps. These steps are, in order:

- **The project goals**: indicate what a government wants to achieve with the project
- **The circular strategies**: a plan of action designed to achieve circular goals
- **The circular economy criteria**: criteria that can safeguard circularity in procurement
- **The impacts of strategies**: represent the effect of a circular strategy on a project

All the steps are interrelated one after the other. Knowing the project goals, it becomes possible to choose a suitable circular strategy for the project to achieve a circular transition. Based on the circular strategies, appropriate CE-criteria can be selected to be considered in the procurement process. Finally, the impacts are used to verify that the defined circular strategies and CE-criteria are achieving the desired outcome. Therefore, the steps must be followed in the given order because the outcome of one step determines the input to the other step. Following the steps in this order will provide governments with insight into circular options and the practicality and value of those options.

1.3 Research question

To achieve the stated research objective, this research seeks to answer the main research question:

How to design and validate a framework for governments to improve the capabilities and knowledge to achieve a circular transition for newly built single-family homes with public procurements?

The main research question is answered by answering the following sub-questions:

I. *What does the concept of the circular economy mean for the construction sector?*
II. *What project goals influence the decision for a circular strategy?*
III. *Which circular strategies exist for newly built single-family homes?*
IV. *What are the influential impacts of a circular strategy?*
V. *Which project goals, circular strategies and impacts are relevant for the framework?*
VI. *What are the CE-criteria and impacts for the determined circular strategies?*
VII. *How can a framework for governments be designed to achieve a circular transition with procurements?*
VIII. *How can a framework for governments to achieve a circular transition with procurements be validated?*

Research limitations

There are several limitations regarding this research. First, the construction sector as a whole is too large to investigate. Therefore, newly built single-family homes are used as the scope for this research. Another important limitation is the lack of a commonly accepted analysis tool that measures the degree of circularity (Venselaar, et al., 2019). This could lead to factors not being identified and included in the framework even though they are relevant to circular ambitions. In order to include and identify all CE-criteria, different circular economy measuring tools are used, depending on how the concerned CE-criteria can best be expressed. Examples of suitable measurement tools are the Building Circularity Index (BCI) and the MPG (Milieu Prestatie Gebouw) building.

1.4 Research design

The chosen research design will be a design science research (DSR) approach because the developed framework will solve a field-based problem and has significant practical relevance (van Aken et al., 2016). In the study by van Aken, et al. (2016), DSR is defined as a research strategy that can be used instrumentally to design and implement actions, processes, or systems to achieve desired outcomes in practice. For this research, a DSR framework proposed by the study of Keskin & Romme (2020) is used. Keskin & Romme (2020) DSR process consists of the four steps: exploration, synthesis, creation, and evaluation. An overview of the DSR process for this particular research is shown in Figure 2. Each step of the DSR process is further elaborated.

Figure 2; Proposed DSR process

Exploration
The first step is exploration, which involves drawing the boundaries of the problem space. In the exploration phase, information is gathered through literature review and field research (Keskin & Romme, 2020). In this research, information is collected through a literature study and expert interviews. The goal of this step is to explore the theoretical perspectives related to circularity in procurement, which in turn can be used for creating the framework.

Synthesis
The second step, synthesis, is about gaining insights from the information gathered in the exploration phase by applying inductive and abductive sensemaking to identify and make connections (Keskin & Romme, 2020). In the synthesis phase, factors for the project goals, circular strategies and the impact of circular strategies to include in the framework are determined. Once the factors have been determined, it is possible to determine the CE-criteria and identify the impact of the strategies. The goal of this step is to translate the literature review and interviews into meaningful project goals, strategies, CE-criteria and impacts for the framework.

Creation
Creation is about designing artifacts for the defined problem (Keskin & Romme, 2020). In this step the framework can be created with the input from the synthesis phases. The goal of this step is to create the framework with CE-criteria.

Evaluation
Finally, the evaluation phase examines whether the designed solution works (Keskin & Romme, 2020). The investigation whether the framework works is conducted with expert interviews. Both government and market parties are interviewed. The goal of this step is to create a framework that is validated and supported by the market and governments.

1.5 Scientifical and practical importance

Several studies highlight the lack of government knowledge as a problem to implement the circular economy in the procurement process (Circular Economy & Copper8, 2018; Neessen et al., 2021; Lenderink et al., 2020). The literature highlights the opportunity to tackle this knowledge gap through the application of frameworks that support the transition to a circular economy (Ebarhardt et al., 2019; Leising et al., 2017; Metabolic, 2019; Goodwin Brown et al., 2021). However, the study of Castelein (2018) addresses the lack of scientific research on the circular economy in the construction sector. Most studies are theoretical with little focus on the circular economy in practice (Castelein, 2018). In current years, more research has been conducted on the circular economy in the construction sector, especially on circular procurement. Several guides on integrating the circular economy into the procurement process can be found in literature. For example, the circular procurement guide from the Platform CB'23 (Platform CB'23, 2021), the circular procurement in 8 steps guide by van Oppen & Bosch (2020) and the circular procurement by van Oppen et al. (2018). However, these guides are often guidelines that lack specific information on how to establish circular criteria. As a result, purchasers still do not know how to include realistic circular criteria in their tenders. In addition to the procurement manuals, thera are also tools for creating criteria. For example, the government has developed the MVI-criteria tool to help purchasers identify relevant criteria to include in their tender documents (Vroom, 2020a). The European Commission has also created a tool, the EU GPP criteria, to facilitate the inclusion of green requirements in public tender documents (European Commission, n.d.). However, both tools only consider office buildings and not residential buildings, or more specifically single-family homes. Another example is Cirkelstad, which created 'het nieuwe normaal'. 'Het nieuwe normaal' is a supported standard with achievable and ambitious circular performance in the built environment. However, this tool looks at buildings in general and does not have a specific focus on single-family homes. Thereby, it does not consider the impact of circular performance. The lack of circular criteria for single-family homes, combined with the lack of knowledge among governments on how to implement circularity in procurement, leads to the call for a framework with circular criteria for governments to realize a circular transition with procurement.

1.6 Reading guide

This thesis consists of 8 chapters. The first chapter introduces this research, the problem statement, the research questions, and the research design underlying this research. The second chapter is the literature study which is used to create boundaries for this research and to determine the factors to consider for the framework. Chapter 3 elaborates the research design and the underlying methods used to conduct the research design.

Chapters 4 through 7 are dedicated to elaborating the results of the design science research (DSR) approach used in this research. Chapter 4 begins by addressing the exploration phase, in which the results of the literature study and interviews are elaborated. The synthesis phase in Chapter 5 determines which project goals, circular materials strategies, and impacts should be included in the framework. In addition, the value of the CE-criteria and impacts is determined. In Chapter 6, the creation phase, the framework is created. Finally, in Chapter 7, the evaluation phase, the created framework is validated.

This thesis finishes with the conclusion, discussion and further recommendations in Chapter 8.

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2. Literature study

The starting point of this research is a literature study. The literature study is the foundation for this research by presenting the theoretical perspectives related to circularity in public procurement for newly built single-family homes. The topics covered in this chapter include recent developments regarding the concept of circular economy and how the circular economy can be implemented through public procurement. Circular strategies are identified for implementing the circular economy in public procurement. In addition, project results are identified to determine whether or not a circular strategy is suitable for single-family homes. Finally, the impact of circular strategies on single-family homes will be identified to support in the decision-making process for selecting suitable circular strategies.

2.1 The circular economy (CE)

In the circular economy the traditional linear take-make-waste economy is replaced (Korhonen et al., 2018; Braungart & McDonough, 2002). According to the Dutch government, there are three types of economies; linear economy, reuse economy and circular economy. The three types of economies are shown in Figure 3. In a linear economy raw materials are used to produce a product and after use, the waste is thrown away. In a reuse economy, some used products are recycled. A circular economy is based on recycling, which means that all materials are reused (Rijksoverheid, n.d.-b).

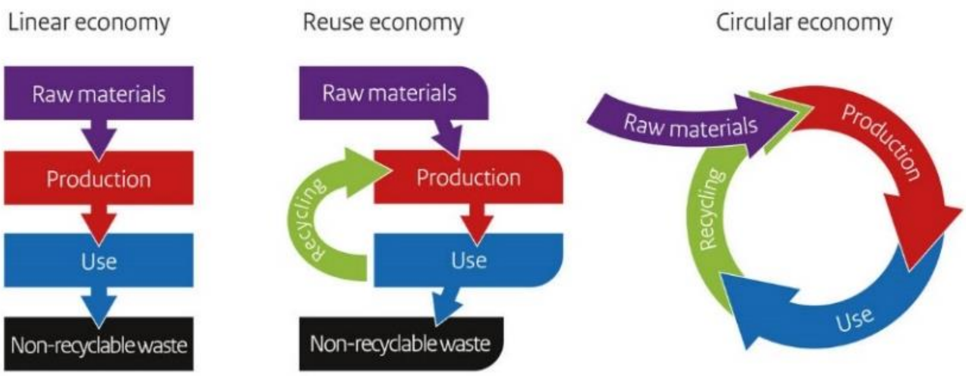

Figure 3; From a linear to a circular economy (Rijksoverheid, n.d.-b)

The idea of material cycles has been around since the beginning of industrialization (Desrochers, 2004). In a circular economy, waste is reduced and considered as an input for other products or chains (De Angelis et al., 2018). Due to the current discussions on climate change mitigation and sustainable development, attention has been paid to material cycles (Korhonen, Nuur, et al., 2018). The circular economy is seen as a way to realize the concept of sustainable development (Ghisellini et al., 2016), by initiating regenerative industrial transformations that lead to sustainable production and consumption. The revolution based on CE will not only have a positive impact on the environment, but will also contribute to economic growth (Korhonen, Nuur, et al., 2018). The growing attention given to the concept of CE by various stakeholders has led to many CE definitions and blurring of the CE concept (Kirchherr et al., 2017). The study by Kirchherr, et al. (2017) sought to address this vagueness by analyzing 114 definitions of a circular economy. Based on their findings, they formulated a final CE definition;

"*an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations*" (Kirchherr et al., 2017).
Although various definitions are used to describe the circular economy, the definition proposed by the Ellen MacArthur Foundation is the most commonly used (Kirchherr et al., 2017; Superti et al., 2021). The Ellen MacArthur Foundation uses the following definition:
"*A circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the end-of-life concept with restoration, shift towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse and return to the biosphere, and aims for the elimination of waste through the superior design of materials, products, systems and business models*" (EMF & McKinsey & Company, 2014, p.15).
The Ellen MacArthur Foundation's definition is used as the working definition in this research, as this definition is the most commonly used and is a fundamental principle in many studies (Kirchherr et al., 2017).

A visual representation of the CE concept, by the Ellen MacArthur Foundation, is given in the butterfly model, as is shown in Figure 4. The butterfly model represents the continuous flow of technical and biological materials through the 'value cycle' (Ellen MacArthur Foundation, 2019). The butterfly model consists of three integrated parts: the biological cycle, the economic model and the technical cycle. The model starts with the economic model by mining materials and manufacturing products. The products are provided in the market and are used or consumed. At the end of the lifecycle, the products are collected and enter one of the many feedback loops. Disposal of materials to be burned for energy recovery or left as landfill must be minimized (Ellen MacArthur Foundation, 2013). The feedback loops are part of the biological or technical cycle. The technical cycle, shown on the right side of the model, involves the management of finite material stocks (Comin et al., 2020). The technical cycle closes the loops with circular strategies such as reuse, refurbish and recycling (TU Delft, n.d.). The biological cycle, shown on the left side of the model, contains flows of renewable materials (Comin et al., 2020). The biological cycle assures the sustainable management of biological resources and the creation of renewable flows and stocks. The butterfly model aims to minimize the extraction of raw materials and waste generation (TU Delft, n.d.).

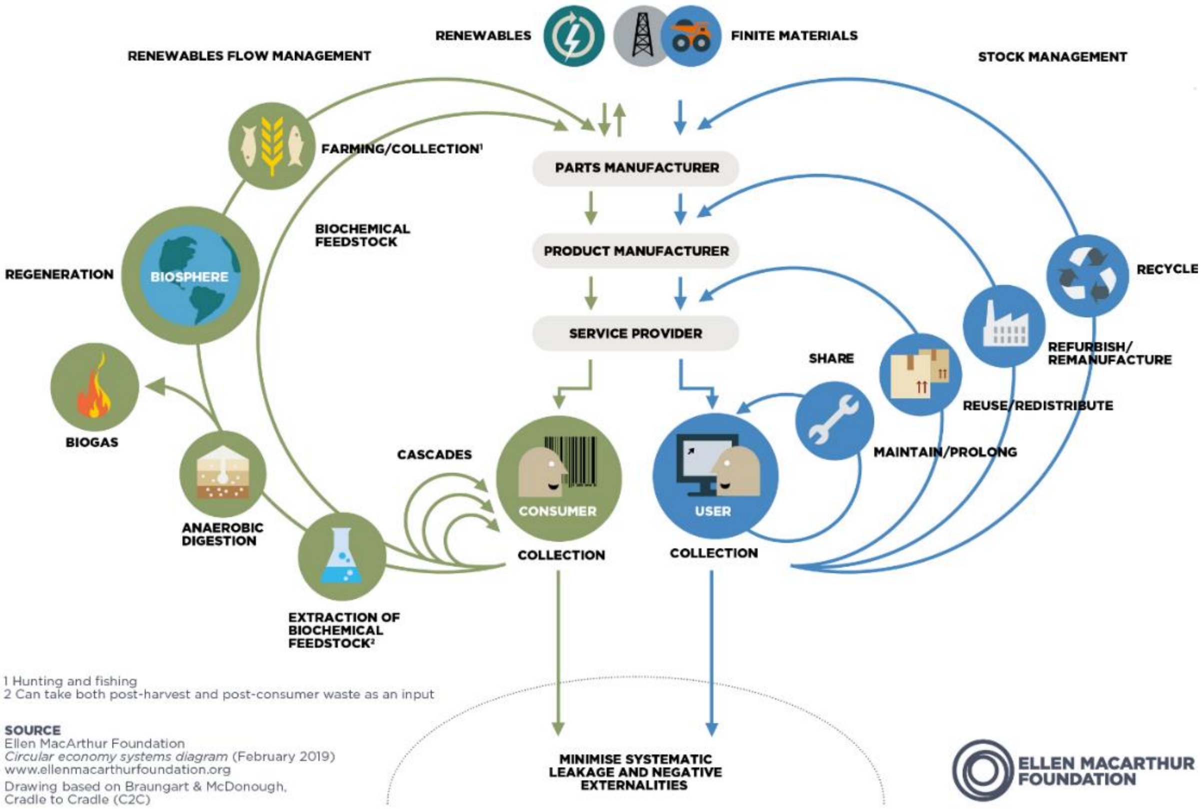

Figure 4; Butterfly model (Ellen MacArthur Foundation, 2019)

In current literature, there is no common understanding of the ultimate goal of the circular economy. For this reason, Metabolic defined seven performance characteristics of a circular economy, as shown in Figure 5. The seven performance characteristics represent the end state of a circular economy once it has been genuinely achieved (Metabolic, 2019). The characteristics include optimal use of materials, energy and water resources, while also maintaining a positive impact on biodiversity, human culture and society, health and wellbeing and the creation of multiple forms of value. In addition to the seven performance characteristics, a circular system should be designed with resilience, transparency and equity (Kubbinga et al., 2018). Resilience is about making sure that knowledge is transferred about the way it works and how it can be disassembled. Transparency is about tracking the materials and knowing what is in the product. Finally, equity is about designing with the principles of equity in mind (Metabolic, 2019). To achieve the seven performance characteristics several strategies can be followed (Kubbinga et al., 2018). Strategies to achieve circularity will be further explained in Section 2.5.

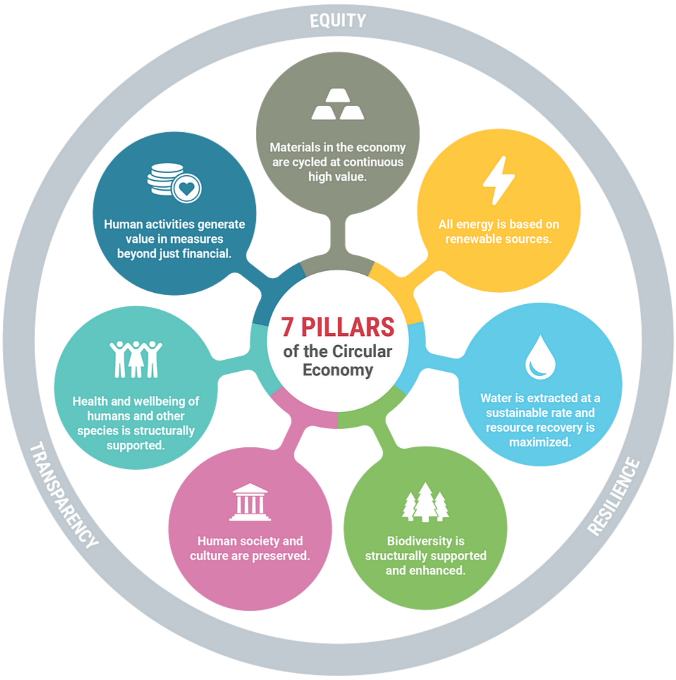

Figure 5; the seven pillars of the circular economy (Metabolic, 2019)

2.2 Circular economy in the construction sector

After defining the concept and context of the circular economy, this section will elaborate on the relationship to the construction sector. Within the 'Nederland circulair in 2050' program the construction sector is assigned as a priority sector. Since the construction sector is responsible for 50 percent of the material consumption and most materials end up as demolition waste. A circular transition within the construction sectors is needed to create a sustainable living environment (Rijksoverheid, n.d.-a). For the construction sector, the transition to a circular economy means high-quality reuse of materials, products and elements and a different approach in production, tendering, design and execution of construction projects (Platform CB'23, 2019).

Circular construction knows many definitions, which could lead to confusion and problems in collaborations (Platform CB'23, 2019). It is important to have a clear understanding of what is meant by circular construction. CLIMATE-KIC (2019) focuses on defining circular construction on a high-value use and reuse of materials and adaptive futureproof design while striving for sustainability concerning energy, water, biodiversity and ecosystems (CLIMATE-KIC, 2019). In addition to the definition of CLIMATE-KIC the definition of Kubbinga, et al. (2018) also includes a contribution to the wellbeing of people and other inhabitants of this earth, here and there, now and later (Kubbinga, et al., 2018). On the other hand, Leising, et al. (2017) define the circular construction as a lifecycle approach that optimizes a buildings useful lifetime, integrates the end-of-life phase in the design, and uses new ownership models in which materials are only temporarily stored in buildings that act as a material bank (Leising, et al., 2017). Also, the Dutch government defined circular construction in the Transition Agenda Circular Construction Economy, which is part of the 'Nederland circulair in 2050' program. The Transition Agenda defines the Circular Construction Economy as follows:

"*the development, use and reuse of buildings, area's and infrastructure, without avoidable depletion of natural resources, pollution of the environment or negatively impacting ecosystems. Construction which is economically responsible and contributes to wellbeing of humans and animals, now and in the future*" (Rijksoverheid, 2018).
This definition is in line with the definition given by the Ellen MacArthur Foundation (EMF & ARUP, 2019). In addition to the definition of the Transition Agenda, platform CB'23 takes besides construction being economically responsible also construction being ecological responsible into account (Platform CB'23, 2019). The definition of the Transition Agenda will be the working definition throughout this research since this definition is made by the government and the framework that will be created in this research is intended for the government.

2.3 Circularity in procurement

In the transition to a circular economy an important role is given to the purchasing and tendering process (Scherpenisse et al., 2021). The government wants to realize a sustainable transition with the aid of purchasing (Ollongren & Veldhoven-van der Meer, 2019). Purchasing is the acquiring of work, services or goods by paying for them. The term procurement, also referred to as tender, is related to purchasing. Procurement is a specific part of purchasing, as shown in Figure 6. Procurement is used to put contracts professionally in the market. Through competition contracting authorities optimize their changes of the best price-quality ratio and supply and demand are better matched (PIANOo, n.d.-i). According to PIANOo, the Dutch expert centrum for procurement, procurement is a weighted manner to contract an appropriate contract partner with the most suitable product (service/work/goods) for the most favorable price, in which price/quality ratio is the most important factor (PIANOo, n.d.-h). The procurement process is divided into the phases specification, selection and contracting, as shown in Figure 6. The specification phase consists of determining the strategy, in which based on previously developed risk analysis, development strategy and collaboration strategy a selection protocol is developed. In the selection protocol the following procedures are elaborated: the question, the procurement process, award criteria (requirements and wishes), the assessment, lead time and decision making. The selection protocol must ensure that the specification, most important frameworks and objectives, and the procurement and assessment method are clear in advance and supported by all those involved. The selection protocol is detailed in separate documents, in line with the phases of the selection phase. Based on the chosen procurement method there is a different number of documents. There may be one document (only award phase), two documents (selection and award phase) or three documents (selection, dialogue and award phase). The contractors involved in the procurement use these documents as a basis for their submission. The second phase, the selection phase, consist of the three phases (Neprom, et al., 2019):

- **Selection phase** is used to select a shortlist of suitable contractors that qualify for the award phase, whether or not through dialogue.
- **Dialogue phase** a limited number of contractors, the preselected contractors, are invited for several dialogues aimed at collaboration to arrive at desired and appropriate solutions and/or remove risks and possibly further shorten the shortlist.
- **Award phase** is used for contractors to submit a tender for a specific date. After the deadline has expired, the tender will be assessed by an assessment committee and the tender can be awarded.

The selection and dialogue phase are optional, based on the chosen procurement method. The final phase is the contracting phase, which is used to sign a contract with the contractor of the winning tender (Neprom, et al., 2019).

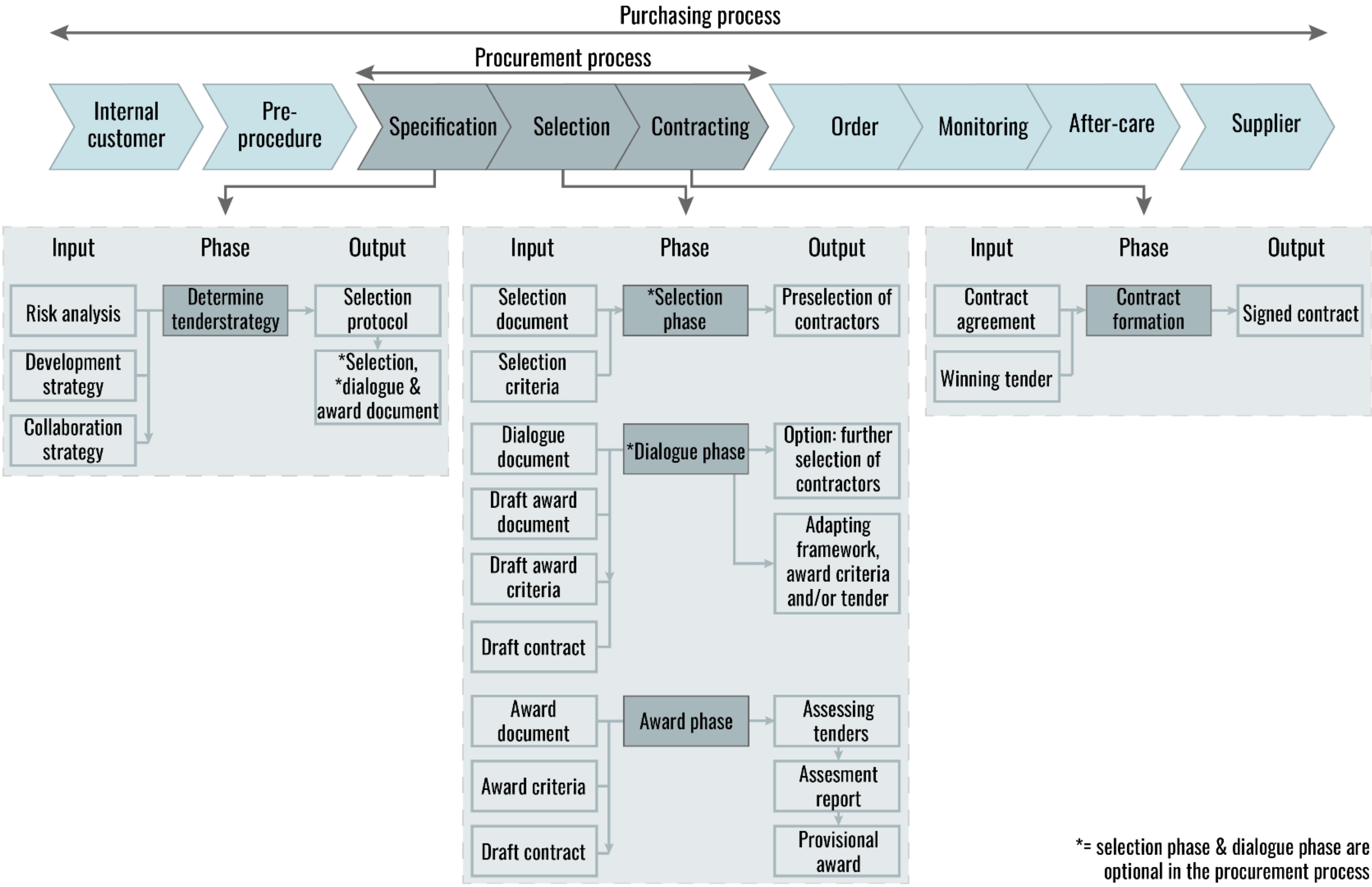

Figure 6; Purchasing process including procurement process based on IBR (2020), Platform CB'23 (2021) and Neprom, et al. (2019)

In a procurement contracting authorities are obligated to award tenders based on the right price/performance ratio instead of the previously used lowest price, according to the Dutch Public Procurement Act 2012. In the right price/performance ratio the economic component is weighted against a quality component (PIANOo, n.d.-a; IBR, 2020). To consider the circular economy in procurement, the contracting authority can include circularity as a quality component in the selection or contracting phase by using criteria that safeguard circularity (PIANOo, n.d.-a). Different types of circular criteria can be applied in procurement. Table 1 gives an overview of the circular criteria types and an explanation.

Circular criteria type	Explanation
Suitability requirements	Suitability requirements are used to determine whether a candidate is able to perform the contract. Suitability requirements always relate to the potential contractor and not the contract. A contractor needs to meet the suitability requirements to be able to proceed in the procurement process (PIANOo, n.d.-d).
Selection criteria	Selection criteria are used in the selection phase to select the most suited contractors regarding their knowledge and experience. The purpose of selection criteria is to limit the number of candidates to a predetermined number, who are then invited to tender (PIANOo, n.d.-l).
Award criteria	Award criteria are used to request additional wishes on top of the minimum requirements (PIANOo, n.d.-a). An example of award criteria can be awarding more points to a relatively higher percentage of recycled materials.
Minimum requirements	Minimum requirements are used to prescribe the minimum that is wanted for the job or what is not wanted for the job (PIANOo, n.d.-e). In case a contractor does not meet the minimum requirements the tender is not included in the assessment.
Contract provision	Contract provision is used to ensure a sustainable execution of the job. Think of a bonus that is linked to increasing material reuse during the execution of the job (PIANOo, n.d-f).

Table 1; Circular criteria types

A contracting authority is obligated by law to perform a public procurement above certain contract values, the so-called European threshold values. These contracting authorities are the government (state, province, municipality, water board), public law institution or a partnership of these governments or public law institutions (PIANOo, n.d.-j). The European threshold for contracting authorities depends on the type of contracting authority (central government, local authorities and special sector companies) and whether the procurement is a work, service or good. An overview of the European threshold values is given in Table 2. Those values apply from 1 January 2022 till 31 December 2023 (PIANOo, n.d.-k). Above or equal to the European threshold contracting authorities are obligated to perform a public procurement at the European level. Below the European threshold, the contracting authorities' own procurement guidelines apply (PIANOo, n.d.-j).

	Central government (state)	Sub-central government	Special sector companies
Works	5.382.000	5.382.000	5.382.000
Services and goods	140.000	215.000	431.000

Table 2; European threshold value 2022-2023 (PIANOo, n.d.-k)

A project for newly built single-family homes starts with an initiative; governments or market parties that want to realize homes at a certain location. Almost always the initiative is taken by parties that own land. To develop homes the land has to be intended for living functions based on the destination plan of the government. Land can be in the hands of the government or market parties. In case the land is owned by market parties, for example developers, the market parties can develop the project entirely under its own management, in collaboration with other market parties or the government. In case the land is owned by the government the land will be sold, often with the aid of public procurement, to market parties that will develop the land (CPB, 2019). The most important procurement method for land development is procurement in the form of a plan, design- or development task. With this procurement method contractors are asked to, based on a public schedule of requirements, come up with a plan of action in the form of a vision and preliminary design, often including a financial bid and planning (Neprom et al., 2019). According to the Dutch Public Procurement Act 2012 a government is not subject to public procurement in case of the purchase or sale of land. Instead, the government uses by the selling of land an one-on-one collaboration or private selection (Neprom, et al. 2019). However, in case a government applies conditions to the land transaction the government becomes subject to public procurement. The "Helmet Muller-arrest" 2010 is applied to see whether there is a case of a land transaction with subject to public procurement or not. According to the Helmet Muller-arrest land transactions become subject to public procurement if the three following conditions apply (Third Chamber, 2010; PIANOo, n.d.-m):

- The municipality has a direct economic interest in the execution of the work;
- There is enforceability of the deliverables; and
- The municipality sets (specific) requirements for the performance to be delivered that go beyond the possibilities of the public law framework.

In case the three conditions of the Helmet Muller-arrest are applicable there is an active land policy by governments. In active land policy building plots are sold through public procurement to market parties who realize homes according to the wishes of the government (CPB, 2019). An example of a government that uses active land policies combined with plot-oriented tenders is the government of Amsterdam. In plot-oriented tenders a tender is divided in different plot, which increases the market competition and smaller companies can also participate in the tender (PIANOo, n.d.-n). With the aid of plot-oriented tenders, Amsterdam wants to give the market broad opportunities for example for sustainability (Neprom et al., 2019). In addition to the Helmet Muller-arrest, which in some cases makes land transactions by the government subject to public procurement, a court decision has been made recently that influences the sale of land by the government. According to the verdict one-on-one tender or private sale by the government is not in line with the principle of equality and therefore not allowed. Potential candidates should always have a chance to compete when a government sells an immovable property, such as a plot of land. The buyer must be selected based on objective, verifiable and reasonable criteria. With this verdict private sale and selection seem to be a thing of the past (Baggerman, 2021), resulting in the government becoming subject to public procurement for the sale of land.

Besides the government also some housing corporations use public procurement for housing projects (CPB, 2019). According to the Dutch government, housing corporations are not subject to public procurement (AKD, 2021). However, there are housing corporations that prefer public procurement for the selection of a contractor. On the other hand, there are housing corporations that do not use public procurement, but instead make use of several permanent contractors (CPB, 2019). The European Commission does not agree with the Dutch government that housing corporations are not subject to public procurement. They argue that the Dutch government does not comply with the European procurement rules, because the Dutch government does not classify housing corporations as contracting authorities. The European Commission beliefs that housing corporations are subject to such intensive supervision by the Dutch government that they qualify as public-law institutions within the meaning of the EU procurement law. On the other hand, the Dutch government believes that housing corporations are no public-law institutions. The European Commission gives the Dutch government time to take the necessary measures to comply with European law. If the

Dutch government does not comply sufficiently, the European Commission will present the case to the European Court of Justice (AKD, 2021). This means that, when it comes to the European Commission, Dutch housing corporations will become subject to public procurement.
This research uses the scope of projects for newly built single-family homes for the creation of a framework with circular criteria that can be applied in procurement. For governments, public procurement is in some cases obligated for selling the land for housing projects. However, there is a high chance that public procurement will be legally required more often by governments. For housing corporations public procurement is not obligated. However, some housing corporations use public procurement anyway. In addition, as well as for governments, for housing associations also a high chance exists that public procurement will be legally required more often. Therefore, governments and housing corporations will be the target groups for this research.

2.4 Project goals

This research focusses on single-family homes. Building new single-family homes is done by using a building project. A building project is a temporary collaboration, with different disciplines, to achieve a predetermined project result within a given budget and time (Grit, 2012). In addition, a building project is always unique and is realized at a specific location and therefore a specific context (SGS Search, 2021). A characteristic of a building project is that it concerns a unique situation with an unique predefined project result. An often used project phasing method in project management literature consists of six steps, as shown in Figure 7.
The initiation phase is the first step in a project. This phase is featured by a problem, a vision or idea that should be handled according to an organization. To start a project the project goal (the why) and the project results (the what) are determined (Grit, 2012). A project goal indicates what the contracting authority wants to achieve with the project. The project goals are described in general terms. The project goals can be realized by applying strategies. In this case strategies act as the how. To choose a suitable circular strategy for a project it is important to know what a contracting authority wants to achieve with the project, so the project goals. The project goals determine whether a circular strategy is suitable for a project or not. Therefore, project goals will be considered in this research and will be implemented as the first step in the framework.
Based on literature and conversations within Alba Concepts, three project goals have been determined. Those project goals are sub-goals that contribute to the main project goal. A sub-goal is a smaller part of the main project goal. The three project goals that will be considered are:

- Circular motives,
- Implementation term and,
- Lifecycle phase.

Each project goal will be elaborated further in the upcoming sections.

Figure 7; Project phasing method (Grit, 2012)

Circular motives

The first step in determining a suitable circular ambition is to determine the motives for circularity in the organization. Circular motives are the reason why a person or company wants to achieve certain circular goals. The circular motives influence the decisions regarding circularity. Examples of circular motives are material scarcity, image, finance and residual value. In this case, the choice for a financial motive leads to different circularity choices compared to the choice for a more positive image (PIANOo, 2019). Besides image and finance, another circular motive is the social motive. The social motive is focused on improving the world for future generations (Kersten, 2017). Other motives that could drive a company to circularity are the law and reducing the impact on the climate. Based on conversations within the company (Alba Concepts) and the literature the following circular motives and their explanation are defined as given in Table 3.

Circular motive	Explanation
Image	A company with image as a motive sees circularity as a way to profile oneself and wants to be visibly circular.
Law	A company with law as a motive chooses circular strategies that are necessary to comply with legislation and regulations.
Finance	A company with finance as a motive sees circularity as a way to reduce total operating costs and chooses circular strategies to reduce costs.
Residual value	A company with residual value as a motive sees circularity as a financial opportunity and chooses circular strategies that create value and yield returns.
Material scarcity	A company with material scarcity as a motive tries to reduce the usage of scare materials, such as aluminum, chrome, vanadium, copper, zinc, tin and lead.
Impact on climate	A company with impact on the climate as a motive has the intrinsic motivation to improve the world that we live in by reducing the impact on the climate.
Social	A company with social motives has the intrinsic motivation to improve the world that we live in by improving the health and well-being of humans.

Table 3; Circular motives (Author, 2021)

Implementation term

Strategies have circular impacts in the short or long term (PIANOo, n.d.-g). To choose a suitable strategy it is important to include whether a strategy influences circularity in the present or future. For example, the use of non-toxic materials will not affect circularity right away, but only when the non-toxic materials are at the end-of-life and ready for recycling. On the other hand, reusing materials will affect circularity right away, because materials are used for a longer time and do not turn into waste.

Lifecycle phase

Time is an important aspect of circular strategies. Circular strategies can focus on the beginning of a buildings lifetime or at the end of a buildings lifetime (Gerding, 2018). At the beginning of the lifetime strategies focus on preventing input, while at the end of the lifetime strategies focus on dealing with the output, for example waste (Addis, 2006). Concerning time a circular material lifecycle consists of three distinct phases: development (input), utility (use) and end-of-life (output)(Amory, 2017). Those three phases are in line with the loops of Bocken, et al. (2016) and Goodwin Brown, et al. (2021), in which regenerating and narrowing represent the development phase, slowing represents the utility phase and closing represents the end-of-life phase.

2.5 Circular strategies

Circularity can be implemented in the construction process using circular strategies, which guarantee reduction, reuse and recycling (Gerding, et al., 2021). Thereby, circular strategies are needed to achieve the end state of a circular economy as formulated by the seven performance characteristics of Metabolic (2019) in Section 2.1. A circular strategy is defined as a plan of action designed to achieve circular goals. Concerning circular buildings, this means how circularity could be implemented (Gerding, 2018). Different circular strategies have been proposed in the literature. However, no agreement is found on how to categorize circular strategies and different terms are used interchangeably (Gerding, 2018). Terms, other than circular strategies, found in the literature to describe circular strategies are for instance 'circular business model', 'circular design' and 'circular principles'. This literature study aims to provide insight into existing circular strategies and their categorization.

Time is an important aspect of circular strategies (Gerding, 2018). Some circular strategies deal with end-of-life waste, while others aim at preventing waste upfront. Depending on the focus a strategy can thus be applied at the beginning or the end of a project (Addis, 2006). The study of Bocken, et al. (2016) uses the time dimension in the categorization of circular strategies in narrowing, slowing and closing loops. Narrowing loops is about reducing resource use associated with the product and production process. Slowing loops is about prolonging the use and reuse of goods over time, through the design of long-life goods and product life extension. On the other hand, closing loops is about the reuse of materials through recycling at the end of life (Bocken et al., 2016). In addition to narrowing, slowing and closing loops, the study of Circle Economy (2021) and Goodwin Brown, et al. (2021) adds regenerating as a fourth loop. Regenerating loops is about making clean, in which fossil fuels, pollutants and toxic materials are replaced with regenerative sources (Circle Economy, 2021). In summary, the following loops can be identified:

- Regenerating (making clean)
- Narrowing (using less)
- Slowing (using longer)
- Closing (using again)

Besides the categorization in loops, the study of Amory (2017) categorizes circular strategies as circular design strategies and circular material usage strategies. Circular design strategies, in general terms Design for Circularity (DfC), refer to options for value retention and value recovery for the future through clever and anticipating design. Design for X (DfX) paradigms are developed to perform better in regard to X (Verberne, 2016; Amory, 2017). In which X can be any aspect of circularity, for example disassembly (Design for Disassembly) or reuse (Design for Reuse). Circular material usage strategies concerns limiting the amount of materials and using durable, reusable and recyclable materials (Verberne, 2016; Amory, 2017). The circular material usage strategies are divided into a technical and biological cycle. The technical cycle is about recycling in which products, components and materials are restored into the market with the highest possible quality for as long as possible. In the biological cycle, materials are restored in the biosphere and renewed using natural processes (Ellen Mac Arthur, 2013; Verberne, 2016).

In this research, the categorization of Brown, et al. (2021) and Amory (2017) will be applied for structuring the circular strategies found in the literature. This means that all the strategies will be divided into regenerating, narrowing, slowing and closing and within these categories a distinction will be made between material and design strategies.

In this research different circular strategies have been identified in the literature. In total 31 references have been found with overall 330 circular strategies. However, this enormous list of circular strategies is too extensive for validating by experts and too ambitious for this research. For this reason, the 330 circular strategies have been reexamined in several steps. The process of reexamining the circular strategies has been visualized in Figure 8.

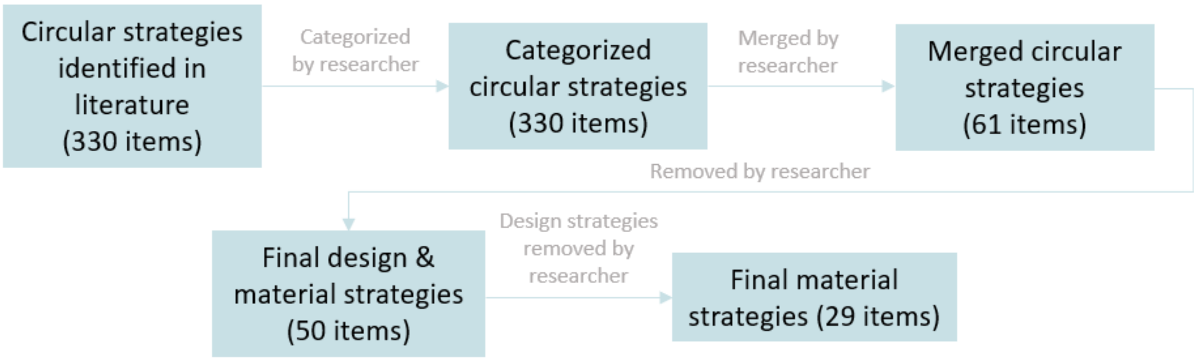

Figure 8; Process of reexamining the list of circular strategies

The starting point is the list with 330 circular strategies, as represented in appendix A. The first step is the categorization of all identified strategies to narrowing, slowing, closing and regenerating. Thereby, a differentiation is made between material strategies and design strategies. The second step is merging duplications and comparable circular strategies into one circular strategy. The third step is removing circular strategies that do not suit the purpose of this research. For instance, some circular strategies include an aim instead of a strategy, for example maximizing product life. Other circular strategies focus on knowledge sharing, the usage of products or digitization. Those circular strategies are not part of the construction process or the building and are therefore not taken into account. The result is a list of 50 circular material and design strategies, as represented in appendix B. The last step is to remove the design strategies. According to the study of Gering (2018) design strategies relate to the material strategies. Also, the study of Amory (2017) addresses the relation between materials strategies and design strategies by mentioning that Design for X (DfX) strategies can be any aspect of circularity. This indicates that design strategies are an interpretation of material strategies. The way to give substance to a circular strategy, for example in design, is not part of this research. For this reason, design strategies are not taken into account, only circular material strategies will be considered within this research. The result is a list of 29 circular material strategies, as presented in Table 4. It must be noted that multiple circular material strategies could be used to realize a circular building (Kraaijenhagen et al., 2018).

Loops	Strategy	Explanation
Regenerating	Rain/grey water usage	Reusing water and replacing freshwater use with rainwater, fog water, seawater, etc. (Knowledge Hub, n.d.)
	Biobased materials	Using bio-based materials such as bioplastics, mushroom-based materials, etc. (Knowledge Hub, n.d.)
	Non-toxic materials	Replacing toxic and hazardous materials with regenerative sources (Knowledge Hub, n.d.)(Kubbinga, et al., 2018)(Circle Economy, 2020)
	Non-critical materials	Using materials that are not considered critical (Knowledge Hub, n.d.)
	Non-fossil fuels	Replace fossil fuels with regenerative sources (Circle Economy, 2020)
	Renewable energy	Using renewable energy like solar, wind, etc. or renewable fuels like biomass, etc. (Knowledge Hub, n.d.)
	Electrification	Converting fossil fuel based operations to electric (Knowledge Hub, n.d.)
Narrowing	Refuse	Preventing the use of raw materials, water and energy (Amory, 2017)(van Buren, et al., 2016)
	Reduce	Reduce the use of raw materials, water and energy and reduce the amount of waste generated (Xing, et al., 2017)(van Buren, et al., 2016)
	Rethink	Reconsider the options regarding material, energy and water usage and consider the impact on the environment (Xing, et al., 2017)
	Redesign	To design something again or differently through innovative techniques to make it more sustainable (Yan & Feng, 2014)
	Water efficiency	Optimize water usage by doing more with less or using less water (Garding, 2018)(Knowledge Hub, n.d.)
	Material efficiency	Optimize material usage by doing more with less or using fewer materials and resources (Gerding, 2018)(Knowledge Hub, n.d.)
	Energy efficiency	Optimize energy usage by doing more with less or using less energy (Garding, 2018)(Knowledge Hub, n.d.)
Slowing	Retain	Keeping the existing product
	Reuse	The reuse of products or components for the same function (Rahla, Mateus & Braganca, 2021)(Potting, et al., 2017)(Yan & Feng, 20141)(Gerding, 2018)(Ghisellini, et al., 2016)
	Repair	Fix a defective product so it can be used with its original function (Potting, et al., 2017)(Rahla, Mateus & Braganca, 2021)
	Refurbish	Renovate an outdated product to provide an appropriate physical condition (Rahla, Mateus & Braganca, 2021)(Potting, et al., 2017)(Gerding, 2018)
	Remanufacture	Make a new product by using parts of a discarded product with the same function (Rahla, Mateus & Braganca, 2021)(Potting, et al., 2017)(van Buren, et al., 2016)
	Resilient	The ability of materials and components to withstand difficult conditions
	Durable	The resistance of materials and components to deterioration over time while maintaining the minimal requirements (Rahla, et al., 2021)(Amory, 2017)
	Maintain	Prolong use of materials and components through maintenance (Rahla, et al., 2021)
	Upgrade	Raising products to a higher standard by adding or replacing components
	Multifunctional products/building	Fulfilling multiple functions within one product/building
Closing	Repurpose	Make a new product by using parts of a discarded product with a different function (Rahla, Mateus & Braganca, 2021)(Potting, et al., 2017)(van Buren, et al., 2016)
	Recycle	The reprocessing of waste materials into new products or materials with the same, higher (upcycling) or lower (downcycling) qualities for original or other functions (Ghisellini, et al., 2016)(Rahla, Mateus & Braganca, 2021)(Potting, et al., 2017)(Gerding, 2018)
	Recover	The incineration of non-recyclable materials with retrieving heat, electricity or fuel (Rahla, Mateus & Braganca, 2021)(Potting, et al., 2017)(van Buren, et al., 2016)
	Renewable	The usage of renewable resources, such as biobased materials and renewable energy (Ghisellini, et al., 2016)(Elia, et al., 2017)
	Biodegradable	The disintegration of products into the natural environment without ecological damage (Rahla, Mateus & Braganca, 2021)

Table 4; Final list of circular material strategies

2.6 Impact of circular strategies on building projects

Impacts represent the effect of an circular material strategy on a building project. For governments, it is important to know the impact of a strategy on the building project to select a realistic and suitable strategy to implement. Circular economy implementation does not necessarily guarantee a reduction in the related economic and environmental impacts (Zink & Geyer, 2017). Therefore, it is important to evaluate the economic and environmental impacts of circular economy implementations in decision-making (Braakman et al., 2021). Being able to compare the impacts of each circular strategy will support the decision making process, allowing governments to make better informed decisions when it comes to strategy selection (Hammed et al., 2019). Within this section, impacts are identified that are influenced by circular strategies.

Traditionally, in construction importance is given to factors that impact costs associated with projects (Pasquire and Connolly, 2002). In addition, the study of Fischer & Achterberg (2016) also addresses financial factors as an important factor supporting decisions. However, incorporating numerical evidence for environmental impact will result in a more inclusive financial decision making process (Fischer & Achterberg, 2016). Thereby, time is a relevant impact due to its large influence on decision making (Pasquire and Connolly, 2002). Also, the study of Hussin, et al. (2013) identifies the importance of time and costs on construction projects. Besides time and costs also construction waste, excessive resource consumption and the threat to the environment of construction projects are important impacts (Hussin et al., 2013). The study of Többen (2021) identifies besides costs and time also quality as an important aspect that should be managed in a project. Quality is also an important aspect of public procurement. Due to the Dutch Public Procurement Act 2012 contracting authorities are obligated to award tenders based on the right price/performance ratio. In the right price/performance ratio the economic component is weighted against a quality component (PIANOo, n.d.-a; IBR, 2020).
To categorize the impacts several literature studies divided the impacts of a construction project into the categories of economic, environmental and social impacts (Hammad, et al., 2019; Kamali & Hewage, 2017; Rizos, et al., 2017). These categories are the three key dimensions of sustainability, also referred to as the triple bottom line (Kamali & Hewage, 2017). The study of Hammad, et al. (2019) identifies as most relevant economic impacts time and costs. For environmental impacts are embodied and operational energy most relevant in construction. The most relevant social impacts are noise pollution and the enhanced safety of workers (Hammad et al., 2019). The study of Kamali & Hewage (2017) ranked the indicators design and construction time and costs as very high importance indicators. High importance environmental indicators are waste management, energy performance and efficiency strategies, material consumption and greenhouse gas emissions. Social indicators of very high importance are workforce health and safety. In addition, the social indicators community disturbance, safety and security and user acceptance and satisfaction are of high importance (Kamali & Hewage, 2017).
Overall, the impact of costs and time on a building project are mentioned most often. Besides costs and time also the impact on quality plays an important role in public procurement, due to the Dutch Public Procurement Act 2012. Thereby, impacts on the environment are mentioned a couple of times. Environmental impacts that are mentioned are construction waste, energy consumption, greenhouse gas emissions and material consumption. The focus

of this research is on circularity, and not sustainability. Circularity focuses on resource cycles, while sustainability covers people, the planet and economy more broadly (Het Groene Brein, n.d.-c). Therefore, only the environmental impacts of construction waste and material consumption will be taken into account. The social impacts will not be taken into account in this research, since the focus is on circularity and not sustainability. Therefore, the impacts that will be taken into account in this research are costs, time, quality, construction waste and material consumption, as shown in Table 5.

Impact	Explanation
Costs	The total financial resources needed to finance the building, from initiation till realization (NIB, 2019).
Time	The total time needed to realize the building, from initiation till realization (NIB, 2019).
Quality	The extent to which a building, and products within a building, meet established standards.
Construction waste	The total amount of waste during realization of a building, including material waste and packaging (Hussin, et al., 2013; Kamali & Hewage, 2017).
Material consumption	The total amount of materials needed to realize the building.

Table 5; Final list of impacts of strategies

2.7 Conclusion literature study

The literature study is the foundation for this research by presenting the theoretical perspectives related to circularity in public procurement for newly built single-family homes. The insights from the literature study are used to create boundaries for this research and to determine the factors to consider for the framework.

Boundaries for this research

Literature shows that there are many definitions to describe the concepts of the circular economy. The definition proposed by the Ellen MacArthur Foundation is used most often and forms a fundamental principle in many studies. Therefore, the definition of the Ellen MacArthur Foundation will be the working definition throughout this research.

Similar to the concept of circular economy, also the concept of circular construction knows many definitions. The circular construction definition of the Transition Agenda will be the working definition throughout this research since this definition is made by the government and the framework of this research will be developed for governments.

Public procurement is used for the transition to a circular economy. The procurement process is part of the purchasing process and can be divided into specification, selection and contracting phase. To consider the circular economy in procurement, the contracting authority can include circularity as a quality component in the selection or contracting phase by using circular criteria. The different types of circular criteria that can be applied in procurement are suitability requirements, selection criteria, award criteria, minimum requirements and contract provisions. For the realization of single-family home projects land is developed by governments or market parties that own the land. Market parties can develop the land entirely under their own management. The government will sell the land, often with the aid of public procurement, to market parties that will develop the land. For selling the land, the government is in some cases subject to public procurement. However, there is a high chance that public procurement will be legally required more often for governments due to a new verdict. For housing corporations public procurement is not obligated. However, if it is up to the European Commission housing corporations will become subject to public procurement. Therefore, governments and housing corporations will be the target groups for this research.

Factors for the framework
The framework consists of the steps project goals, circular strategies and impacts. Within this literature study the factors for each step have been determined. Starting with the project goals. A project starts with determining the project goals. The project goals are realized by using strategies. To choose a suitable circular strategy for a project it is important to know the project goals. The project goals that will be considered are circular motives, implementation term and lifecycle phase.
Circular strategies are used to implement circularity in the construction process and eventually to achieve the end state of a circular economy. Within this literature study a list of 330 circular strategies has been identified and merged to a final list of 29 circular material strategies. The circular material strategies are categorized into regenerating, narrowing, slowing and closing.
Each strategy has an impact on a project. Being able to evaluate comparable impacts of each circular strategy will support the decision making process, allowing for better informed decisions when it comes to circular strategy selection. The impacts that will be taken into account in this research are costs, time, quality, construction waste and material consumption.

3. Methodology

In this chapter, the research methodology is be explained. As research methodology the four steps of the design science research (DSR) approach are described. Thereby, the research methods used to give substance to each step of the DSR approach are elaborated. These include the literature study, the expert interviews and the Fuzzy Delphi Method.

3.1 Research methodology

The research methodology chosen is a design science research (DSR) approach because the developed framework will solve a field-based problem and has significant practical relevance (van Aken et al., 2016). For this research, a framework proposed by the study of Keskin & Romme (2020) is used, which consists of the four steps of exploration, synthesis, creation, and evaluation. An overview of the DSR process for this particular research is shown in Figure 9. Each step of the DSR process is further elaborated.

Figure 9; Proposed DSR process

3.1.1 Exploration

The first step of the DSR approach is the exploration. Exploration is about drawing the boundaries of the problem space, in which information is gathered through a literature study and field research (Keskin & Romme, 2020). In this research, the exploration phase is used to gather information through a literature study and expert interviews. In the literature study information is collected to create the boundaries of the concept of circular economy and the procurement process. In addition, information is collected about the existing project goals, circular strategies and impacts of strategies. Expert interviews are used to validate whether the project goals, circular material strategies and impacts from het literature study are in line with field experts. The goal of the exploration phase is develop a list of project goals, circular strategies and impacts to be considered for the framework based on a literature study and expert interviews.

3.1.2 Synthesis

The second step, synthesis, is about gaining insights from the information in the exploration phase by applying inductive and abductive sensemaking to identify and make connections (Keskin & Romme, 2020). In the synthesis phase, the results of the exploration phase are used to determine the factors for the project goals, circular strategies, and the impact of circular strategies to be considered for the framework. This is done using the Fuzzy Delphi Method as explained in Section 3.4. Once the factors to be considered are determined, the CE-criteria and the impact of the strategies for each circular strategy can be determined. The goal of this step is to translate the results of the exploration phase into meaningful project goals, strategies, CE-criteria, and impacts to consider for the framework.

3.1.3 Creation

The creation phase is about designing an artifact for the defined problem (Keskin & Romme, 2020). In this step, the framework is created using the input from the synthesize phase. Several sketches are assembled into a final design and the application of the framework is explained. The goal of the creation phase is to create the framework with the project goals, circular strategies, CE-criteria, and impacts that helps governments identify circular options and determine the practicality and value of those options to achieve a circular transition in procurement.

3.1.4 Evaluation

The final step is the evaluation phase. The evaluation phase examines whether the designed solution works (Keskin & Romme, 2020). The examination of whether the framework works is done through expert interviews, through which the framework is validated in terms of its functionality, completeness, consistency, performance, usability and fairness (Hevner, et al., 2004). Both government and market parties are interviewed. Based on the input provided by experts, the framework is improved. The goal of the evaluation phase is to validate the framework and gain market and government support for the framework.

3.2 Literature study

In the literature study, data is collected from academic articles, journals, and reports found in the university online library, Google Scholar, ResearchGate, ScienceDirect and the internet in general. In addition, well-known sources such as PIANOo, platform CB'23, the Dutch Green Building Council and the Ellen MacArthur Foundation were used as data sources. Furthermore, references from other theses, articles, journals and reports were reviewed and used as input. Finally, the collaborating company Alba Concepts also provided information, documents and data used in this research.

3.3 Expert interviews

In the exploration and evaluation phase, expert interviews are used for validation. Interviews are a qualitative research method in which questions are asked to enquire people's thoughts, beliefs, experiences, attitudes, and behavior (Stuckey, 2013)(Babu et al., 2013). Generally, there are three different types of interviews: the structured interview, the semi-structured interview and the unstructured interview (Alsaawi, 2016)(Többen, 2021) (Neergaard & Leitch, n.d.). The different interview types are explained in more detail in Table 6.

Interview type	Description
Structured	This type of interview is planned in advance to focus the interview on the target topic. The researcher uses the same predetermined question for all interviewees, with a limited number of response categories (Stuckey, 2013). For this reason, interviews lack variation in responses and limit the availability of in-depth data (Alsaawi, 2016). Structured interviews are best suited when there is extensive knowledge about a topic and the researcher knows what type of information they are seeking (Turner, 2010)(Alsaawi, 2016).
Semi-structured	Semi-structured interviews are most commonly used in qualitative research and are a combination of structured and unstructured interviews (Stuckey, 2013). The interview is pre-planned, but the researcher gives the interviewee the opportunity to elaborate on specific topics through the use of open-ended questions (Alsaawi, 2016).
Unstructured	In an unstructured interview, the researcher does not know all the necessary questions in advance. The results in a free flowing and open conversation that allows the interviewee to elaborate on unpredictable directions (Alsaawi, 2016)(Qu & Dumay, 2011). In order to conduct this type of interview, the researcher must be well informed about the topic to be able to respond and answer appropiartely (Lucas, 2016).

Table 6; The different types of interviews

In this research, the researcher wants to validate the results while remaining open to other suggestions or insights. Therefore, the semi-structured interview is determined to be the most suited interview type and will be used for all interviews. For the semi-structured interview, predetermined questions are used that cover the topics needed to address during the interview. All questions must be addressed in the interviews to ensure good comparison and data analysis between the different interview results (Cohen & Crabtree, 2006). However, deviation from the predetermined questions is possible.

According to Robson's (2011) study, an interview should be divided into five phases:

1. Introduction: the interviewer introduces him/herself and describes the aim of the interview.
2. Warm-up: start with simple questions to ease the situation from the beginning.
3. Main body: the interviewer focuses on the main topic of his study.
4. Cool-off: again, simple questions that conclude the interview.
5. Closure: the interviewer thanks the interviewee for his valuable contribution.

To ensure the right output of the interview, the phrasing of the interview question is crucial (Lucas, 2016). Robson's (2011) study warns interviewers against asking long questions, using duplicate or multiple questions, asking biased questions, using jargons or steering the interview in a particular direction. These mistakes in questions can make the interviewee's less likely to understand the questions overall, and will make it more difficult for the interviewee to respond accurately. Overall, questions should be as neutral as possible (Robson, 2011). Mcnamara's (2009) and Sande's (2019) study also recommends questions to be worded as neutrally as possible. In doing so, they recommend open-ended and clear wording, asking one question at a time, and being careful with asking 'Why' questions (Mcnamara, 2009; Sande, 2019).

The interviews in this research are conducted based on Robson's (2011) five phases. Starting with an introduction to set the basis for the interview. In the introduction, the researcher will introduce the research, the aim of the interview and, the content of the interview. The interview itself consists of a warm-up phase, a main-body phase and a cool-off phase. The questions in these phases will be formulated using the above recommendations. The formulated questions will be discussed in the section describing the specific interview for each phase. The interview ends with a wrap-up and thanks to the interviewee for his participation and valuable contribution.

Due to covid restrictions, all interviews take place through Microsoft teams. Before each interview, the expert receives an information sheet. This explains how the interview data and personal data will be handled and processed in this research. The experts will be asked to approve the handling of personal data as indicated in the information sheet. Thereby, the experts are also asked for their consent to record the interviews and the use of anonymous quotes.

All interviews will be recorded in Microsoft Teams, with the experts' consent. In addition to recording, Microsoft Teams has the ability to create an automated transcript. However, the automated transcripts contain several mistakes. Using the Atlas.ti software program, the automated transcripts can be combined with the recordings to create an accurate transcript. The transcription of the interviews took 2 to 3 times as long as the duration of each interview. Since all interviews were conducted in Dutch, the transcripts and analysis of the interviews will also be conducted in Dutch.
The transcripts were analyzed using open and axial coding in Atlas.ti. First, the transcripts were coded using open coding, which is the process of examining all interviews and adding codes to sections or words that were relevant to this research. The codes provide an overview of the opinions of the experts interviewed. The next step is to apply the axial coding technique, where the open codes in Atlas.ti are divided into code groups. This results in different themes with corresponding codes. Codes that do not fit the purpose of this research or codes that are too vague to use in this research are deleted.

3.3.1 Expert interviews exploration phase

The purpose of the expert interviews in the exploration phase is to validate the information found in the literature. In the literature study, information is gathered about project goals for single-family homes, possible circular strategies and the impact of strategies. The findings and insights from the literature study form the basis for the development of the framework. However, to ensure the completeness and correctness of the literature study, the literature study needs to be validated. The validation is done with the aid of expert interviews. The aim of the expert interview is to validate whether the project goals, circular material strategies and impacts from the literature study are consistent with experts in the field. Experts from different companies with knowledge of the circular economy and the procurement process are interviewed.

A total of nine experts with knowledge of the circular economy and the procurement process were interviewed. The experts with knowledge about the circular economy and procurement process were selected by approaching experts who work in organizations known to be involved in the circular economy. In addition, the experts themselves participated in several procurements projects that had circular aims.

Among the selected experts two different groups of experts can be identified. The first group of experts are contracting authorities. In this case, they are experts from the province, municipality or housing corporation. The second group of experts are consultants, who work for both the contracting and contractor side. Thus, the consultants have experience with working for the government or housing corporations and, on the other hand, also have experience with working for private organizations. In this way, input was gathered from both sides of the market. Table 7 provides an overview of the experts interviewed.

Experience as contracting authority or as contractor	Type of company	Function within company	Interview Date
Contracting authority	Province	Project manager	11-01-2022
Contracting authority	Municipality	Project manager	13-01-2022
Contracting authority	Housing corporation	Coordinator	17-01-2022
Contracting authority	Municipality	Project manager	20-01-2022
Both	Consultancy	Project manager	06-01-2022
Both	Consultancy	Co-owner	13-01-2022
Both	Consultancy	Project manager	14-01-2022
Both	Consultancy	Senior advisor	14-01-2022
Both	Consultancy	Consultant	18-01-2022

Table 7; Overview interviewed experts exploration phase

The questions for this interview were formulated according to the recommendations in Section 3.3. In doing so, the questions are divided into five phases based on the study by Robson (2011). In each step, the following is discussed:

1. **Introduction**: an introduction was given about the research problem, research goal, the framework and the aim of this interview.
2. **Warm-up**: questions are asked about the experts function within the company and the experts experience with circularity
3. **Main-body**: questions are asked about the project goals, circular material strategies and impacts of the framework.
4. **Cool-off**: questions are asked about the functioning of the framework in general.
5. **Closure**: experts are asked if there is anything left undiscussed during the interview, and they are thanked for their valuable contribution and time.

The interview questions, in both English and Dutch, can be found in Appendix C. During each interview, the researcher used a PowerPoint presentation to support the content and questions of the interview.

All interviews were conducted in Microsoft teams and ranged in duration from 30 to 60 minutes. The interviews were transcribed, coded, and analyzed using Atlas.ti. The results of the expert interview of the exploration phase can be found in Section 4.2.

3.3.2 Expert interviews evaluation phase

One of the simplest ways to validate a designed artifact is to seek experts opinions. In this way, poor designs can be weeded out early on (Wieringa, 2014). Obtaining expert opinions is done through expert interviews. The purpose of the expert interviews in the evaluation phase is to validate the framework. From a pragmatic perspective, the framework can be evaluated in terms of its functionality, completeness, consistency, performance, usability, fairness and fit with the organization (Hevner, et al., 2004). Both government and market parties are interviewed. The goal of this step is to create a framework that is validated and supported by the market and governments.

A total of eight experts have been interviewed. The eight experts interviewed for the framework assessment were also interviewed in the exploration phase. The same experts were interviewed because they were already familiar with this research and the framework. Thereby, all of the experts fit the goals of the interview to interview experts who are familiar with the circular economy in the procurement process and who are involved with contracting authorities and/or contractor organizations. This ensures that both government and market perspective are included.
Table 8 provides an overview of the experts interviewed. Experts experienced as contracting authorities work for provinces, municipalities or housing corporations. Experts experienced with both contracting authorities and contractors work for a consultancy organization.

Experience as contracting authority or as contractor	Type of company	Function within company	Interview Date
Contracting authority	Province	Project manager	09-06-2022
Contracting authority	Municipality	Project manager	07-06-2022
Contracting authority	Housing corporation	Coordinator	14-06-2022
Contracting authority	Municipality	Project manager	08-06-2022
Both	Consultancy	Project manager	08-06-2022
Both	Consultancy	Co-owner	09-06-2022
Both	Consultancy	Project manager	07-06-2022
Both	Consultancy	Senior advisor	10-06-2022

Table 8; Overview interviewed experts evaluation phase

The questions for this interview were formulated according to the recommendations in Section 3.3. The questions are divided into five phases based on Robson's (2011) study. In each step, the following is discussed:

1. **Introduction**: an introduction was given about the research problem, research goal and the aim of this interview.
2. **Warm-up**: questions are asked about the framework in general.
3. **Main-body**: questions are asked about the content of the framework.
4. **Cool-off**: questions are asked about the application of the framework.
5. **Closure**: experts are asked if there is anything left undiscussed during the interview, and they are thanked for their valuable contribution and time.

The interview questions, in both English and Dutch, can be found in Appendix G. No personal warm-up questions are asked, as the same experts were interviewed as for the interviews in the exploration phase. Therefore, the function within the company and the work experience with the circular economy were already known for each expert. During each interview, the researcher used a PowerPoint presentation to support the content and questions of the interview.

All interviews were conducted in Microsoft teams and ranged in duration from 30 to 45 minutes. The interviews were transcribed, coded and analyzed using Atlas.ti. The results of the expert interview of the evaluation phase can be found in Section 7.1.

3.4 Fuzzy Delphi method

In the exploration phase, project goals, circular material strategies and impacts were identified through a literature study and expert interviews. In order to include the most relevant project goals, circular material strategies and impacts the results of the exploration phase need to be assessed to determine what should be included in the framework. This assessment is conducted using the Fuzzy Delphi Method (FDM). This chapter explains the Fuzzy Delphi Methodology and the setup of the FDM for this research.

The FDM is derived from the traditional Delphi technique and fuzzy set theory (Hsu et al., 2010). The Delphi technique is used to acquire the most reliable consensus on a subject using experts opinions. Questionnaires are sent to a panel of selected experts for data collection (Habibi et al., 2015). The Delphi technique is a valid method for forecasting and collective decision-making (Többen, 2021). However, the Delphi technique has some limitation. One limitation is that experts opinions cannot be properly quantified. This leads to some ambiguity due to different interpretations and meanings of the expert opinions, as linguistic terms such as “good” or “very good” are used to reflect the expert opinions (Hsu et al., 2010). For example, the term “good” for expert A is different from the term “good” for expert B. In other words, expert opinions are used for decision-making, but the quantification of expert opinions cannot fully reflect the human thinking style. To solve this problem, the fuzzy set theory is applied. Using fuzzy sets in combination with the Delphi technique is more in line with the human thinking style and it is better to make decisions in real world using fuzzy numbers. Therefore, the Fuzzy Delphi Method (FDM) is more suitable for making decisions based on respondents opinions compared to the Delphi technique (Habibi et al., 2015).
Two types of FDM can be distinguished (Habibi et al., 2015):

- FDM for screening criteria
- FDM for forecasting

The FDM for screening criteria can be used for determining the importance of criteria and screening key criteria. The FDM for forecasting is used in studies that aim to make predictions (Habibi, et al., 2015). In this research, the FDM is used for screening criteria.

The Fuzzy Delphi Method consists of five steps (Hsu et al., 2010; Glumac et al., 2011):

1. Validate predefined list of features
2. Collect opinions of expert group
3. Set up overall triangular fuzzy number
4. Defuzzification
5. Screening evaluation indexes

Each step will be elaborated further in the upcoming sections.

Validate predefined list of features
The first step of the FDM is to validate the predefined list of features. For this research, a literature study is used to obtain a predefined list of project goals, circular material strategies and impacts. This list of features from the literature study is validated using expert interviews.

Collect opinions of expert group
In order to obtain the opinions of the expert group, three steps had to be taken. First, the expert panel must be selected. Second, the fuzzy spectrum must be determined. Finally, the

questionnaire must be created and the data must be collected (Hsu et al., 2010; Habibi et al., 2015; Többen, 2021).

To form the expert panel, experts must be approached who have knowledge about the circular economy and procurement. The experts who are approached are involved in housing project either on the side of the client or the contractor. This includes government organizations, housing corporations, consultancy firms, project developers and construction companies. The number of experts to be considered in data collecting varies in the literature. Hogarth (1978) argues that six to twelve members are ideal for the FDM. Some studies consider fewer than 10 members in their panel (Malone et al., 2005; Strasser et al., 2005), while other studies include more than 100 participants (Kelly and Porock, 2005; Meadows et al., 2005). For this research, the aim is to go above the minimum of 10 experts. A larger expert panel leads to a more accurate outcome of the FDM, which in turn leads to commonly supported factors in the framework. However, it is not possible to include more than 100 participants for the questionnaire due to time constraints and limited network. For this reason, an expert panel of 30 experts is preferred.

Secondly, the fuzzy spectrum needs to be determined. The fuzzy spectrum consists of a linguistic expression and the corresponding fuzzy numbers. The linguistic expressions are used in the questionnaire and the fuzzy numbers are used in the calculations. As a linguistic expression, the different types of Likert scale can be easily used to capture the expert opinions (Habibi et al., 2015). In this research, the five-point Likert scale is used. The five-point Likert scale is used because it is easier for an expert to choose a suitable answer compared to the seven or nine-point Likert scale. Thereby, the five-point Likert scale is suitable to reflect the opinion of the expert panel (Többen, 2021). Table 9 shows the five-point Likert scale used in this research and the corresponding fuzzy numbers, based on the study by Habibi et al. (2015).

Value questionnaire	Very unimportant	Unimportant	Neutral	Important	Very important
Fuzzy numbers (a_{ij}, b_{ij}, c_{ij})	(0, 0, 0.25)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1)	(0.75, 1, 1)

Table 9; Fuzzy spectrum based on Habibi, et al. (2015)

Once the expert panel is selected and the fuzzy spectrum is determined, the questionnaire can be made and sent to the expert panel for data collection. The expert opinions are analyzed using fuzzification and triangular fuzzy numbers, as explained in the next step.

Set up overall triangular fuzzy number

Using the fuzzy spectrum the expert opinions are fuzzified, resulting in a table as represented in Table 10 (Habibi et al., 2015; Többen, 2021).

	E_1	**E_2**	**...**	**E_n**
C_1	F_{11}	F_{12}	...	F_{1n}
C_2	F_{21}	F_{22}	...	F_{2n}
...	...	...	...	...
C_m	F_{m1}	F_{m2}	...	F_{mn}

Table 10; Fuzzification of linguistic expressions for criteria j by expert i

Where:
E_i = The i[th] expert, i = 1, 2, …, n
C_j = The j[th] criteria, j = 1, 2, …, m
F_{ij} = The fuzzification of linguistic expressions for criteria j by expert i

Once each expert opinion is fuzzified, the next step is to derive the overall triangular fuzzy number of each criteria. Using the general mean model of Klir and Yuan (1995), the overall opinion of each criteria is represented by a triangular fuzzy number. The triangular fuzzy number is represented by w_{ij}, in which $w_{ij} = (a_{ij}, b_{ij}, c_{ij})$, i = 1, 2, …, n and j = 1, 2, …, m. Then the fuzzy weighting w_{ij} of j is:

$$\tilde{w}_j = a_j + b_j + c_j \text{ , where } j = 1,2, \ldots . m \text{ and,}$$
$$a_j = \underset{i}{Min}\{a_{ij}\}, \qquad b_j = \frac{1}{n}\sum_{i=1}^{n} b_{ij}, \quad c_j = \underset{i}{Max}\{c_{ij}\}$$

Defuzzification
The next step is to convert all triangular fuzzy numbers into a single real number, which is called defuzzification. In this research, the simple center of gravity method is used for defuzzification. The fuzzy weight w_j of each criteria is converted into a single real number S_j, where j = 1, 2, …, m:

$$S_j = \frac{a_j + b_j + c_j}{3}$$

Screening evaluation indexes
The last step is to screen the criteria to be included in the framework by setting a threshold value α. All criteria equal to or higher than the threshold are included in the framework. All the criteria that are lower than the threshold are not included in the framework. The principle of screening is as follows:
- If $S_j \geq \alpha$ Criteria j is more important and is included in the framework
- If $S_j < \alpha$ Criteria j is less important and is not included in the framework

In the literature, the threshold is typically set at 0.7. However, the threshold value varies in different studies depending on the opinion of the researcher (Habibi et al., 2015). In addition to the typical threshold value, it is possible to use the mean of the single real numbers as the threshold. Thereby, it is also possible to search for a significant margin between the single real numbers and use the upper bound of the margin as the threshold (Többen, 2021).

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4. Exploration phase

The exploration phase is used to gather information through a literature review and field research (Keskin & Romme, 2020). In this research the information is gathered through a literature study and expert interviews. The goal of the exploration phase is to determine the list of project goals, circular strategies and impacts to consider for the framework.

4.1 Recap literature study

A literature study has been conducted in chapter 2. The literature study is used to create boundaries for this research and to determine the factors to consider for the framework. The subjects discussed in the literature study are the concept of circular economy and the way to realize circularity with the aid of public procurement. In addition, the literature study is used to define project goals, circular strategies and impacts. The CE-criteria are not considered in the literature study, since the CE-criteria are dependent on the circular material strategies that will be part of the framework. The circular material strategies that will be part of the framework are not yet determined. Therefore, the CE-criteria are not considered yet.
The result of the literature study is the creation of boundaries for the concept of circularity and circularity in procurement within this research. Thereby, the result of the literature study is a list of 3 project goals, 29 circular strategies and 5 impacts that are considered relevant for the framework. The project goals taken into account are circular motives, implementation term and lifecycle phase. Each project goal consists of several sub-project goals. For the circular strategies a list of 29 circular material strategies will be considered, in which the circular material strategies are categorized into regenerating, narrowing, slowing and closing. The impacts that will be considered are costs, time, quality, construction waste and material consumption. An overview of all the factors that will be considered from the literature study is shown in Figure 10. For a broader explanation of the factors see chapter 2 Literature study.

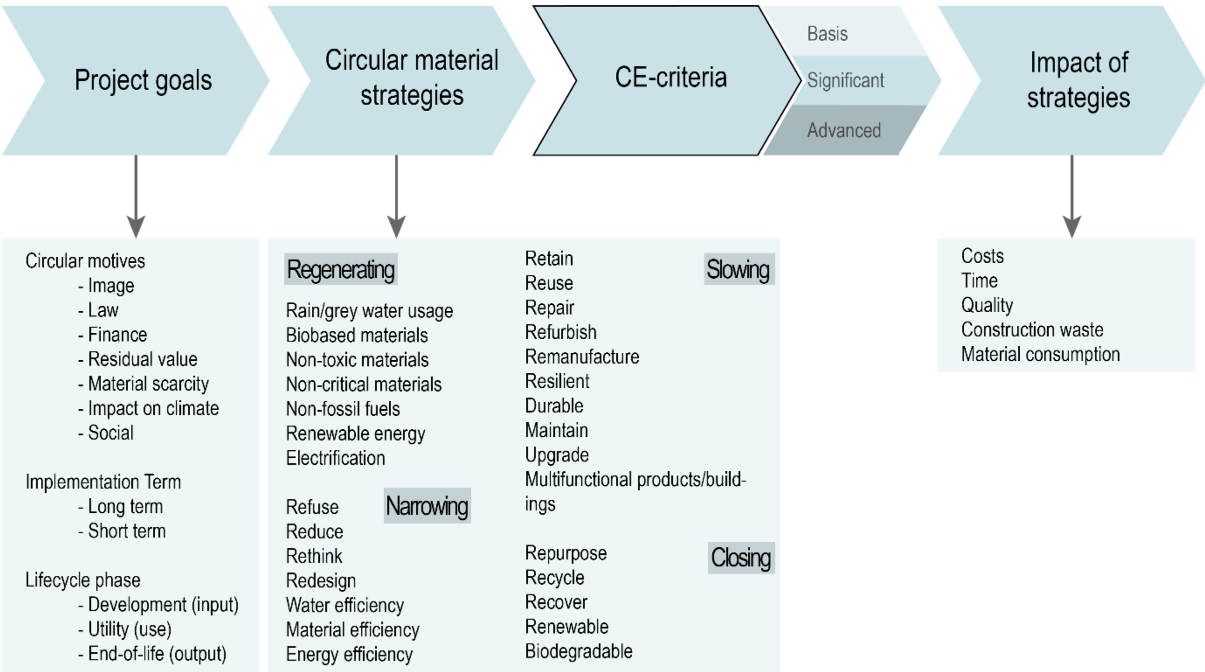

Figure 10; Project goals, circular material strategies and impacts considered from the literature study

4.2 Results expert interviews

The expert interviews in the exploration phase are used to validate the completeness and correctness of the factors found in the literature study. Therefore, the aim of the expert interviews is to validate whether the project goals, circular material strategies and impacts from the literature study are in line with the opinions of experts from the field. In chapter 3.3 the method for conducting and analyzing the expert interviews is elaborated, in this chapter the results of the expert interviews will be discussed.

In total nine experts from different companies with knowledge about the circular economy and the procurement process have been interviewed. Within the interviews, the experts were asked whether they agreed or not with the results of the literature study. All experts indicated that they agreed with the results of the literature study. Therefore, all the results of the literature study will be taken into account for the framework. In addition to the verification of the literature study the experts gave additional input for project goals, circular strategies and impacts. To get a clear overview of the additional input from the expert interviews, the interviews needed to be analyzed. The process of analyzing the nine transcriptions for the additional input of project goals, circular strategies and impacts has been visualized in Figure 11.

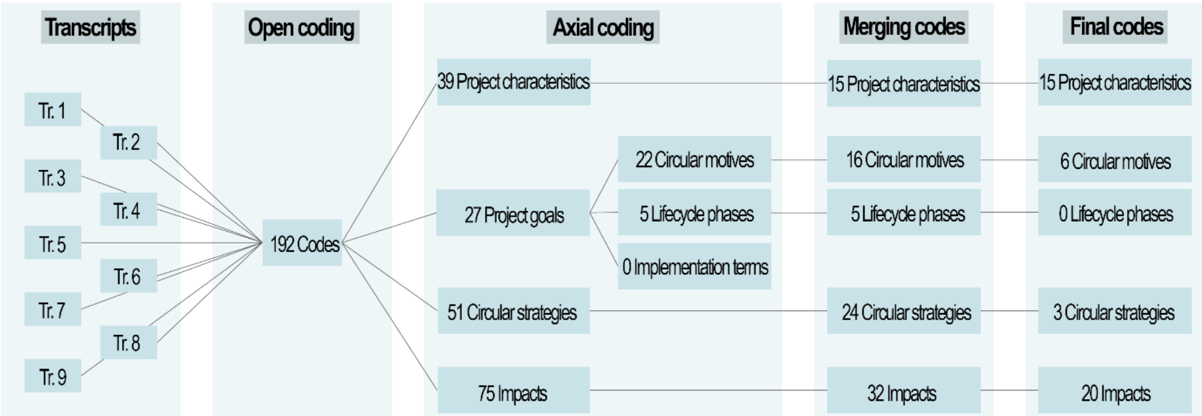

Figure 11; Process of analyzing the nine transcripts for additional input of experts.

Each step in Figure 11 will be shortly explained, a detailed explanation per group is given below. The first step is to transcribe all interviews within Atlas.ti. Once all the interviews had been transcribed, codes are created for all transcriptions using open coding. In total 192 codes have been derived from the nine interviews. The next step is to apply the axial coding technique, in which the open codes are divided into code groups. The first three code groups that were created are in line with the steps of the framework, which means that the code groups are divided into project goals, circular strategies and impacts. In addition, a fourth group called project characteristics is created. In total 39 project characteristics, 27 project goals, 51 circular strategies and 75 impacts are identified with axial coding, which can be found in Appendix D. The 27 project goals are divided into three sub-groups. After the axial coding, the next step is to merge duplications and comparable project characteristics, project goals, circular material strategies and impacts per group. In addition, codes that did not fit the purpose of this research or codes that are too vague to use in this research are deleted. The final step is to compare the project goals, circular material strategies and impacts from the expert interviews with the literature study to merge the last duplications and

comparisons. For the project characteristics, this step is not applicable, since no project characteristics have been identified in the literature study.
The result of the analysis is a list of 15 project characteristics, 6 circular motives, 3 circular strategies and 20 impacts, which are added to the results of the literature study. The analysis of the expert input for the project goals, project characteristics, circular strategies and impacts is further elaborated below.

Project goals
Within the interviews each expert agreed with the project goals that are identified in the literature study, however additional input for project goals was given. The input given by experts consists of additional input for the three project goals of the literature study. For this reason the project goals are in the axial coding step categorized into the three project goals from the literature study, those are;

1. circular motives
2. implementation term
3. lifecycle phase

In total input was given for 27 project goals, which is divided into 22 circular motives and 5 lifecycle phases. No additional input for the implementation terms was mentioned by the experts, therefore the implementation term is not considered in the analysis of the interviews. After merging the circular motives and lifecycle phase, the final result is a list of 6 circular motives. The lifecycle phase resulted in no additional input from the experts since the input given by experts consist of suggestions to rename the three phases that were already identified in the literature study. For this reason the life cycle phases changed from development, utility and end-of-life to development and realization, exploitation and end-of-life. The six circular motives that have been identified, besides the results of the literature study, are shown in Table 11. One side node has to be made, the circular motive law, which was already considered in the literature study, is extended to law, regulations and legal obligations, since the term law did not cover the full load.

Circular motive	**Explanation**
Law, regulation and legal obligations	A company with law, regulations and legal obligations as a motive chooses circular strategies that are necessary to comply with legislation, regulations and legal obligations.
Emotional value	A company with emotional value as motive chooses to react on what is happening in the area and society.
Intellectual value	A company with intellectual value as motive chooses to stimulate development and innovation.
Amenity value	A company with amenity value as motive chooses to focus on the value created by experiences with products and buildings for the users.
Intrinsic motivation	A company with intrinsic motivation as motive chooses unconstrained to do good.
Social purpose	A company with social purpose as motive wants to contribute to solving social problems.
Grants	A company with grants as motive takes efforts that are necessary for obtaining the grants.

Table 11; Expert input for circular motives.

Project characteristics
The project characteristics emerged from the experts input for the project goals. During the interviews experts input was given for the project goals that went beyond the scope of project goals within this research. By analyzing the input that went beyond the scope of the project goals it could be concluded that this input could be seen as project characteristics. Project characteristics are features by which a project can be identified. The 15 project characteristics that are identified in the expert interviews are shown in Table 12.

Project Characteristic	Explanation
Chain collaboration	The smart collaboration between companies within the chain.
Priority	The importance and attention that is given to circularity within a project.
Ambition	Striving for a specific goal.
Willingness and acceptance	The benevolence of the client, contractor and consumer to implement and use circular measures.
Availability of second-hand materials	To what extent second-hand materials are available for the project.
Budget	The total financial resources available to finance the project, from initiative to realization.
Innovation	To what extent it is possible to renew and/or improve goods, services, processes or a combination thereof.
Knowledge level	The amount of information, knowledge and experience available in a project.
Quality	The value that the building is expected to deliver.
Lifespan	The expected period during which the realized building functions as required.
Organization	The total number of persons, companies, parties and other entities that can undertake activities for the project, from inside or outside.
Risks	The probability that a potential threat will result in an actual incident and the severity of the injury or damage that results.
Time	The total time available to realize the building, from initiative to realization.
Vision	Your organization's view of the (future) world and the role of your organization in that world.
Laws and regulations	The laws and regulations that an organization must comply with during a project, from initiative to realization.

Table 12; Expert input for project characteristics

However, the project characteristics that resulted from the interviews led to some unclarities with relation to the project goals and with relation to the framework. It is not clear how the project characteristics relates to the project goals and the framework. Since the project characteristics are not part of the project goals but rather an extension to the project goals. This lack of clarity could lead to any confusion during the final functioning of the framework. For this reasons the relation of the project characteristics to the project goals and to the framework must be elaborated to create one clear and uncluttered list of factors.
Based on the results of the interviews it can be concluded that experts found project characteristics an important aspect to determine a suitable circular material strategy for a project, due to the high amount of project characteristics that emerged from the interviews. In addition, during the interviews there was uncertainty about project goals being the first step of the framework, while project goals are the final result of a project. The interviewed experts did consider the step before the circular material strategies relevant to make a thoughtful decision for a circular material strategy, however the term project goals did lead to confusion and uncertainty. One expert suggested to rename project goals to project characteristics. Considering the definition of project goals and project characteristics given in

this research, the identified project goals could also be seen as project characteristics. The identified project goals can be seen as a feature that identifies a project, and therefore can be part of the project characteristics. For those reasons there is chosen to change the project goals to project characteristics. In which the former project goals circular motives, lifecycle phase and implementation term will become part of the project characteristics. However, the project goals consists of sub-factors while the project characteristics do not consists of sub-factors. Including the sub-factors leads to a long and complex list of project characteristics. Thereby, the inclusion of all sub-factors could lead to any confusion during the final functioning of the framework. Therefore, the sub-factors will not be included in the list of factors to create a clear and understandable list of project characteristics and to reduce the amount of project characteristics. The result of these adjustments is a final list of 18 project characteristics, as shown in Figure 12.

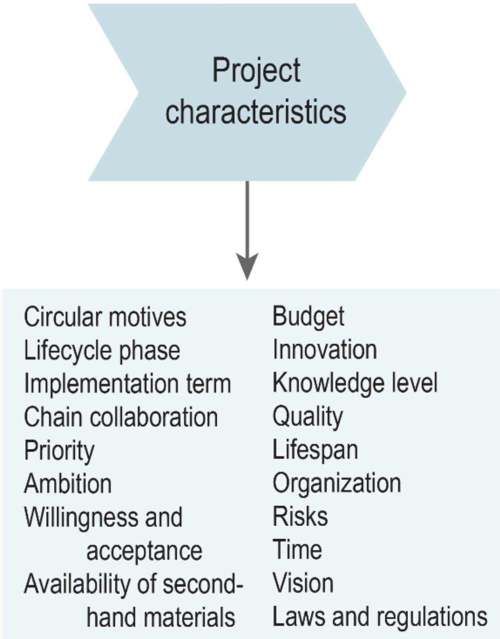

Figure 12; Final list of project characteristics

Circular strategies

All interviewed experts agreed with the circular strategies identified in the literature study, however additional input for the circular strategies was given. After analyzing and merging the expert input, the result is a list of three circular strategies that are added to the results of the literature study. The three circular strategies are shown in Table 13. One of the three strategies can be categorized under the regeneration loop, the other two strategies are categorized under the slowing loop. No additional circular strategies are identified for the narrowing or closing loop.

Loops	Strategy	Explanation
Regeneration	Pure materials	A pure material consisting of one type of atom or molecule
Slowing	Flexible	A product or building can be easily adapted over time to a different use or be expanded
	Demountable	Designing products or buildings of multiple parts that can be easily separated and reassembled

Table 13; Additional circular material strategies identified by experts.

Impacts

Besides the results of the literature study, to which all experts agreed, in total 20 additional impacts have been identified by the experts. The additional impacts that will be considered are shown in Table 14.

Impacts	Explanation
Acceptance	The willingness of people to use circular products or buildings.
Biodiversity	The degree of variety of life forms within a given ecosystem.
Land use	The amount of land used to realize a building.
Construction logistics	The logistics process of a project, including supply and disposal of materials, equipment's and people.
CO2 emission	The total amount of CO2 produced during the realization of a building.
Flexibility of a building	A building can be easily adapted over time to a different use or be expanded.
Image	The image a company evokes with regard to circularity.
Information and communication	The amount of information that is available about a building during the project, from initiation till realization (NIB, 2019).
Climate adaptation	The process of adapting to the changing climate by becoming less vulnerable to climate change or taking advantage of climate change.
Lifespan	The period of time in which a product or building is used, from purchase till disposal.
Material scarcity	The shortage of materials, mainly metals and mineral resources.
Environmental impact	The influence of a building on the natural environment and ecosystems of the planet, think of pollution, deforestation, and so on.
Development capacity and innovation power	The ability, willingness and vigor to develop and market innovations.
Organization	The total amount of individuals, companies, parties and other entities that are able to undertake activities for the building from the inside or outside (NIB, 2019).
Residual value	The value of a product or building at the end-of-life.
Risks	The chance that a potential threat will result in an actual incident and the severity of the injury or damage that results.
Social	The impact of the building on the health and well-being of humans.
Future proof construction	The building is able to withstand all changes the future will bring.
Water consumption	The amount of water used to realize a building.
Certainty	The amount of certainty that the predetermined result of a building will be achieved with minimum risks.

Table 14; Additional impacts identified by experts.

4.3 Conclusion exploration phase

The result of the exploration phase is a list of 18 project characteristics, 32 circular material strategies and 25 impacts based on a literature study and interviews to consider for the framework. The results of the exploration phase are shown in Figure 13.

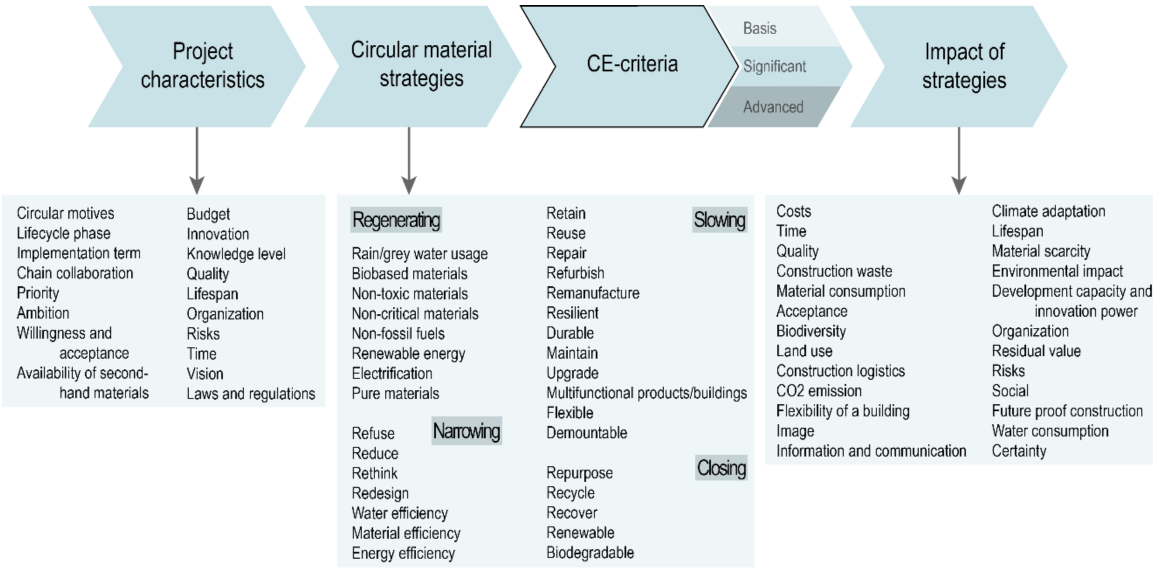

Figure 13; Results of the exploration phase.

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5. Synthesize phase

The synthesis phase is about creating insights in the information from the exploration phase, by applying inductive and abductive sensemaking to identify and forge connections (Keskin & Romme, 2020). In this research, the synthesis phase is used to determine the factors to consider for the project goals, circular material strategies and the impact of circular strategies. Once the factors have been determined it becomes possible to determine the CE-criteria and to determine the impact of the circular strategies. The goal of this step is to translate the results of the exploration phase into meaningful project goals, circular material strategies, CE-criteria and impacts for the framework.

5.1 Results Fuzzy Delphi Method

In the exploration phase the project goals, circular material strategies and impacts to include in this research have been identified with a literature study and expert interviews. To include the most relevant project goals, circular material strategies and impacts for the framework the results of the exploration phase have to be judged. This judgment will be conducted with the Fuzzy Delphi Method (FDM). In Section 3.4 the method and setup of the FDM is elaborated, in this chapter the results of the FDM will be explained according to the five steps of the FDM.

Validate predefined list of features

The first step of the FDM is to validate the predefined list of features. For this research the validated list of the exploration phase will be used as predefined list of features, as shown in Figure 13 in chapter 4.3.

Collect opinions of expert group

To collect opinions of the expert group, three steps have to be taken. First of all the expert panel has to be selected, secondly the fuzzy spectrum has to be determined and finally the questionnaire has to be made and data needs to be collected (Hsu et al., 2010; Habibi et al., 2015; Többen, 2021).

The expert panel consist of experts who have knowledge of the circular economy and procurement. The experts that are approached are involved in housing projects from either the client or contractor side, this includes government organizations, housing corporations, consultancy firms, project developers and construction companies. In total 120 experts within the network of Alba Concepts have been approached. The aim is to have at least 30 experts to respond.

The second step is to determine the fuzzy spectrum, which consist of a linguistic expression and the corresponding fuzzy numbers. The fuzzy spectrum for this research will consist of a five-point Likert scale and the corresponding fuzzy numbers consisting of the numbers 0, 0.25, 0.5, 0.75 and 1.

The last step for collecting the expert opinions is to create the questionnaire and send it to the expert panel for data collection. The questionnaire has been made in Google forms and consists of six sections. Those sections are:

1. **Introduction**: the research is shortly introduced, the aim of the questionnaire is introduced and the rating of the factors is explained to the experts.
2. **General information**: the kind of company and the function within the company is asked of the experts.
3. **Project characteristics**: the experts are asked to rate the 18 project characteristics.
4. **Circular material strategies**: the experts are asked to rate the 32 circular material strategies.
5. **Impacts of circular strategies**: the experts are asked to rate the 25 impacts.
6. **Closure**: the experts are thanked for their valuable contribution.

For each step of the framework (the project characteristics, the circular material strategies and impact) is explained what is meant by it, so that all experts understand the three different steps. Thereby, for each factor a definition is included to ensure that the experts understand the factors. The questionnaire can be found in appendix E. The questionnaire is in Dutch, since al approached experts are Dutch.

The link of the questionnaire has been send to the 120 experts by mail on the 18th of February. The questionnaire was available for one week. In total 39 experts completed the questionnaire. Figure 14 shows the number of responses for each type of company that was approached.

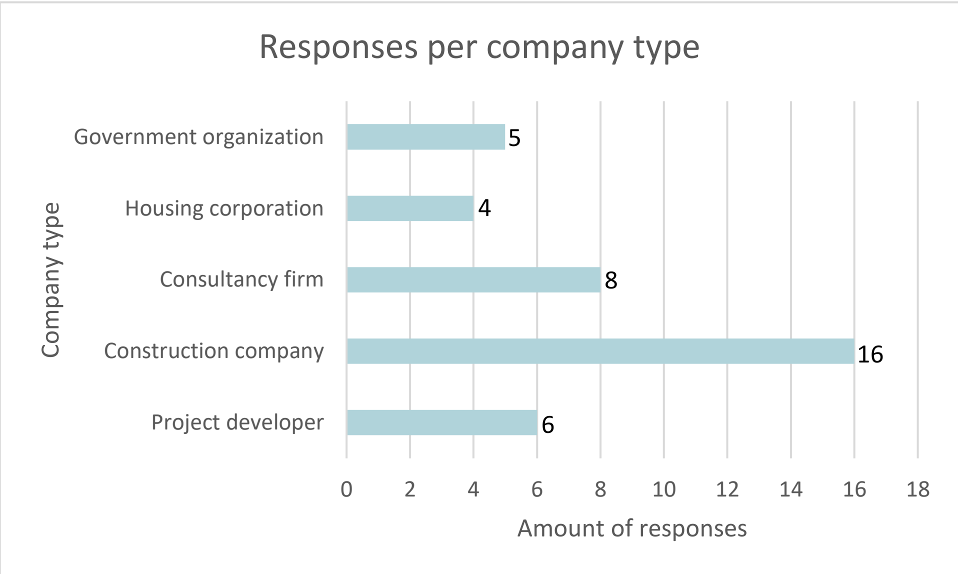


Figure 14; Expert responses per company type

The results of the 39 responses were downloaded and opened in excel to be analyzed for the fuzzification in the next step.

Set up overall triangular fuzzy number

By using the fuzzy spectrum the expert opinions for each factor are fuzzified. This means that the linguistic expressions of all answers are transformed to the corresponding fuzzy number, as shown in Table 10 in Section 3.4. The next step is to derive the overall triangular fuzzy number for each factor.

Defuzzification

The next step is converting all triangular fuzzy numbers into a single real number, which is called defuzzification. The fuzzy weight w_j of each criteria is converted to a single real number S_j for each factor. The single real numbers S_j for each factor are listed in Appendix F.

Screening evaluation indexes

The last step is screening the criteria that should be included in the framework by setting a threshold α. All the criteria equal to or higher than the threshold will be included in the framework. All the criteria lower than the threshold will not be included in the framework. The principle of screening is as follows:

- If $S_j \geq \alpha$ Criteria j is more important and will be included in the framework
- If $S_j < \alpha$ Criteria j is less important and will not be included in the framework

For selecting a suitable threshold is important to be aware of the aim of this Fuzzy Delphi Method. The aim of the FDM is to come up with a list of project characteristics, circular material strategies and impacts that are considered relevant for a circular transition with the aid of procurement by a group of experts. The project characteristics, circular material strategies and impacts that come out of the FDM will be used for creating the framework.
In this research a framework is defined as an overview that captures a (new) idea in an overall picture such that it is easy to remember and apply the (new) concept. Preferably, the overall picture can be easily printed or used online. Therefore, there is chosen to create the framework in a maximum of one A3 format. In addition, for the framework to work it must be clear and understandable. This was mentioned by seven out of the nine experts during the interviews. In order to realize a clear and understandable framework it was mentioned that the framework must not be to extensive. Therefore, not to many project characteristics, circular material strategies and impacts should be included to keep the framework clear and understandable. Another constrain, is the time within this research. For each chosen circular material strategy the CE-criteria and the impacts should be determined elaborated. Therefore, due to time constrains within this research it is also preferred not to have to many project characteristics, circular materials strategies and impacts. For these reasons, an estimation is made to include approximately 5 project characteristics, circular material strategies and impacts.

Preferably, the overall picture can be easily printed or used online. Therefore, there is chosen to make the framework a maximum of one A3 format. The framework will be an infographic that compactly illustrates the most important information. An infographic can easily be printed and used physically or can be displayed in an online session.

The single real numbers of the project characteristics, circular material strategies and impact have been plotted in a graph, see Figures 15, 16 and 17. Looking to the overall single real numbers and the graphs it can be seen that the overall score per factors is quite high. The lowest single real number is 0.54, which is above the single real number of the neutral score (which is 0.5). Looking to the answers given by the experts it can be seen that 48% of all answers were ranked as important, 26% was ranked as very important and 21% was ranked as neutral. Only 4% of the answers were ranked unimportant and 1% as very unimportant.

Besides the overall high score of the factors it can also been seen that the differences between the factors is small. All factors lay between a score of 0.54 and 0.82. The high score of all factors and the small difference between the factors can be explained by the fact that all factors have been identified in literature and verified with expert interviews. All factors will contribute to or are important to consider for a transition to a circular economy with procurement. However, not all factors can be included, therefore the aim is to include the most important factors.

Figure 15; Overview of single real number per project characteristic

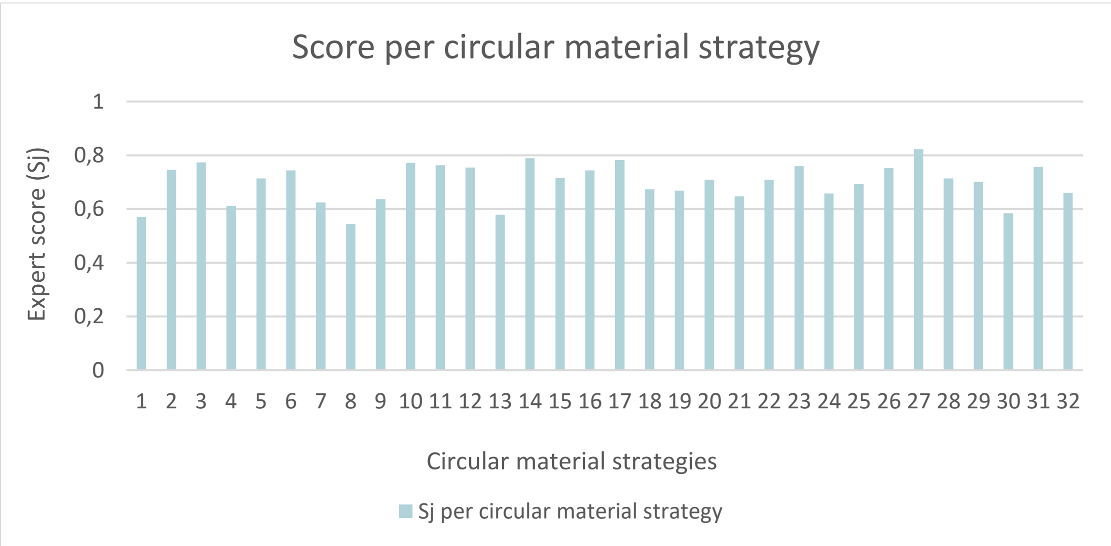


Figure 16; Overview of single real number per circular material strategy

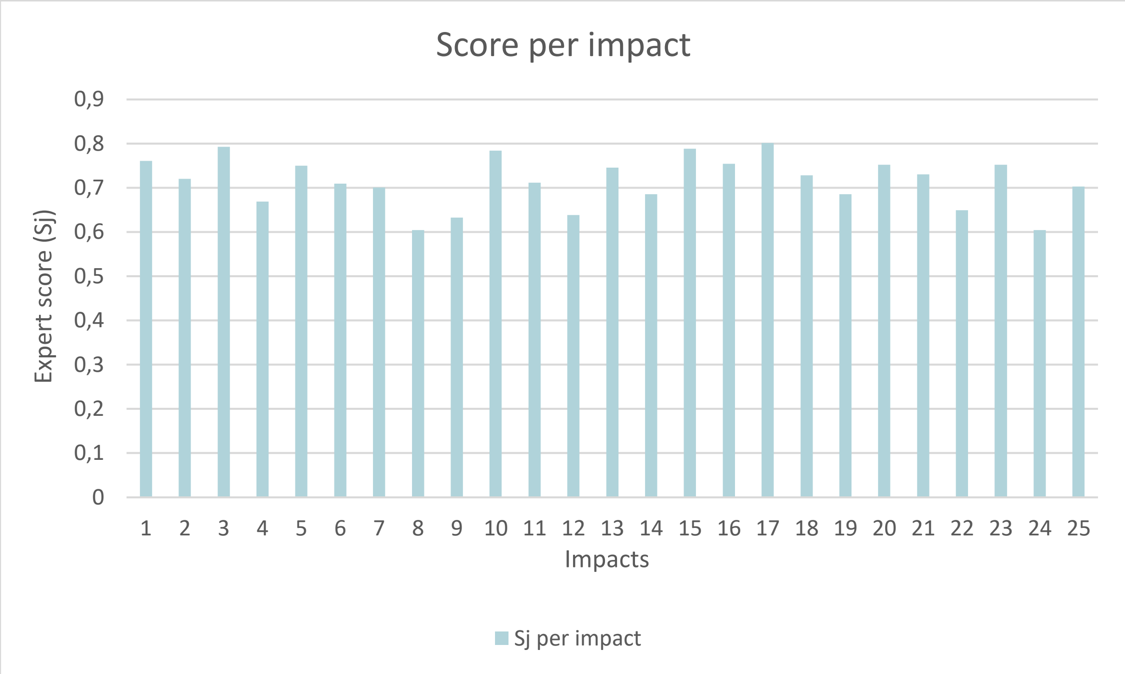


Figure 17; Overview of single real number per impact of circular strategies

For determining the most important factors to include in the framework a threshold has to be selected. In order to select a suitable threshold, the single real numbers are changed to a normalized value. As can be seen in figure 16, 17 and 18 the values of the single real numbers have little difference. To make the comparison of the single real numbers and the selecting of a threshold more convenient, the single real numbers are changed to a normalized value. A normalized value is used to bring all values to a common scale between 0 and 1, without disturbing the differences in the value ranges (Lakshmanan, 2019). Normalized values are also known as min-max scaling. The minimum value is represented by 0 and the maximum value is represented by 1, all other values lie between 0 and 1 (Aniruddha, 2020). The equation to calculate the normalized values is to deduct the minimum value from the variable to be normalized. This result is divided by the maximum value minus the minimum value (Lakshmanan, 2019). Mathematically the equation for the normalized value is represented as:

$$Xnormalized = \frac{(X - Xminimum)}{(Xmaximum - Xminimum)}$$

Using the equation, the single real numbers for each factor are changed to a normalized value, which can be found in Appendix F. Based on the normalized value a threshold can be selected. There is chosen to apply the method in which is searched for a significant margin between the normalized values and use the upper bound of the margin as a threshold. To search for a significant margin the normalized values of the project characteristics, circular material strategies and impact have been plotted in a graph, see Figures 18, 19 and 20. There is chosen to include approximately 5 project characteristics, circular material strategies and impacts. In the graphs a tipping point can be seen around a value of approximately 0.8. Therefore, there is chosen to use a threshold of 0.8. For each graph the threshold of 0.8 will be further elaborated.

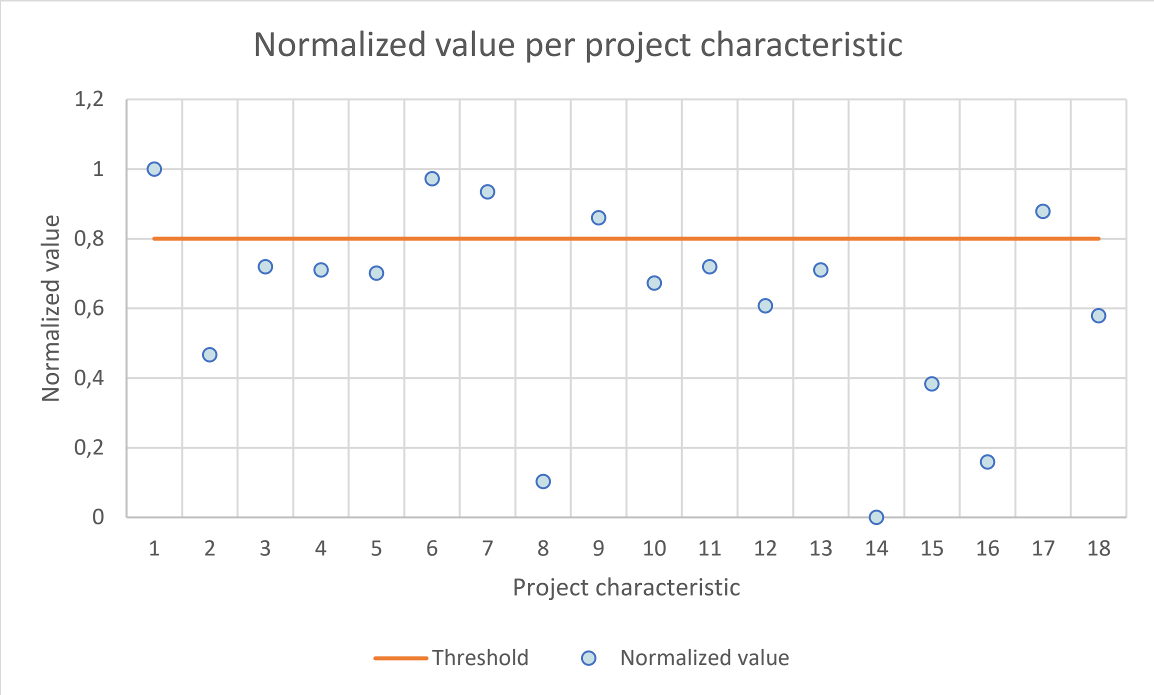


Figure 18; Overview of normalized value per project characteristic

Using a threshold of 0.8 for the project characteristics means that number 1, 6, 7, 9 and 17 are accepted and will therefore be included in the framework. Those project characteristics are the circular motives, ambition, willingness and acceptance, budget and vision.

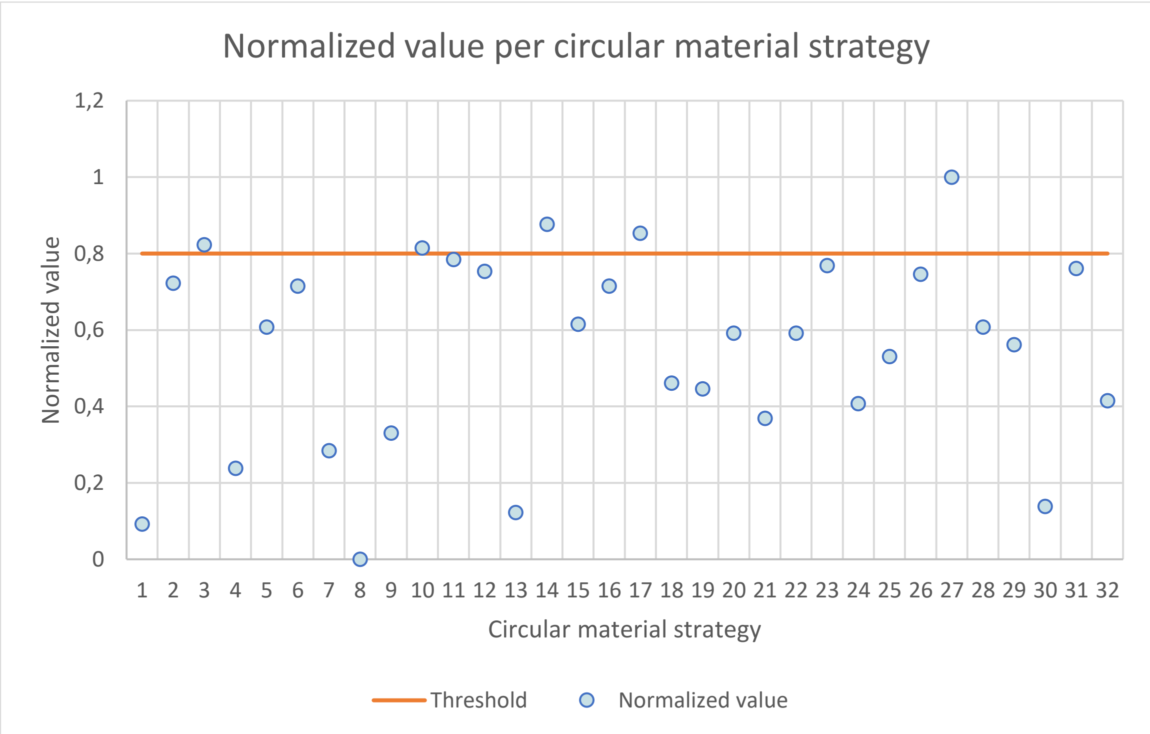


Figure 19; Overview of normalized value per circular material strategy

For the circular materials strategies a threshold of 0.8 means that number 3, 10, 14, 17 and 27 are accepted and will therefore be included in the framework. Those circular material strategies are non-toxic materials, reduce, material efficiency, reuse and demountable. Circular material strategy 11 lays, with a value of 0.78, close to the threshold of 0.8, as can be seen in Figure 19. However, there is decided not to include circular material strategy 11, which is rethink, to keep the framework compact. In addition, no method or tool to calculate the circular material strategy rethink exist yet and little information about the application of rethink can be found in literature. Therefore, it will be difficult to determine CE-criteria for rethink.

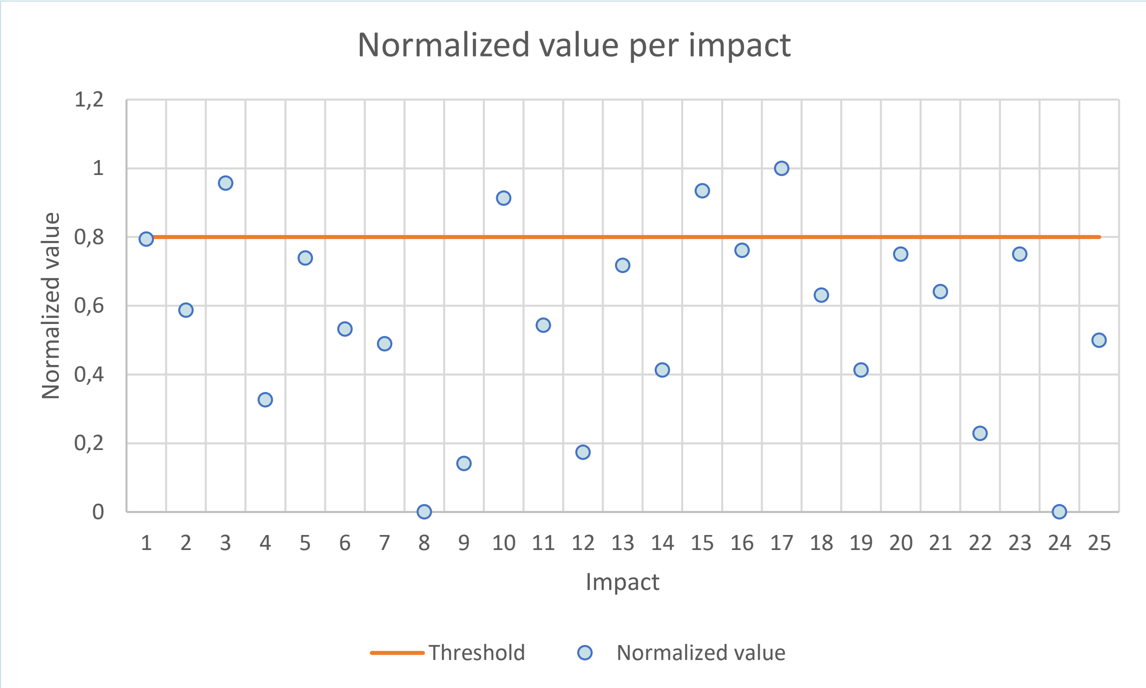


Figure 20; Overview of normalized value per impact

Finally, using a threshold of 0.8 for the impact results in number 3, 10, 15 and 17 being accepted and will therefore be included in the framework. Those impacts are quality, CO2 emission, lifespan and environmental impact. In Figure 20, it can be seen that impact 1, costs, lays really close to the threshold with a value of 0.79. There is decided to include the costs, since costs were often mentioned as impact in literature during the literature study. Thereby, within 6 out of the 9 experts interviews costs was mentioned as impact. For these reasons, costs are included as impact in the framework.

5.1.1 Conclusion of the Fuzzy Delphi Method

The result of the Fuzzy Delphi Method is a list of 5 project characteristics, 5 circular materials strategies and 5 impacts of strategies to consider for the framework. The project characteristics, circular material strategies and impacts that need to be considered for the framework are shown in Figure 21 in orange.

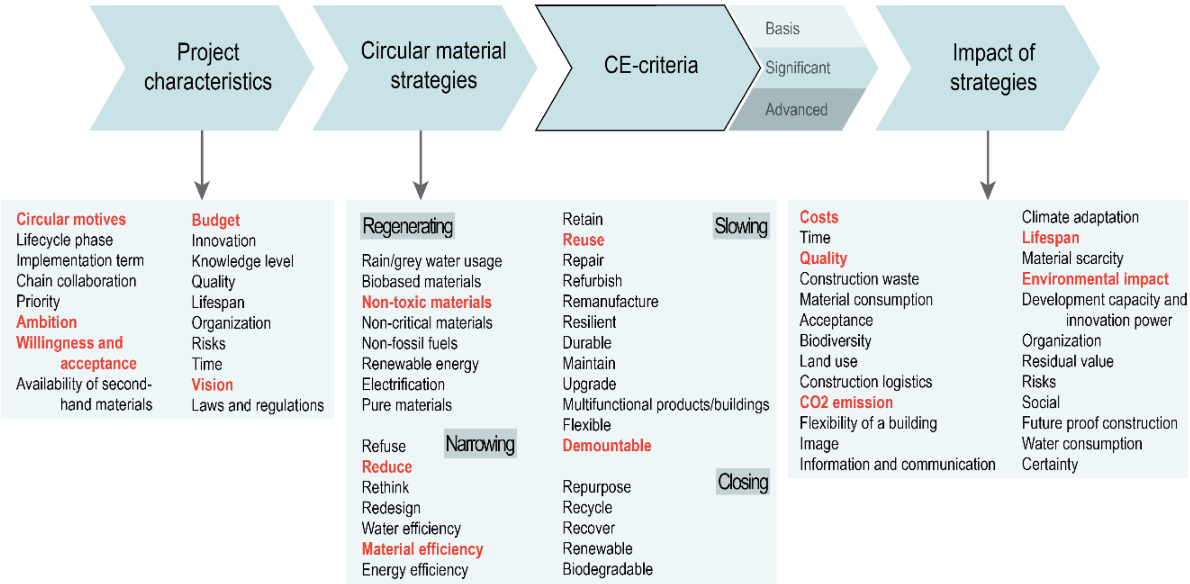


Figure 21; Project characteristics, circular materials strategies and impacts to be included in the framework

5.2 Determining CE-criteria

With the results of the Fuzzy Delphi Method, the factors to be considered for the framework are known. Now it is possible to determine the CE-criteria that belong to the considered circular material strategies. Based on the availability of data, the current knowledge on measuring circularity and characteristics of the circular material strategies, a distinction is made between quantitative criteria and qualitative criteria. In which the circular material strategies reuse and demountable are quantitative criteria and the circular material strategies non-toxic materials, material efficiency and reduce are qualitative criteria. This chapter explains the determination of the quantitative and qualitative criteria.

To determine the quantitative and qualitative criteria for each circular material strategy, three ambition levels are distinguished. The different ambition levels are applied because each project differs in their feasibilities. Thereby, strategies know different motives, one of them is the level of ambition of a circular strategy (Spatial Foresight, 2019). Therefore, the CE-criteria of the circular material strategies are divided into the three ambition levels basis, significant and advanced, according to the ambition levels of PIANOo (PIANOo, n.d.-c). Based on PIANOo and 'Het Nieuwe Normaal', the three ambition levels are defined as (PIANOo, n.d.-c; Vroom, 2020b):

- **Basis**: the minimum limit for circular construction
- **Significant**: to encourage circular construction
- **Advanced**: to stimulate new solutions and innovations for circular construction

5.2.1 Quantitative criteria

Quantitative criteria are criteria that can be measured. The circular material strategies reuse can be measured among others by using the Building Circularity Index (BCI) of Alba Concepts, the GPR materiaal of W/E adviseurs, the Building Circularity tool of One Click LCA, the Madaster Circularity Indicator and measuring circularity of CB'23. The circular material strategies demountable can be measured among others by using the Building Circularity Index (BCI) of Alba Concepts and the Building Circularity tool of One Click LCA. Within this research the Building Circularity Index (BCI) of Alba Concepts will be used to measure demountability and reuse, because this calculation method contains the option to calculate both demountability and reuse. In addition, data is available within this research to determine the CE-criteria for demountability and reuse with the aid of the BCI.

The BCI is a measurement method that can be used to determine the degree of circularity and the circular potential of real estate objects in an objective and consistent manner. To determine the BCI, the origin of materials, the future scenario of materials and the demountability of materials and elements are taken into account. In which the reusability of materials is divided in the origin of materials and the future scenario of materials. The BCI data is used to determine the quantitative criteria for reuse and demountability.

Alba Concepts has a dataset consisting of the BCI calculation for newly built single-family homes from April 2021 to present. In this data the reusability and demountability level of the newly built single-family homes are reported separately. These separate values for reuse and demountability are used to determine the quantitative CE-criteria. The determination of the quantitative criteria for the application of the criteria for demountable and reuse is explained below.

Demountable

Within the BCI, demountability is indicated by the demountability index. The demountability index is determined by the type of connection, accessibility of the connection, the form inclusion and the crossing.

A dataset of the BCI is used to determine the demountable ambition levels. Before the dataset was used, it was scanned and cleaned to include only newly built single-family homes that meet the purpose of this research. This means that buildings such as apartments or lofts that did not fit within the scope of this research were deleted. In addition, newly built single-family homes with multiple calculations were combined into a single calculation. Finally, outliers were deleted from the dataset. In the end, a list of 91 newly built single-family homes was used as the dataset for determining the demountable ambition levels.

A boxplot is used to determine the three ambition levels for demountability. A boxplot is a standardized method for plotting the distribution of data based on a five number summary. This five number summary consists of the (Galarnyk, 2018):

- **Minimum**: the least value, without outliers
- **Lower quartile**: the middle number between the smallest number and the median of the dataset
- **Median**: the middle value of the dataset
- **Upper quartile**: the middle number between the median and the highest value of the dataset
- **Maximum**: the greatest value, without outliers

The median is also referred to as the 50th percentile because it represents the middle of the dataset. The lower quartile is also referred to as the 25th percentile because 25 percent of the dataset lays below the lower quartile. The upper quartile is also referred to as the 75th percentile, because 75 percent of the dataset lays below the upper quartile. Figure 22 provides a visual explanation of the boxplot.

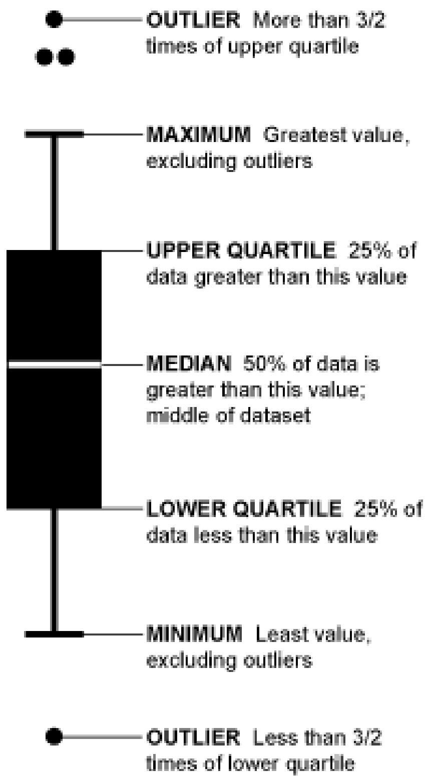
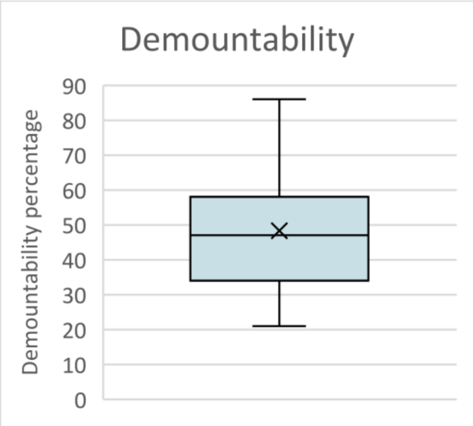


Figure 22; Visual explanation of the boxplot (Flowingdata, 2008)

Based on the boxplot, the lower quartile is used as basis ambition level, the median is used as significant ambition level, and the upper quartile is used as advanced ambition level. The lower quartile is used as basis ambition level, because it sets the boundary for circular construction at the lowest 25 percent of the dataset, thereby still challenging to stimulate the circular economy. The median is used as a significant ambition level, because it can be seen as a percentage that encourages circular construction. The median represents a percentage that is not quite easy to achieve, but is still feasible with a little effort. The upper quartile is used as an advanced ambition level, because it represents the highest 75 percent of the dataset. In this way, the upper quartile stimulates new solutions and innovations for circular construction.

A boxplot is created with the dataset to determine the three ambition levels of demountability. The boxplot is shown in Figure 23 and the corresponding percentages can be found in Table 15.



Boxplot levels	Demountable
Minimum	21 %
Lower quartile	34 %
Median	47 %
Upper quartile	58 %
Maximum	86 %

Table 15; Boxplot values for demountable data

Figure 23; Boxplot demountability data

Based on the boxplot, the lower quartile is used as basis ambition level, the median as the significant ambition level, and the upper quartile as the advanced ambition level. The CE-criteria for the demountable ambition levels are shown in Table 16. All CE-criteria are rounded to integers.

Circular material strategy	Ambition level	CE-criteria
	Basis	34 %
Demountable	Significant	47 %
	Advanced	58 %

Table 16; CE-criteria for demountable

Reuse

Within the BCI, reuse is divided into reuse in terms of the origin of the materials and the future scenario of the materials. Reuse in terms of the origin of materials is the percentage of materials that are reused by another building, i.e. secondary materials. Reuse in terms of the future scenario of the materials is the percentage of materials that can be reused in another building after the end of the life of the current building. The distinction between the origin of the materials and future scenario of the materials is applied to determine the reuse criteria.

A dataset of the BCI is used to determine the origin and future reuse ambition levels. In the dataset, the origin and future reuse are based on the Milieukostenidicator (MKI). However, within BCI, it was decided to determine the origin and future reuse based on a percentage of a building's total mass. This decision is made recently causing this change to not be consider yet in the BCI. Therefore, the BCI data for origin and future reuse must be manually adjusted. This was a time consuming calculation and only a limited number of calculations could be performed due to time constrains. To calculate the percentages of origin and future reuse, the dataset was scanned and cleaned to include only newly built single-family homes that fit the purpose of this research. This means that buildings such as apartments or lofts that did not fit the scope of this research were deleted. In the end, a list of 41 newly built single-family homes was calculated and used as the dataset for determining the origin and future reuse ambition levels.

A boxplot was created with the dataset to determine the three ambition levels of the origin and future reuse. The boxplots are shown in Figures 24 and 25 and the corresponding percentages are shown in Table 17.

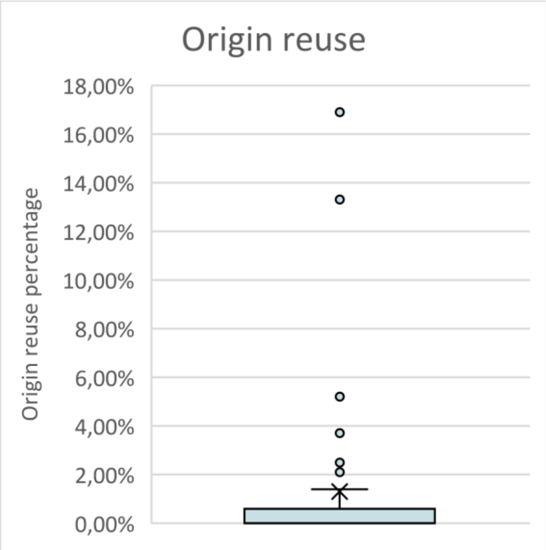


Figure 25; Boxplot origin reuse data

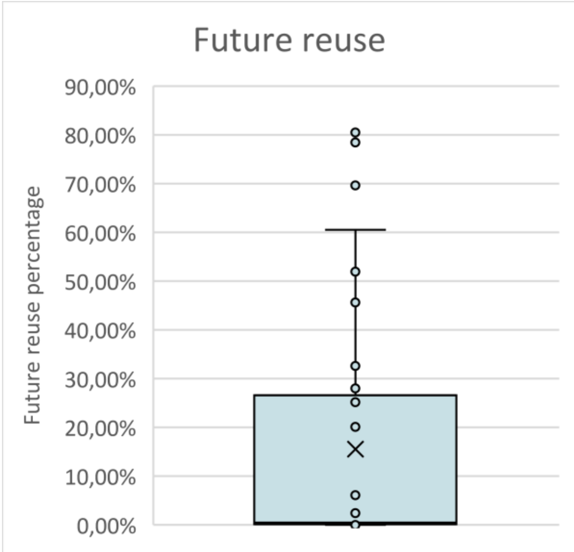


Figure 24; Boxplot future reuse data

Boxplot levels	Origin reuse	Future reuse
Minimum	0.00 %	0.00 %
Lower quartile	0.00 %	0.15 %
Median	0.00 %	0.50 %
Upper quartile	0.60 %	26.60 %
Maximum	1.40 %	60.5 %

Table 17; Boxplot values for origin and future reuse data

The boxplot representations of the origin and future reuse data have a different appearance than the general appearance of a boxplot, as shown in Figure 22. This can be explained by the fact that the data for origin and future reuse are very divided. For the origin reuse, the percentage of reused building materials is in general very low till none. The low percentage of reuse can be explained by several problems encountered by parties in the supply of secondary materials and products. These problems are related to warranties, quality marks, insurance, and the quality of secondary raw materials and products, leading to additional costs, delays, and ambiguities (Timmermans et al., 2021). In addition, the cost of reusing materials is higher compared to primary materials due to the higher costs of deconstruction, treatment, testing, transport and storage (Draaijer, 2020; Rakhshan et al., 2020; SGS Search, 2021). However, a few buildings in the dataset have incorporated reused materials into their project, resulting in a higher percentage of origin reuse. These differences in percentages result in a split data set and unexpected results in the boxplot. The same is true for future reuse, except that future reuse is already applied more frequently, resulting in a less split dataset compared to the origin reuse. However, it can be concluded that the boxplot for both origin and future reuse does not give the intended result for determining realistic and usable CE-criteria. Therefore, the results of the boxplot are adjusted. Instead of considering the median in the boxplot, the boxplot approach is used with respect to the mean. In this way, the mean of the dataset is used and the mean of the upper and lower parts of the dataset compared to the mean are used. The mean of the lower part of the dataset is used as basis ambition level, the mean is used as significant ambition level, and the mean of the upper part of the dataset is used as advanced ambition level. The mean of the lower part of the dataset is the mean of all values below the identified mean. The mean of the lower part is used as basis ambition level, since it sets the limit for circular construction at the lower part of the dataset, thereby still challenging to stimulate circularity. The mean is used as significant ambition level because it represents a percentage for reuse that can be considered as a percentage that encourages circular construction. It represents a percentage that is not the easiest percentage to achieve, but still doable with a little effort. The mean of the upper part of the dataset is the mean of all values above the identified mean. The mean of the upper part is used as advanced ambition level, because it represents average of the highest percentage in the dataset. In this way, the upper mean stimulates new solutions and innovations for circular construction. The lower mean, mean and upper mean for origin and future reuse are shown in Table 18.

Circular material strategy	Origin reuse	Future reuse
Lower mean	0.09 %	0.72 %
Mean	1.20 %	15.96 %
Upper mean	6,44 %	51.51 %

Table 18; Lower mean, mean and upper mean for reuse data

Based on the calculations given in Table 17, the lower mean will be used as the basis level, the mean as the significant level and the upper mean as the advanced level. The CE-criteria for reuse, both in terms of origin of materials and the future scenario of materials, is shown in Table 19. All CE-criteria are rounded to integers.

Circular material strategy	Ambition level	CE-criteria
Origin reuse	Basis	0 %
	Significant	1 %
	Advanced	6 %
Future reuse	Basis	1 %
	Significant	16 %
	Advanced	52 %

Table 19; CE-criteria for reuse

5.2.2 Qualitative criteria

Qualitative criteria are criteria that are being assessed. In many cases, there is no numerical measurement tool to measure criteria. In the case of the circular material strategies non-toxic materials, material efficiency, and reduce also no measurement tool exists. Therefore, qualitative criteria are determined for these circular material strategies. However, there are few studies in the literature on the qualitative criteria for non-toxic materials, material efficiency and reduce. Therefore, suggestions are made to determine qualitative criteria based on existing theories and current knowledge in literature. The determination of the qualitative criteria for the application of non-toxic materials, material efficiency and reduce is explained below.

Non-toxic materials

One of the biggest challenges for the circular economy is the toxicity of materials and products (European Environment Agency, 2020). In the circular construction economy, toxicity is a crucial factor as it limits the possibilities of reuse in the next 'cycle' (Durmisevic et al., 2017). The use of toxic materials makes it impossible to recycle or reuse materials for future use at the end of a building's life (Akanbi et al., 2018; Ellen MacArthur Foundation, 2015; Heijer & Kadijk, 2020). Therefore, the use of toxic products or materials is not wanted at all in a circular economy (Kuppevelt & Stoutjesdijk, 2020). In a circular economy, not only are toxic products or materials unwanted, but so is contamination. Contamination is the application, combination or mixing of different materials and resources in a way that makes reuse difficult or impossible. In the case of contamination, the result is not necessarily a toxic mixture, but a virtually irreversible mixture that has become unusable for reuse in construction. Because of this contamination the material can no longer be reused and/or separation is labor-, energy- or cost-intensive, making high-quality reuse economically infeasible. For this reason, both toxicity and contamination are limiting factors for a circular economy in construction (Heijer & Kadijk, 2020).

It is difficult to estimate how to determine toxicity at an early stage (Kentie, 2021). Indicators to determine toxicity are not available at the moment (Prins & Rood, 2020). In order to provide guidance on toxicity, Heijer & Kadijk (2020) have made a theoretical classification of toxic materials. This classification can serve as an initial guide to reduce toxicity and contamination in the construction industry. The classification is presented in Table 20. For measuring the use of toxic materials the framework of Kubbinga et al. (2018) gives a concrete suggestion (Heijer & Kadijk, 2020). The framework suggests not using materials in a building that are on the C2C Banned List of Chemical Materials, and if they are, the materials must be used in quantities that are below the appropriate threshold (Kubbinga et al., 2018).

Production process	Example
1. Toxic	Asbestos/Chromium 6/Pur/Arsenic/ Lead pipes
2A. Tox with non-tox chemical contamination	Concrete with fly ash slag / Reuse of gypsum (slabs) in agriculture / Released EPS beads / PIR sheets as filler / PFAS soil / Sheet material with formaldehyde / EPS with bromine
2B. Tox with non-tox physical contamination	Spray plaster / Spray insulation / Varnished wood / PUR brick / Sealant dilatation joint brick / Glass sealant / Adhesive channel board / Spray plaster concrete / PVC lead pipe.
3A. Non-tox with non-tox chemical contamination	Wood with natural stain / Loam with natural paint / Rock wool
3B. Non-tox with non-tox physical contamination	Gypsum on concrete brick
4. Non-toxic homogeneous	Untreated timber

Table 20; Categorization toxicity and contamination (Heijer & Kadijk, 2020)

The four main categories of Heijer & Kadijk (2020) are used to determine the qualitative CE criteria for nontoxic materials. When using materials in new buildings, it makes sense to choose only completely non-toxic materials (Heijer & Kadijk, 2020). This means that toxic materials should be avoided. Therefore, the basis CE -criteria is to avoid the use of toxic materials. The significant CE -criteria is to avoid toxic materials and contamination. Finally, the advanced CE-criteria stipulate that only non-toxic homogeneous materials are used. An overview of the CE-criteria for non-toxic materials can be found in Table 21. This classification is consistent with Kentie's (2021) study evaluating toxicity in which toxic materials were not

given a score, contamination was given the second score and non-toxic homogeneous scored the highest.
Whether a material is toxic or not can be determined using the C2C Banned List of Chemical Materials (Kubbinga et al., 2018)(Kentie, 2021). Whether or not a material is contaminated can be determined by using the examples provided by Heijer & Kadijk (2020) (Kentie, 2021). When using this list, it is important to be aware of the constant changes in the state of knowledge and changes in toxicity and contamination. Little or nothing is known about some (potentially) toxic substances, and some of today’s problems may be solved by innovations of the future. Despite these uncertainties and changes, it is indeed possible to distinguish between better and less good decisions regarding toxicity and contamination (Heijer & Kadijk, 2020).

Circular material strategy	Ambition level	CE-criteria
	Basis	Avoid toxic materials
Non-toxic materials	Significant	Avoid toxic materials and contamination
	Advanced	Apply only non-toxic homogeneous materials

Table 21; CE-criteria for non-toxic materials

Material efficiency and reduce

Using the Fuzzy Delphi Method, the circular material strategies of material efficiency and reduce are determined to be important to the framework. However, these two circular material strategies are very similar in definition, which could lead to confusion. Material efficiency and reduce are defined as follows:

- Reduce: reducing the use of raw materials, water and energy and reducing the amount of waste generated (Xing et al., 2017)(van Buren et al., 2016).
- Material efficiency: optimizing material usage by doing more with less or using fewer materials and resources (Gerding, 2018)(Knowledge Hub, n.d.).

From these definitions, it is clear that both circular material strategies focus on reducing materials, with “reduce” having a broader context that includes reducing water, energy and waste. Two other definitions of reduce can be found in literature. The first definition of reduce is to increase efficiency in product manufacture or use of products by using fewer natural resources and materials (Kirchherr et al., 2017)(Potting et al., 2017). A second definition from the Dutch Enterprise Agency is using raw materials more efficient by reducing raw material consumption during the production and use of products (RVO, 2020). In both of these definitions, material efficiency is already part of the definition of reduce. To avoid overlap and confusion between the two circular material strategies, it was decided to combine the two circular material strategies. Since material efficiency is already part of the definition of reduce in some definitions and reduce is mentioned more frequently in the literature, this research will only continue with the circular material strategy reduce.

In the Dutch construction sector, there is a mismatch between the annual demand for construction materials and the supply of materials from demolition (Verhagen et al., 2021)(Arnoldussen et al., 2020). This mismatch is caused by a growing population and a limited ability to supply the types and quantities of materials needed. As a result, large quantities of primary materials must continue to be consumed in the future (Yang et al., 2022). Thereby, most environmental impacts occur in the extraction and processing of materials and the production of building materials in the construction sector. To reduce material consumption and associated environmental impacts it is important to improve the material efficiency along the building lifecycle (Herczeg et al., 2014). Therefore, reduce is an important circular material strategy to reduce material use and associated environmental impacts of the (primary) materials that will be consumed in the future.

To reduce the amount of materials and associated environmental impacts of buildings, it is necessary to examine where the greatest gains can be made, because not all building components have the same environmental impacts (SGS Search, 2021). To identify the greatest environmental impacts per building component, buildings should be considered as dynamic structures. Brand's (1994) study is an example of considering a building as a dynamic structure by dividing a building into six layers. The layers are defined based on the various components in a building and the lifetime of those components. The model of Brand is an extension of Duffy's (1990) 4-layer model. The six layers of Brand and their meaning in the building sector are listed in Table 22 and shown in Figure 26, including lifetime. The layers, as defined by Brand, serve as the basis for a circular design strategy to determine and maintain value (Platform CB'23, 2019).

Layers of Brand	Meaning in building sector
Site	Location, land
Structure	Foundation and load-bearing structure
Skin	Outer wall, roof and lower floor
Service	Installations
Space plan	Spatial plan of the interior
Stuff	Movable and fixed furniture

Table 22; Layers of Brand with meaning (Brand, 1994)(Platform CB'23, 2020)

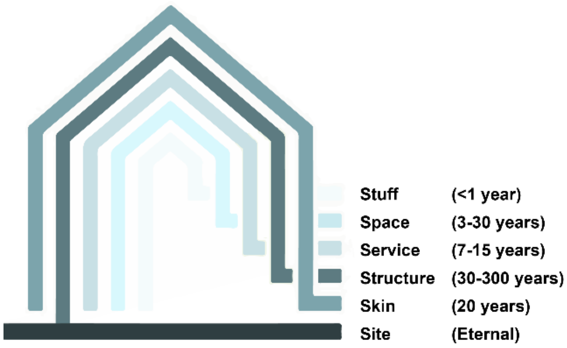


Figure 26; Layers of Brand and lifetime (Author, 2022) based on Brand (1994)

In the Netherlands, building components are classified with the aid of SfB-coding. The Dutch SfB-coding is a generally accepted coding system for the construction sector, most known for its element table. In the element table, building elements are classified in eight functional building elements, as shown in Table 23 (BNA, 2005).

Functional building element	Elements
Foundation	Ground supplies, floors on base, foundation structures and pile foundations
Structural work	Outer and inner walls, floors, stairs and ramps, roof and main load-bearing structures
Space plan	Exterior and interior wall openings, floor openings, balustrades and handrails, roof openings and installation kits
Finishing	Exterior and interior wall finishing, floor finishing, stair and ramp finishing, ceiling finishing, roof finishing and finishing kits
Mechanical installations	Heat generation and distribution, drainage, water, gas, cold generation and distribution, air treatment and climate and sanitary regulation
Electrical installations	Central electrotechnical facilities, power, lightning and communication
Fixed facilities	Fixed user, sanitary, storage and maintenance facilities
Free inventory	Free user, sanitary, storage and maintenance inventory

Table 23; Functional building elements according to SfB-coding including element specification (BNA, 2005)

To reduce the amount of materials and associated environmental impact as efficient and effective as possible, it is important to know which functional building elements have the highest material and environmental contribution. In the study by Arnoldussen et al. (2020), the construction mass and the environmental impact are calculated for each of the functional building elements in the SfB-coding for newly built homes. The functional building element free inventory is not included in calculations for the construction mass and environmental impact. In the construction of newly built houses, nearly three-quarters of the construction mass consist of structural work. The foundation and finishing of a newly built houses contributes to approximately a quart of the construction mass. The space plan has a small contribution of approximately 3 percent to the construction mass. The share of installation and fixed facilities is very small in the total mass and therefore neglectable (Arnoldussen et al., 2020).
The environmental impact for newly built houses is calculated with the aid of the Milieukostenindicator (MKI). The MKI is an indicator that simplifies the outcome (environmental profile) of an Lifecycle analysis (LCA) to a single value. The MKI is used to communicate and compare the environmental performance of construction products (NMD, 2020). With the aid of the MKI the environmental impact of the different functional building elements is given for newly built homes, as can be seen in Figure 27. It can be seen that structural work has the highest environmental impact, followed by finishing. For finishing the highest environmental impact is generated for floor and façade finishing. Installations and fixed facilities are accountable for 7% of the environmental impact (Arnoldussen et al., 2020).

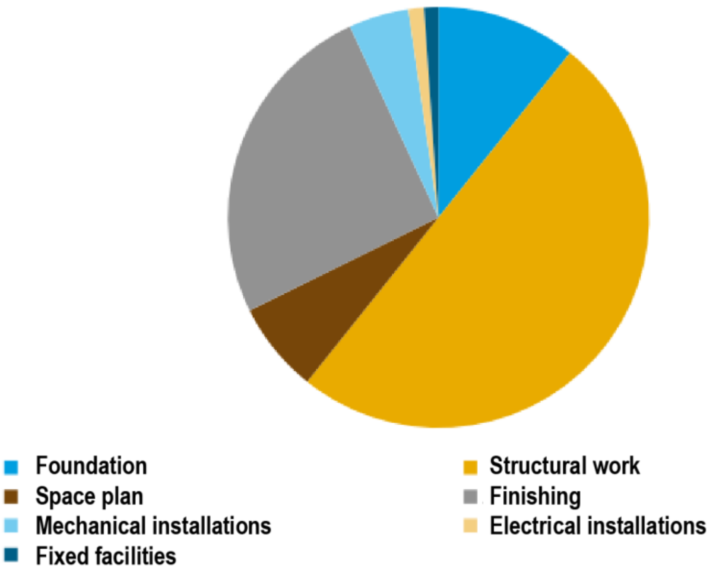


Figure 27; MKI-distribution across the functional building elements for new-build homes (Arnoldussen et al., 2020)

Based on the construction mass and environmental impact per functional building element of newly built homes, it can be concluded that in both cases, structural work has the greatest impact, followed by finishing and foundation. Dismantling, installations, and fixed facilities have the lowest impact. Therefore, due to the high percentage of mass and environmental impact, it is preferable to reduce the amount of material used for structural work.
When determining the CE-criteria for reuse the results with the highest positive impact belong to the highest ambition level. Therefore, due to the high percentage of construction

mass and environmental impacts, reducing the amount of materials for structural work is the preferred measure. For this reason, reducing material use in structural work is classified as an advanced CE-criteria. The second highest impacts are caused by the foundation and finishing. For this reason, reducing the material use in finishing and foundation is classified as a significant CE-criteria. Finally, dismantling, installations and fixed facilities contribute the least and are therefore classified as basis CE-criteria. In addition to considering the impact, the highest ambition level should include a reduction in materials for the entire building. Therefore, the ambition levels complement each other. An overview of the CE-criteria for reduce can be found in Table 24.

Circular material strategy	Ambition level	CE-criteria
Reduce	Basis	Reduce material usage in space plan, installations and fixed facilities
	Significant	In addition to basis level reduce material usage in finishing and foundation
	Advanced	In addition to significant level reduce material usage in structural work

Table 24; CE-criteria for reduce

There are several ways to reduce the amount of materials in construction. Construction projects often use more materials than necessary due to design decisions and overspecification (Ellen MacArthur Foundation, n.d.-a). Additional design time is required to properly size structural elements and operate efficiently, but these design decisions can result in significant material savings. Thereby, lightweight designs can minimize material consumption (University of Cambridge, 2014). The basic principle of lightweight design is that reducing material consumption in turn results in less use of raw materials and less waste and environmental impact (Ministerie van Infrastructuur en Milieu, 2015). In addition, the use of prefabricated building elements can reduce material demand and reduce or eliminate waste (Ellen MacArthur Foundation, n.d.-a). On average, waste is reduced by 52 percent when prefabricated building elements are used (Li et al., 2014). Using construction waste reduction strategies is another way to reduce material consumption (University of Cambridge, 2014). Finally, new technologies such as 3D printing for foundations and load-bearing structures can reduce the amount of materials through innovations in structural forms (Ellen MacArthur Foundation, n.d.-a).

5.2.3 Conclusion of CE-criteria

The result of determining the CE-criteria is a list of CE-criteria, divided into three ambition levels, that can be applied to the circular material strategies of reuse, demountable, reduce and non-toxic materials. The CE-criteria for each circular material strategy are shown in Figure 28. The ambition levels are based on current data and knowledge. However, over time, the ambition levels should be adjusted to keep up with new knowledge and innovations to further stimulate circular construction.

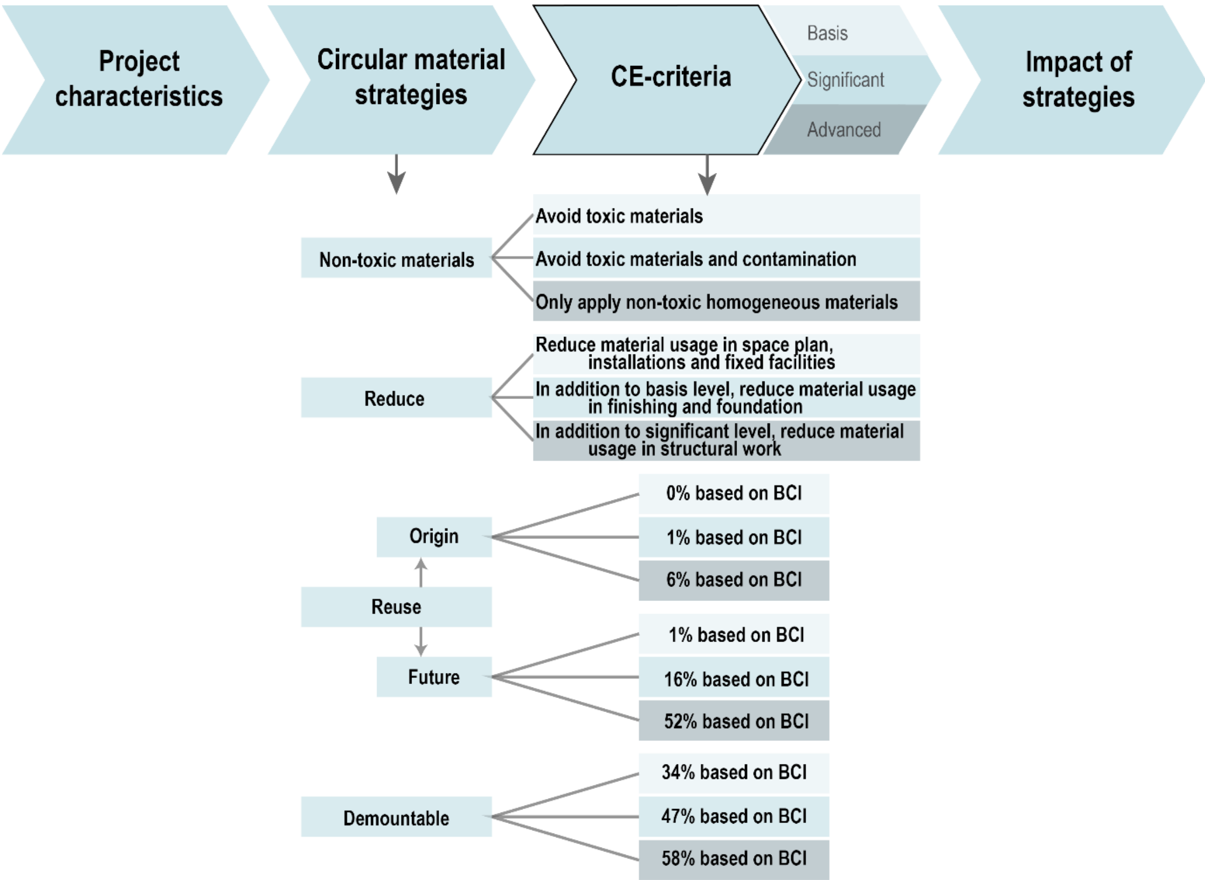


Figure 28; The CE-criteria for each circular material strategy

5.3 Determining impact of circular strategies

The final step of the synthesis phase is to determine the impact of each circular strategy based on the CE-criteria. Several approaches were taken to determine the impacts of each strategy. First, impacts were determined by using data from Alba Concepts. However, this data was not suitable because it represented a combination of different strategies per impact. As a result, it was not possible to determine the impact of each individual strategy. The next step was to use the data of Alba Concepts for a regression analysis, to see if there was a relation between the impacts and the strategies. The results of the regression analysis were insignificant for almost all impacts in relation to the strategies. Therefore, this method was not suited as well. Finally, the impacts are determined based on current knowledge in the literature. However, the literature does not distinguish between the ambition levels basis, significant and advanced, but only considers a generic impact. Therefore, a generic impact is given for the different impacts of each strategy. The generic impact shows the impact of a circular material strategy on a building project compared to a general building project based on a linear economy approach.

The impacts are indicated in four different ways, namely:

- **Positive**; in case the circular material strategy positively contributes to the impact.
- **Negative**; in case the circular material strategy negatively contributes to the impact.
- **Not applicable**; in case the circular material strategy does not influence the impact.
- **Not supported**; in case the contribution of the circular material strategy to the impact cannot be determined from literature.

The determination of the different impacts for each circular material strategies is explained below.

5.3.1 Costs

In this research costs are defined as the total financial resources needed to finance the building, from initiation till realization.

Introduction

In general, circular construction is more expansive than traditional construction (Girolami & Vanneste, n.d.). According to a case study by Copper 8 & Alba concepts (2017) the investment costs for circular construction are 9 to 48 percent higher than for traditional construction. The percentage difference is based on the circular ambition level in the construction project. The costs of circular building components are relatively high because current costs for circular alternatives are often based on small-scale production. Scaling up the production of circular building components reduce the cost (Copper8 & Alba Concepts, 2017). In addition, van Dijken's (2021) study implies 24 percent higher costs for circular construction, due to the additional costs of recycled and bio-based materials. However, other studies note that there is a lack of knowledge and data on the costs and benefits of circular buildings. Circular buildings are often assumed to add costs. For example, due to higher costs for circular building materials. However, cost-reducing elements such as shorter construction time and lower risks due to prefabrication and lower material use are rarely considered. There is insufficient data to objectively demonstrate the costs and benefits of circular buildings (Copper8, 2021).

Higher costs for circular construction only apply if we adhere to the traditional, short-term view. However, circular construction goes beyond short-term thinking (Girolami & Vanneste, n.d.). Based on circular principles, it is desirable that elements, products, and materials can be reused, so that these elements, products, and materials represent value at the end of life of the building. This 'residual value' should be considered in circular buildings (Copper8, 2021). Accounting for residual value has the potential to make circular revenue models more financially attractive (Copper8, 2020). However, applying residual value in practice is proving difficult. There are three reasons for this (Copper8, 2020):

- Demand for used materials is currently limited, which means that the price offered may be lower than the actual residual value.
- Working with used materials is relatively labour-intensive, which means that products made of used materials cannot always compete with new products.
- In construction there is a long period between the application and the withdrawal of materials, this makes it difficult to make accurate estimates of future value.

Studies by Transitieteam Circulaire Bouweconmie (2020) and Nußholz & Whalen (2019) also adress labour as a barrier to circular construction. Labour costs are in the Netherlands relatively high, making it difficult for labour-intensive reuse options to compete with new factory-produced products. In addition, there is no clear method to determine the residual value of used building materials (Transitieteam Circulaire Bouweconomie, 2020).

Reduce

Construction projects often use more materials than necessary (Ellen MacArthur Foundation, n.d.-a). With additional design time, material use can be reduced to ensure lightweight designs (University of Cambridge, 2014; Ministerie van Infrastructuur en Milieu, 2015). With material management, some companies have reduced material use, producing 25 percent less waste and saving 30 percent in costs (Transitieteam Circulaire Bouweconomie, 2020). However, the cost of the additional design and management time may not be in line with the material cost savings because labor costs are relatively high compared to material costs. The additional design cost for lightweight design can be reduced by using optimization software and BIM (University of Cambridge, 2014). In addition, material costs account for 15 to 20 percent of the total construction costs. Therefore, small changes in the material costs have only a marginal impact on the total construction costs (Herczeg et al., 2014).

Overall, no clear conclusion can be drawn about the cost of reducing material consumption. Material costs can be saved through lightweight designs, but material costs have only a marginal impact on the total costs. It is unclear whether the savings in material costs are in line with the additional cost in design time. Further research needs to be conducted to determine if reducing material usage contributes positively or negatively to a building project cost. Therefore, the relation between reduce and cost is addressed as not supported by the literature in this framework.

Reuse

Currently, it is often not yet possible to reus materials from buildings. If deconstruction is too complex or time-consuming, it is be cheaper and more environmentally friendly to use new materials instead of used materials (Draaijer, 2020). The study by Rakhshan et al. (2020) also confirms that in some cases, the fabrication costs of recovered building components can be higher than the fabrication costs of new materials. Secondary materials and products are often more expensive than primary alternatives due to the additional costs of disassembly, transportation and inspections (Draaijer, 2020; SGS Search, 2021). Disassembly requires more time is to carefully remove and sort the recovered building components (Rakhshan et al., 2020; SGS Search, 2021). In this process, disassembly times sometimes exceed expectations due to issues such as lack of space for equipment, complexity of the building design and the geographical location of the building. These factors can increase the disassembly costs, which in turn can increase the price of the recovered components (Rakhshan et al., 2020). Another cost driver for reused components is the higher cost of design. When using reused components, the design team needs to remain as flexible as possible and make extra efforts to find suitable reused components. Sometimes reused components must be purchased early in the project to eliminate uncertainties about the timely availability of the desired components. As a result, the total cost increases due to additional storage costs (Rakhshan et al., 2020). Other additional cost include the costs of testing the recovered components and additional costs for treatment (Rakhshan et al., 2020; SGS Search, 2021). In addition, high initial investments required to be able to harvest or apply certain secondary materials and products may hinder certain parties or products, especially with long payback periods (Timmermans et al., 2021).

The higher overall price of reused materials appears to be a major barrier for requesting parties. Many parties state that the price of secondary materials and products must decrease to stimulate demand (Timmermans et al., 2021). If the price of reused materials is attractive, the demand may increase, which in turn will encourage the development of a reuse market and increase revenues from the sale of reused materials (Rakhshan et al., 2020). Ideally, the price of secondary materials and products is even lower than that of primary alternatives, as it is indicated that clients often prefer the primary material or product when prices are the same (Timmermans et al., 2021).

In some cases, the reuse of materials can be financially beneficial (PIANOo, n.d.-n; SGS Search, 2021). For example, in the study by Transititieteam Circulaire Bouweconomie (2020) some companies found that it pays off to reduce the quantities of primary materials required by means of primary material management and the reuse of materials. This made it possible to produce a quarter less waste and save 30 percent in costs (Transitieteam Circulaire Bouweconomie, 2020). In addition, Draaijer's (2020) study indicates a 56 percent cost reduction in concrete reuse.

However, due to the adjustments that must be made to reused materials, these materials are generally more expensive than new materials. One way to decrease the cost of reused materials is to design for disassembly. Currently, only 1 percent of the total building stock is designed for disassembly. If all real estate is built using the design for disassembly principle, many more materials will be directly reusable, the material banks will be many times more extensive and accessible and the cost of circular construction are expected to be lower (Draaijer, 2020). Design for disassembly could stimulate the reuse of materials in the long term. Another attempt to make the cost of recovered components more competitive in the short term is to increase the landfill tax. If the cost of other waste treatment options increases in favor of reuse, the additional cost of deconstruction, treatment and testing could be compensated (Rakhshan et al., 2020).

Currently, the cost of reuse is higher than for primary materials due to the higher costs of deconstruction, treatment, testing, transportation and storage. In the future, reuse could be financially beneficial if design for disassembly is applied. However, in the current situation, reuse is more expensive than primary materials. Therefore, the relation between reuse and cost is presented as negative in this framework.

Demountable

Strategies for a demountable design are rarely implemented due to the somewhat higher initial cost (University of Cambridge, 2014). However, costs can be saved during the operation and demolition of a building. During operation demountable products are easier to maintain, reducing maintenance costs (PIANOo Expertisecentrum Aanbesteden, 2019; DGBC, 2021a; van Vliet et al., 2021). Reducing maintenance costs has a positive impact on a building's operating costs (DGBC, 2021a; van Vliet et al., 2021). In addition, a demountable building is easier and faster to assemble, which saves labor time and costs (Draaijer, 2020; DGBC, 2021a). The reduced labor and costs ensures a higher residual value of the recovered materials (Draaijer, 2020; DGBC, 2021b). In general, demountable objects have a higher residual value, certainly with a consideration period of up to 15-20 years (PIANOo Expertisecentrum Aanbesteden, 2019). In the future, the reuse of demountable materials will be cheaper. Especially, when primary materials become scarce (PIANOo, n.d.-n).

Overall, no clear conclusion can be drawn about the cost of demountable buildings. Little can be found about the investment costs of demountable components compared to standard components. Only one source cites somewhat higher design costs for demountable buildings. On the other hand, several sources indicate cost savings during operation and deconstruction of the building. However, in this study, costs are defined as the total financial resources needed to finance the project, from initiation till realization. This means that the operation and deconstruction phases are not considered in the definition of the costs in this research. Therefore, these cost savings are not considered. Further research needs to be conducted to determine if demountable buildings positively or negatively influence the cost of a project. Therefore, the relation between demountable and cost is addressed as not supported by the literature in this framework.

Non-toxic materials

In most cases, hazardous goods are less expensive compared to their safer counterparts (Envirofluid, n.d.-a). Using non-toxic or renewable materials results in an additional investment of 10 percent (Draaijer, 2020). However, while the non-hazardous goods may appear more expensive at first glance, substituting safer alternatives for hazardous goods pays off in the long run (Envirofluid, n.d.-a). In addition to the benefits to personnel safety and the environment, there are additional benefits through cost savings. Non-toxic, bio-based, eco-friendly chemicals save cost on waste disposal (Envirofluid, n.d.-b). These cost savings from using non-toxic, biobased and eco-friendly chemicals is confirmed by the study of Rakhshan et al. (2020), which shows a strong correlation between costs and health and safety requirements of a project with deconstruction and reuse. This correlation suggests that the presence of hazardous materials increases health and safety precautions for deconstruction and reuse activities, which could potentially increase the overall cost of the project (Rakhshan et al., 2020).

Overall, there is limited information on the cost implications of non-toxic materials. Some sources cite higher costs for non-toxic materials. On the other hand, sources cite cost savings for non-toxic materials due to lower waste disposal risks. However, in this study, cost is defined as the total financial resources needed to finance the project, from initiation till realization. This means that waste disposal costs are not considered in this research. Further research needs to be conducted to determine if non-toxic materials positively or negatively affect the cost of a project. Therefore, the relation between non-toxic materials and cost is addressed as not supported by the literature in this framework

5.3.2 Quality

In this research quality is defined as the extent to which a building, and products within a building, meet established standards.

Introduction

Although the construction sector has recognized the importance of a circular economy in construction, there are still many questions and obstacles. And many steps to take. One of the questions and ambiguities is about demonstrating and ensuring quality (Timmermans et al., 2021; Meuffels & Hoppe, 2021). Customers are still hesitant to use secondary materials because they are afraid of the quality of the materials (Meuffels & Hoppe, 2021). There is still little insight into the quality of the released materials, while this quality partly determines whether and for which product the secondary materials and products can be reused (Prins & Rood, 2020). As a result, parties are reluctant to engage in high-quality reuse and tempt to reach for what they already know, namely the use of primary materials (Meuffels & Hoppe, 2021).

In the supply of secondary materials and products, the parties encounter various problems related to warranties, quality marks, insurance, and the quality of secondary raw materials and products, resulting in additional costs, delays, and ambiguities. Parties indicate that they are dealing with changes in the quality of supply (Timmermans et al., 2021). In addition, the study by Rakhshan et al. (2020) cites the lack of quality certificates for reused components has a negative effect for reuse. All these problems are a barrier for builders to opt for circular construction with secondary materials and products. Customers want clarity on the quality of secondary materials and products before they use them. They want assurances in the form of guarantees and agreements on quality and liability (Meuffels & Hoppe, 2021). However, ensuring the quality of secondary materials can be challenging (Timmermans et al., 2021). During deconstruction, building components are more susceptible to damage because deconstruction is not considered during the design phase. Damage to the reused building components can reduce the quality, which in turn affects the reusability of the components. Damage can also occur due to corrosion, subsequent alterations, water exposure, weathering, remediation, living organisms, frost, degradation, the kind of connections, and during storage and transportation of the reused components (Rakhshan et al., 2020).
In general, the problems related to quality and guarantees do not seem insurmountable. In practice, however, they are serious obstacles, complicating, increasing the cost of, or slowing down the process, and requiring time that is often not available. Moreover, these issues lead to a lack of clarity that discourages parties from using secondary materials and components. There is still a long way to go in this area. Ideally, all secondary materials offered would meet the same requirements and conditions as primary materials and require no further action on the part of the customer (Timmermans et al., 2021). However, this is not always the case.

When building products are "re-marketed" for high-value reuse and no major additions are required, they usually carry the original certification. Take, for example, a joist that is reused as a joist. If there are still issues with maintaining quality for the purposes of certification or testing oversizing may provide a solution to address this issue. Oversizing means using extra material for a support structure, for example, so that there is no risk of collapse. However, oversizing has the dilemma that it costs more material, while material reduction is desired. Therefore, it is always good to make a project-specific assessment of which solution is most appropriate (Meuffels & Hoppe, 2021).

Regarding the demand for secondary materials and products, some customers, builders, and end users do not (yet) accept secondary materials and products (Timmermans et al., 2021). There is a lack of confidence in quality that negatively impacts component reuse (Rakhshan et al., 2020). Several possible causes are cited for this. Certain clients and contractors consciously or unconsciously impose contractual restrictions on the use of secondary materials and products in their tenders. Regulators do not always accept certain inadequacies related to the use of secondary materials and products. Some of the private end users and clients are dismissive and demand new materials and products. The reason for this aversion to secondary materials and products seems to be some habituation to new materials and products and prejudice against secondary materials and products (Timmermans et al., 2021). This negative perception of stakeholders toward reuse of secondary materials and products can act as a barrier to reuse. Stakeholders' negative attitudes toward reuse are related to the perceived risks in the various project phases where recycled construction elements are used, the need for regulatory compliance, and are fueled by concerns about stakeholder health and safety (Rakhshan et al., 2020). Another reason for this negative perception is the appearance of secondary materials and products. Customers describe secondary materials and products as less attractive (Rakhshan et al., 2020; Timmermans et al., 2021). This less attractive appearance could be interpreted as lower quality compared to a new element. Steps should be taken to improve stakeholder awareness of recycled building elements. For example, the development of standard testing procedures for the testing, evaluation, and certification of recycled building elements can contribute positively to this effort. Such standards and guidelines can alleviate concerns and resistance in the construction sector to recycled building elements and promote the growth of a market for reuse by offering quality products (Rakhshan et al., 2020).

For future reuse, it is important to design buildings in a way that preserves the materials and their quality (Geldermans & Jacobson, 2015). The better the quality of the product, the better the product can be used in a circular way (Wals, 2020). This is especially relevant for the future, where material scarcity will have economic consequences. The current building stock in the Netherlands is based on traditional construction methods and materials. Some obstacles with current buildings are that the buildings are not demountable, technical and biological materials are mixed, and low-quality materials are used. It is practically impossible to formulate circular principles for such buildings. One reason for this is that circular principles related to the use of materials must be co-created in the initial phase of a project. This is the only way to provide guarantees for quality maintenance and material recovery (Geldermans & Jacobson, 2015). Information technology and data collection play a crucial role in this process (Geldermans & Jacobson, 2015; Prins & Rood, 2020). The availability of information can stimulate reuse and also influences demolition and renovation processes (Geldermans & Jacobson, 2015). One way to collect and store information is to use a material passport. A material passport can be used to efficiently reuse or recycle materials after demolition. The material passport provides insight into the quality and quantity of processed materials and components (Stichting Stimular, 2019; HEVO B.V., 2021).

Reduce

The aim of reduce is to reduce the amount of new raw materials and raw materials in general, while maintaining the same functionality and quality (SGS Search, 2021). All building products and materials must comply with European legal requirements, for example the European EN-standards. In the Netherlands, these European EN-standards are converted to the NEN-standards in which compliance with the standard is represented with a CE-marking (Meuffels & Hoppe, 2021). These standards must also be met when reducing material use. Therefore, reducing the material usage does not influence the quality of materials since the same standards need to be met. Therefore, the relation between reduce and quality is addressed as not applicable in this framework.

Reuse

Reuse occurs when the building components still meet the functional requirements in the context and no components need to be replaced. If this is not the case, a building component is instead remanufactured or refurbished (SGS Search, 2021).
Ensuring the quality of secondary materials can be challenging. Therefore, it can sometimes be attractive to focus on products and materials that are easily and (almost) immediately reusable (Timmermans et al., 2021). When building components are reused without major additions, they usaully contain the original certification. Take, for example, a joist that is reused as a joist. If there are still issues with maintaining quality for the purposes of certification or testing oversizing may be a solution to this problem (Meuffels & Hoppe, 2021). However, if there is no certification to prove that the reused building components and materials will not jeopardize the quality of the new building, clients may be reluctant to reuse components and materials (Bougrain & Laurenceau, 2017). In the study by Rakhshan et al. (2020) and Timmermans et al. (2021), the lack of quality certificates for reused components is also cited as a boundary for reuse.
Besides the issues regarding certification, reuse building components are more susceptible to damage because deconstruction is not considered during the design phase. Damage to reused building components can reduce the quality, which in turn affects the reusability of the components. Damage can also occur due to corrosion, subsequent alterations, water exposure, weathering, remediation, living organisms, frost, degradation, the kind of connections, and during storage and transportation of the reused components (Rakhshan et al., 2020). However, demountable components increase reusability by reducing damage to the reused components and surrounding components and materials (Nationale MilieuDatabase, 2020; DGBC, 2021a).

Overall, no clear conclusion can be drawn about the quality of reused components. Specific information on whether the quality of reused components is better or worse cannot be found in literature. Only information about current reuse problems related to quality can be found and possible solutions to overcome these problems are mentioned. Further research needs to be conducted to determine if the quality of reused building components and materials is affected. Therefore, the relation between reuse and quality is addressed as not supported by the literature in this framework.

Demountable
Demountable design and construction have several advantages (DGBC, 2021a). A demountable building is easy to maintain during its lifespan, which ensures the quality of building products and components (DGBC, 2021a; van Vliet et al., 2021). In addition, demountable components increase reusability by reducing damage to the reused components and surrounding components and materials (Nationale MilieuDatabase, 2020; DGBC, 2021a). The higher the demountability, the higher the quality of reuse (Nationale MilieuDatabase, 2020).

Based on the literature, it can be concluded that demountable building components positively influence the quality because they provide the opportunity to maintain building components and reduce damage by reuse. Therefore, the relation between demountable and quality is presented as positive in this framework.

Non-toxic materials
Several articles mention quality and toxicity together as important characteristics for reuse and recycling (Geldermans & Jacobson, 2015; SGS Search, 2021; Wals, 2020; Prins & Rood, 2020). The quality of a material or product that is released from a building is determined, among other things, by the purity of the material (Geldermans & Jacobson, 2015). This means the avoidance of contamination or toxic materials.
Toxicity affects the reuse or recycling quality of a product. For example, in the case of concrete with poured plastic/PVC pipes, recycling is difficult because concrete with poured plastic/PVC pipes is difficult to separate. As a result, the recycled concrete granules contain small PVC residues, making them of lower quality than concrete granules without PVC residues. In addition, environmental pollution due to the spreading/dilution of toxic substances, usually during the use phase, is an important factor that can affect the quality of large quantities of raw materials. The PFAS issue is an example of such dilution that has affected large quantities (Heijer & Kadijk, 2020).

From the literature, it can be concluded that toxic materials negatively affect the quality of materials, resulting in low quality recycling or polluted materials and resources. If non-toxic materials are used, these problems with recycling and pollution can be avoided. Therefore, the relation between non-toxic materials and quality is presented as positive in this framework.

5.3.3 CO2 emission
Within this research CO2 emission is defined as the total amount of CO2 produced during the realization of a building.

Introduction
A transition to a circular economy is needed to achieve the goals of the Paris Climate Agreement. A circular economy can make a structural contribution to the Paris Agreement by

producing about 20 percent fewer greenhouse gases, of which CO2 is one of the most important greenhouse gases (Rijksoverheid, 2021). CO2 reduction is part of a circular economy because in a circular economy the demand for new products is lower, and therefore the demand for raw materials is also lower, which leads to lower CO2 emissions in the entire product chain of an industry (Ellen MacArthur Foundation, 2015; SKAO, 2019; Spinhoven, 2021; van Dijken, 2021).

One solution to reduce emissions is to use secondary materials for the production of building materials. The production of building materials with secondary materials has a high potential to save carbon. However, the extend of carbon savings potential depends on the material streams and products. For example, the carbon savings potential of reusing brick is 99 percent. In contrast, wood and plastic reuse for façade material and concrete for structural elements have a potential carbon savings of 30 to 40 percent (Nußholz & Whalen, 2019). Therefore, extending the use of existing structures through maintenance, upgrades, and reuse is more carbon efficient than demolishing and building new structures (Bonnett et al., 2022). This is because building materials with a longer lifespan need to be replaced less frequently, which has a direct influence on raw material consumption and CO2 emissions (Eco Intelligence, 2021). In addition, extending the use of existing structures also offers potential for cost and time savings (Bonnett et al., 2022).

Reduce

In a circular economy, there is less demand for new products, which leads to less demand for raw materials and thus less CO2 emissions (Ellen MacArthur Foundation, 2015; SKAO, 2019; Spinhoven, 2021; van Dijken, 2021). Therefore, by reducing the amount of products and materials, the CO2 emissions will be lower (CITYFÖRSTER, 2022). Therefore, the relation between reduce and CO2 emission is presented as positive in this framework.

Reuse

Carbon emissions from construction can be reduced by reusing building components (Rakhshan et al., 2020). Therefore, reusing existing structures for expanded use is more carbon efficient than demolishing and constructing a new building (Bonnett et al., 2022). Extending the life of buildings, elements, components, and materials through reuse reduces production and associated emissions, such as CO2 emissions (Transitieteam Circulaire Bouweconomie, 2020). From an environmental perspective, it makes sense to reuse elements that have a high environmental impact. Reusing elements with high environmental impacts can be seen as a way to avoid new production or to capture the carbon footprint of existing elements (FCRBE, 2020).

From the literature, it can be concluded that reuse reduces CO2 emissions. Therefore, the relation between reuse and CO2 emission is presented as positive in this framework.

Demountable

Demountable components are a means to enable high-quality reuse (Eco Intelligence, 2021; PIANOo Expertisecentrum Aanbesteden, 2019; van Vliet et al., 2021). Reuse extends the life of building components (Erkelens, 2002; Prins & Rood, 2020). Extending the life of buildings, elements, components, and materials has a direct impact on CO2 emissions (Eco Intelligence, 2021; Transitieteam Circulaire Bouweconomie, 2020). Since demountable components enable reuse, which extends the lifespan, it can be concluded that demountable components reduce CO2 emissions. Therefore, the relation between demountable and CO2 emission is presented as positive in this framework.

Non-toxic materials
There is no information in the literature about non-toxic materials in relation to CO2 emissions. For this reason, the relation between non-toxic materials and CO2 emission is presented as not supported in this framework.

5.3.4 Lifespan

In this research the lifespan of a building or product is defined as the period of time in which a product or building is used, from purchase till disposal.

Introduction
The goals of a circular economy are to extend the lifetime of products, facilitate repurposing of items and returning waste materials from landfills to production lines (Dumée, 2022). One way to extend the lifetime of products is through product life extension. Product life extension, involves using products according to their original purpose for as long as possible or repairing and refurbishing them for multiple reuses, thereby reducing the need to purchase and manufacture new products (Valero et al., 2020). Extending the lifetime of products minimizes the use of raw materials, by using fewer materials through smart design or reuse (Ellen MacArthur Foundation, 2015; Copper8 & Alba Concepts, 2017). For this reason, extending product life is an important contribution to the transition to a circular economy, as it reduces waste and saves resources while preserving the economic value of products (One Planet, 2020). By preserving the economic value of products, it becomes attractive for suppliers to design circular products and maximize the lifespan of products (Copper8, 2020). In addition, extending the life of a building lowers the overall cost of a building (Braakman et al., 2021).

A building consists of different layers, each of which has its own functional life (Copper8, 2020). In Brand's study (1994), six layers are distinguished based on the different components in a building and the lifetime of those components. Figure 29 shows the six layers and their corresponding lifetime. These differences in lifetime highlight the importance of demountable elements, both based on the connections between elements and on lifetime of different elements (Copper8 & Alba Concepts, 2017; Copper8, 2020). Looking at the reuse options, the shell in which the element is located has an impact. It can be observed that the shorter the lifespan of the parts, the more relevant, but also the more potential for reuse. In addition, disassembly options also improve as parts change more rapidly (SGS Search, 2021). In a circularity assessments, and especially in a building circularity assessment, the lifespan of a building layer has a major impact on the circularity score of a building. Building materials in the space plan or skin are replaced more frequently (shorter functional lifespan) than materials in the structure (longer lifespan), so their impact on the overall building circularity score is greater (Braakman et al., 2021). For this reason, building materials with a shorter lifespan are made easily replaceable and building materials with a longer lifespan are made flexible (van Dijken, 2021).

Figure 29; Layers of Brand and lifetime (Author, 2022) based on Brand (1994)

There are several ways to extend the lifespan of products and materials. To extend the life of products, the focus should be on the design phase to design buildings to last over a long period of time. Extending product life in the design phase can be achieved, for example, by designing standardized components in terms of size or material. In the building sector, this means designing modular building components that can be reused in new buildings or repurposed and used in infrastructure or other industries (Valero et al., 2020; Braakman et al., 2021). Another way to extend product life is to use durable materials and high building standards (Valero et al., 2020). Or by increasing the material quality and resilience of buildings. Resilience can be provided by creating flexible spaces (O'Grady et al., 2021). Other studies also address the importance of flexibility and adaptability in the design phase to extend the life of a building (Valero et al., 2020; van Dijken, 2021). Extending the lifespan of buildings, can generate savings by delaying redevelopments and reducing maintenance and end-of-life costs (van Dijken, 2021).
Another way to extend the lifespan of products and materials is through maintenance and repair (Ellen MacArthur Foundation, n.d.-b; Het Groene Brein, n.d.-a; SGS Search, 2021). The lifespan of products should be made as long as possible (Ellen MacArthur Foundation, n.d.-b; Het Groene Brein, n.d.-a).

Reduce
The amount of materials can be reduced through light weight design. However, an important point is that the lifespan of a building is not shortened (Stichting Stimular, 2019). It is not clear to what extend reducing the material input affect the lifespan of a building. Further research need to be conducted to determine the impact of reduce on the lifespan. Therefore, the relation between reduce and lifespan is presented as not supported by the literature in this framework.

Reuse
The lifespan of materials, components or building parts can be extended through reuse (Erkelens, 2002; Prins & Rood, 2020). Lifespan extension through reuse should be applied at all levels, from whole buildings to materials (Erkelens, 2002). Looking at the different layers in a building, it can be observed that the shorter the lifespan of the parts, the more relevant, but also the more potential there is for reuse. As can be seen in Figure 30, the shorter the lifespan of a building, the more frequently the layer changes. In addition, disassembly options also improve as parts change more quickly (SGS Search, 2021).

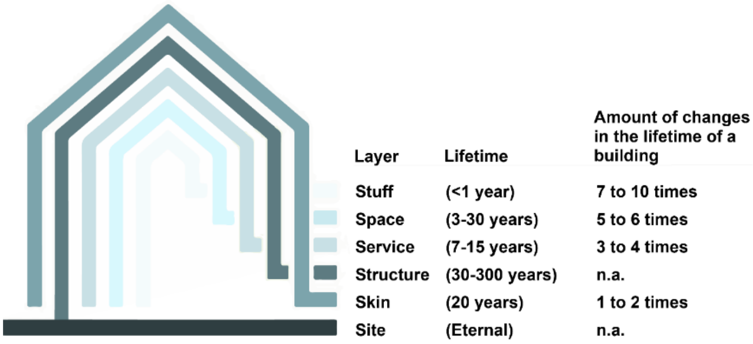


Figure 30; Layers of Brand with lifetime and changes per lifetime (Author, 2022) based on Brand (1994) and SGS Search (2021)

In literature it is stated that the lifespan increases through reuse. Therefore, in this framework the relation between reuse and lifespan is presented as positive.

Demountable

With demountable building components, interim repair, upgrade and future reuse are easier (Copper8 & Alba Concepts, 2017; DGBC, 2021a). The ultimate goal in the ability to repair, upgrade or reuse building components is to extend the lifespan (DGBC, 2021a). By extending the lifespan, building components are used over a longer period of time, reducing the impact of the energy used to manufacture these components over the lifespan of the component (Copper8 & Alba Concepts, 2017). In addition, demountable design encourages and promotes the standardization of component manufacturing, construction methods, component fixing, etc., which improves efficiency and allows for material life extension (Macozoma, 2002).
Considering the different layers and lifespans in a building, demountable buildings extend the functional lifespan of buildings (Macozoma, 2002). Structural products tend to last the entire life of a building, while the surface is replaced several times. Products with a shorter lifespan than that of the building in which they are used are of particular interest if they are demountable (van Vliet et al., 2021). These differences in lifetime highlight the importance of demountable elements, both based on the connections between elements and the lifespan of each elements (Copper8 & Alba Concepts, 2017).

From the literature, it can be concluded that demountable building components positively influence the lifespan due to the ability to repair, upgrade and reuse building parts based on their individual lifespan. Therefore, the relation between demountable and lifespan is presented as positive in this framework.

Non-toxic materials

The aim of a circular economy is to endlessly reuse building components (Heijer & Kadijk, 2020). Toxic or contaminated building components cannot be reused (Akanbi et al., 2018; Durmisevic et al., 2017; Ellen MacArthur Foundation, 2015; Heijer & Kadijk, 2020). As a result, toxic and contaminated building components do not contribute to a circular economy (Heijer & Kadijk, 2020). Because toxic or contaminated building components cannot be reused, the lifespan of these building components is shortened compared to building components that can be reused. In a circular economy, the use of toxic products or materials is unwanted at all (Kuppevelt & Stoutjesdijk, 2020). On the other hand, non-toxic components can be reused, especially if there are designed demountable (Heijer & Kadijk, 2020). Therefore, the lifespan of non-toxic components is longer compared to the lifespan of toxic or contaminated components. For this reason the relation between non-toxic materials and lifespan is presented as positive in this framework.

5.3.5 Environmental impact

In this research environmental impact is defined as the influence of a building on the natural environment and ecosystems of the planet, think of pollution, deforestation, and so on.

Introduction

The environmental benefits of a circular economy include reduced greenhouse gas emissions, preservation of vital soil, air, and water ecosystems and protection of nature reserves. Applying the principles of a circular economy automatically reduces greenhouse gas emissions, as climate change and the use of materials are closely linked. In addition, a circular economy creates vital ecosystems for soil, air and water (Het Groene Brein, n.d.-b). In the current linear economy, the services of soil, air and water are depleted by the constant extraction of products or polluted by the dumping of toxins. When products are used in a cycle and not polluted by toxic substances, the soil, air, and water ecosystems remain resilient and productive (Het Groene Brein, n.d.-b; SYKE, 2018). Thereby, conservation of the nature reserves is important for the preservation of soil, air, and water ecosystems. Mining raw materials and the dumping of waste negatively affects the nature reserves (Het Groene Brein, n.d.-b). In order to systematically preserve nature, the extraction of raw materials and the dumping of waste must stop. This can be achieved with the circular economy (Het Groene Brein, n.d.-b; SYKE, 2018).
Circular construction should reduce the impact on the environment by reducing the environmental impact of the use of (raw) materials (SGS Search, 2021; Timmermans et al., 2021). The use of secondary materials has a high potential to reduce environmental impact by reducing emissions and the loss of resources (EEA, 2020; Nußholz & Whalen, 2019; SGS Search, 2021). However, to what extent depends on the material stream and the product, as not all building components have the same environmental impact (Nußholz & Whalen, 2019; SGS Search, 2021).

Reduce

Reducing building materials reduces the extraction of raw materials, which contributes to preserving nature and thus protecting the soil, air, and water ecosystems (Het Groene Brein, n.d.-b; SYKE, 2018). In addition, by using less building materials, lower emissions of building materials can be achieved (CITYFÖRSTER, 2022). By reducing the amount of building materials, nature, soil, air, and water are conserved and emissions are reduced. Therefore, the relation between reduce and environmental impact is presented as positive in this framework.

Reuse

Reuse of building materials reduces environmental impacts by preventing new production (FCRBE, 2020; Timmermans et al., 2021). However, the amount of environmental impacts ultimately depends on the ability to reuse on location or in the region and whether processing is required. Processing and transportation negatively effects the environmental impact of materials and should be avoided. More knowledge is needed about which material flows have

the greatest environmental impact and where the greatest environmental benefits can be achieved (Timmermans et al., 2021). In addition, reuse extends the life of building materials (Erkelens, 2002; Prins & Rood, 2020). Extending the life of building materials through reuse reduces the production of associated emissions (Transitieteam Circulaire Bouweconomie, 2020).
From the literature, it can be concluded that reuse reduces environmental impacts. Therefore, the relation between reuse and environmental impact is presented as positive in this framework.

Demountable
Reuse of building materials has great potential to reduce environmental impacts. To realise this potential, it is important that materials and products are manufactured in such a way that they can be easily reused, for example, through demountable design (Timmermans et al., 2021). Demountable components enable reuse by extending the life of building components (Erkelens, 2002; Prins & Rood, 2020). Extending the life of building components reduces material production and associated emissions (Transitieteam Circulaire Bouweconomie, 2020). Furthermore, reducing material production reduces the extraction of raw materials, which contributes to the preservation of nature and thus the preservation of the soil, air, and water ecosystems (Het Groene Brein, n.d.-b; SYKE, 2018).
Overall, it can be concluded that demountable construction reduces environmental impacts. Therefore, the relation between demountable and environmental impact is presented as positive in this framework.

Non-toxic materials
In today's linear economy, the ecosystems of soil, air, and water are polluted by the dumping of toxins. When products are not contaminated with toxins, the soil, air, and water ecosystems remain resilient and productive. Maintaining resilient soil, air, and water ecosystems also contributes positively to the conservation of nature reserves (Het Groene Brein, n.d.-b; SYKE, 2018). By using non-toxic materials in construction, soil, air, and water ecosystems are not polluted. Thus, the use of non-toxic materials reduces environmental impact. Therefore, the relation between non-toxic materials and environmental impact is presented as positive in this framework.

5.3.6 Conclusion of impact of circular strategies

The result of determining the impacts per circular material strategies is an overview that provides insight on the impact costs, quality, CO2 emission, lifespan and environmental impact for the circular material strategies reuse, demountable, reduce and non-toxic materials. An overview of the impacts per circular material strategy is given in Figure 31.

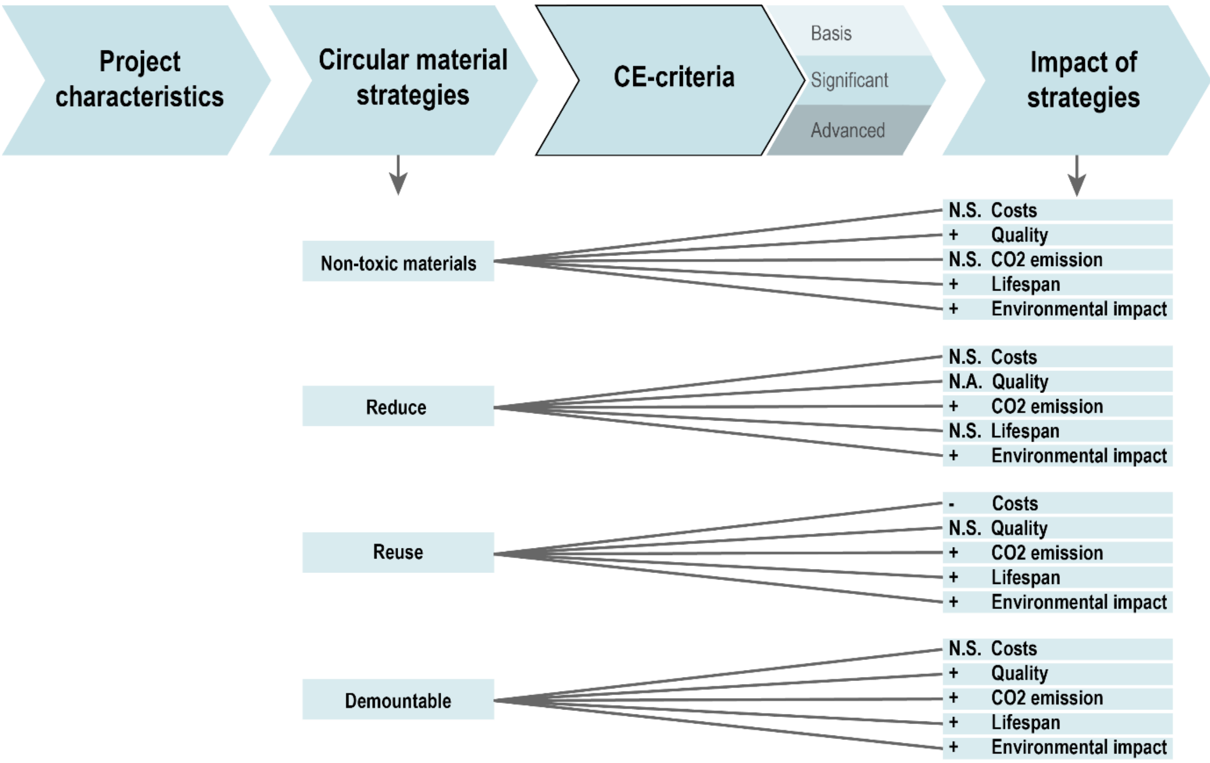


Figure 31; The impacts for each circular material strategy (+ = positive impact, - = negative impact, n.s. = not supported in literature, n.a. = not applicable)

5.4 Conclusion synthesize phase

The result of the synthesize phase is a list of 5 project characteristics, 4 circular material strategies and 5 impacts to consider for the framework. In addition, the CE-criteria for each circular material strategy are determined in three ambition levels and the impacts of each circular strategy are determined. The results of the synthesize phase are shown in Figure 32.

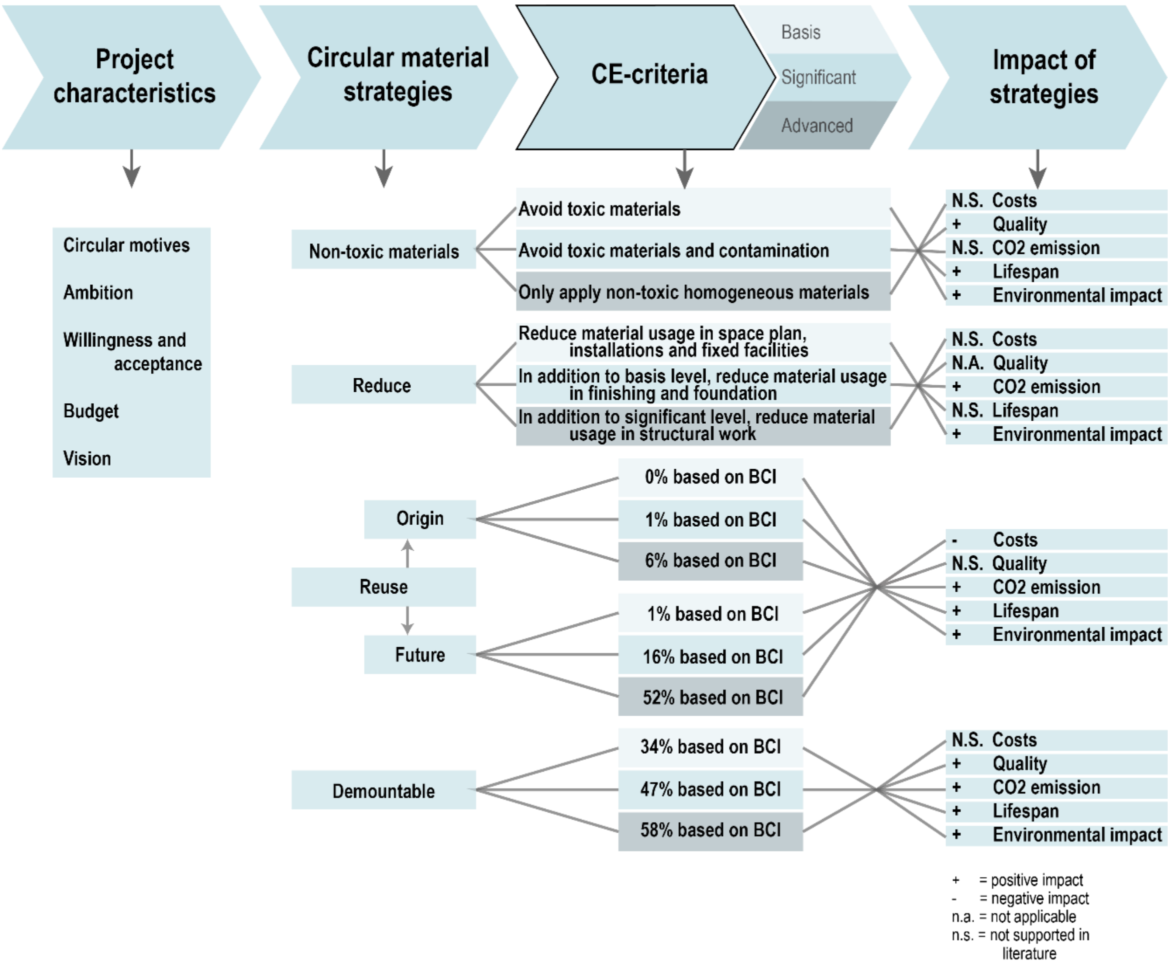


Figure 32; Results synthesize phase

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6. Creation phase

The creation phase is about designing artifacts for the defined problem (Keskin & Romme, 2020). In this step the framework can be created with the input from the synthesize phase. The goal of this step is to create the framework with CE-criteria.

6.1 Introduction

In this research, the term framework refers to an overview that captures (new) ideas in an overall picture so that it is easy to remember and apply the (new) concept.

In the study by Ebarhardt et al. (2019) and Leising et al. (2017), it is stated that frameworks have not yet been developed for the complex problems in the construction sector. Frameworks are needed to make the concept of the circular economy more accessible, promote the transition to a more circular built environment, guide decision making in the adoption of the circular economy, and measure the impact and effectiveness of circular procurement (Acharya et al., 2018; Goodwin Brown et al., 2021; Metabolic, 2019; WBSCD, 2020). Currently, a number of frameworks have been developed for implementing the circular economy in the construction sector (Kubbinga et al., 2018; Platform CB'23, 2019). These frameworks provide a clear overview of the circular concept in relation to the construction sector in the form of a report that exceeds 40 pages. In addition to the circularity frameworks, several guidelines have been developed on how to implement circularity in the procurement process (Scherpenisse et al., 2021; van Oppen et al., 2018; Van Oppen & Bosch, 2020; Vos et al., 2019). In these guidelines, the integration of circularity into the procurement process is explained in different steps in the form of a report that contains more than 35 pages. In addition to these reports, some frameworks have been developed that capture the circular concept in an overall picture (European Commission, 2018; Hammad et al., 2019; Moreno et al., 2016; Többen, 2021). In these cases, the framework is explained in several pages and visualized in an overall picture. However, these frameworks focus on integrating circularity into design and construction and measuring and monitoring circularity. A framework that presents the integration of circularity into the procurement process in an overall picture is still missing. The reports or overall pictures that are for download have too many pages. Project managers do not have the time to read many pages. Therefore, it is preferred to have a clear overview on a few pages that can be used as an interactive tool (Többen, 2021). Preferably, the overall picture should be easy to print or use online. Therefore, it was decided to limit the framework to a maximum of one A3 size. The framework will be an infographic that compactly illustrates the most important information. An infographic can be easily printed and used physically or displayed in an online session.

6.2 Framework content

The content used in the framework consists of the results of the synthesize phase. The results of the synthesize phase can be found in chapter 5.4.

The framework uses four steps that are introduced in this research. The four steps are:

- The project characteristics
- The circular material strategies
- The circular economy criteria (CE-criteria)
- The impact of strategies

For each step, a brief explanation about the application of the step is provided, along with additional content about the definition of the step and additional information needed to apply and understand the step. Thereby, the results of the synthesize phase are given for each step.

6.3 Framework design

The framework is intended for governments that want to realize a circular transition using circular economy criteria in the procurement process. The content of the framework consists of the results of the synthesize phase and should fit into an A3 format.
To create the framework, four layout sketches were made, which are shown in appendix H. In these sketches, the relationship between the four steps and the content of each step was visualized. The sketch with the clearest and most understandable layout was selected to develop into a final design. The result is a framework in an A4 format that illustrates the relationship between the four steps and explains the content of each step. Thereby, each step is explained and additional information about the four steps and the content of the step is provided. The final framework is shown in Figure 34 on the next page.

6.4 Framework application

The aim of this research is to create a framework for governments to realize a circular transition with procurements. The framework serves as a tool that defines the boundaries for the circular economy by suggesting strategies and corresponding CE-criteria that can integrate circularity into the procurement process. Through the application of the framework, governments and other organizations can define suitability requirements, selection criteria, award criteria, minimum requirements or contract provisions for the procurement process. The framework can be applied throughout the procurement process, as shown in Figure 33. Preferably, however, the framework is applied as early as possible within the procurement process, i.e. the specification, to ensure that circularity is properly included in the procurement process.
To apply the framework for determining clear and realistic CE-criteria governments must follow four steps. These four steps are, in order, the project characteristics, circular material strategies, CE-criteria and impacts. The steps must be followed in the given order because the outcome of one step determines the input for the other step. Following the steps in this order will provide governments with insight into circular options and the practicality and value of those options. For each step, there is an explanation of the step on the left side. The content to apply the step is given in the implementation of the step, which is shown in the center of the framework. On the right side of each step, additional context is provided on the definition of the step and additional information is provided on how to implement the step correctly. Following the four steps will provide governments with information to integrate clear and realistic CE-criteria into their procurement process that align with their ambitions. In case the impacts in the final step do not match the desired project characteristics, the previous steps must be reviewed to determine why the outcome of the impacts does not match the established project characteristics. Once the default has been determined, adjustments can be made in one of the previous steps to achieve to the desired results. To insert the adjustments correctly, it is important to follow the sequence of steps again.
In this way, the framework help governments, and other organizations, achieve their circular ambitions through public procurement. By using clear and realistic CE-criteria in public

procurement governments stimulate a circular transition, which in turn supports their goal of being fully circular by 2050.

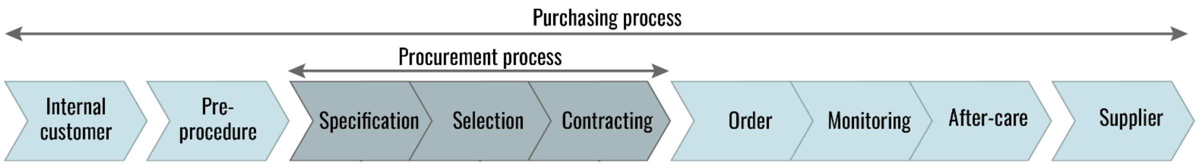

Figure 33; The purchasing and procurement process based on IBR (2020)

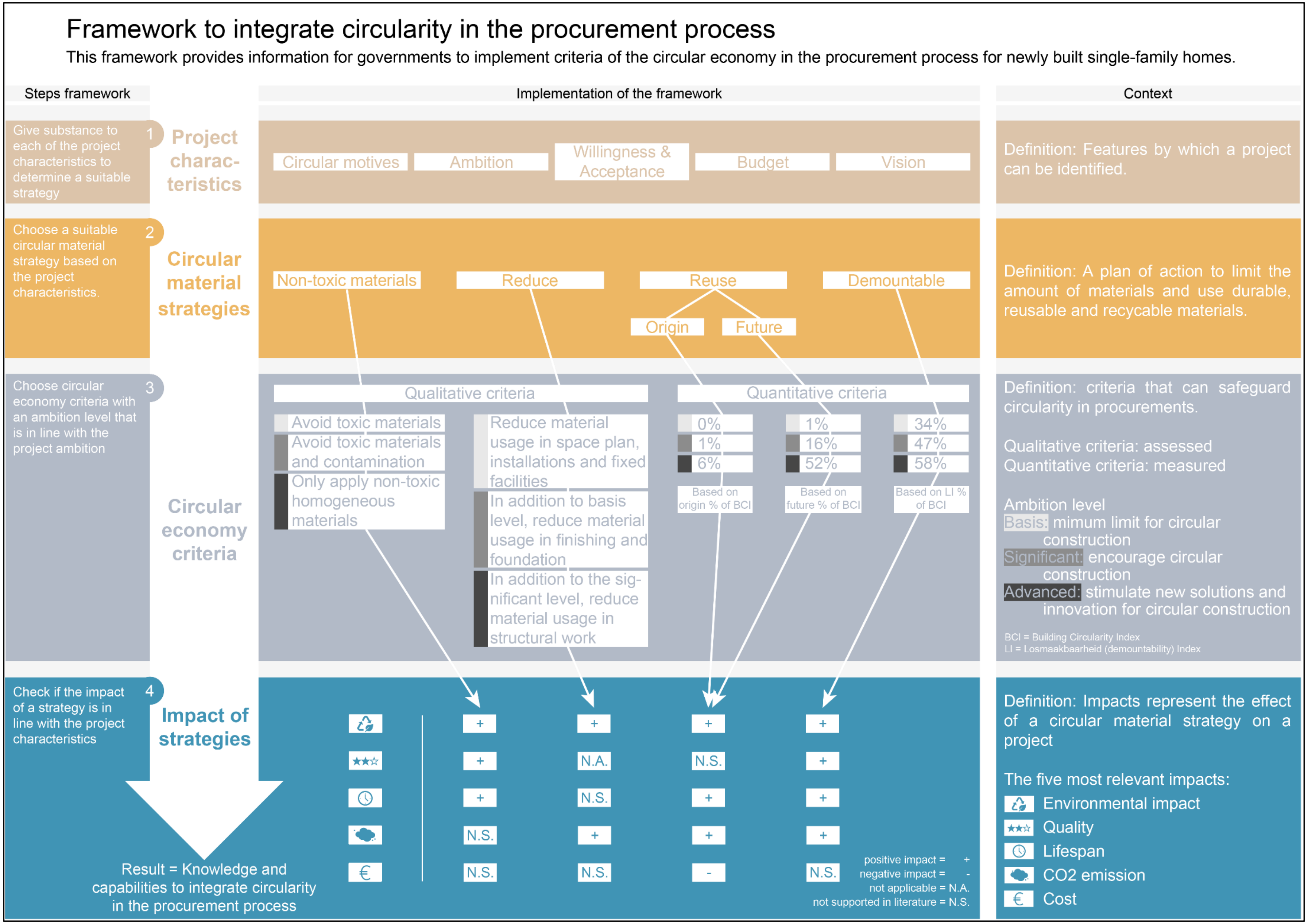

Figure 34; Framework final design creation phase

6.5 Conclusion creation phase

In the creation phase, the framework is created in the form of an infographic that compactly presents the most important information about integrating the circular economy into the procurement process. An infographic is used because it can be easily printed and used physically or displayed in an online session.

The content of the framework created during the synthesize phase and the sketches resulted in an A4-size framework. The framework presents the project characteristics, circular material strategies, circular economy criteria, and impact of strategies in the order to follow. To apply the framework correctly, the order of the steps must be followed. Following the steps in this order will provide governments with insight into circular options and the practicality and value of those options. Furthermore, each step is explained and additional information about the application of each step is provided.

The result of the creation phase is a framework of CE- criteria that will help governments and other organizations achieve their circular ambitions through public procurement.

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7. Evaluation phase

In the evaluation phase, the framework is validated using expert interviews. Both government and market parties are interviewed. The goal of this step is to validate the framework and gain market and government support for the framework. Section 3.3.2 explains the method and structure of the validation interviews with experts and this chapter explains the results of the validation interviews with experts.

7.1 Results experts interviews

A total of eight experts from different companies with knowledge of the circular economy and the procurement process were interviewed. Of the experts, four experts are experienced as contracting authority for provinces, municipalities or housing corporations. The other four experts are consultants with experience for both contracting authorities and contractors. In this way, both government and market perspectives are included in the interviews.
In the interviews, the experts validated the framework in terms of its appearance, clarity, correctness, and applicability. In general, the experts provided positive feedback about the framework. The framework and steps are clear, it is nice to have everything in one view and the framework clearly shows the options available for the circular economy and the criteria associated with them. In this regard, seven of the eight experts agreed that the framework is applicable in the procurement process for newly built single-family homes. The expert who disagreed with the applicability of the framework argued that the framework can only be used by experts and not by ordinary employees. Moreover, seven experts would apply the framework themselves. One expert was hesitant to use the framework because circularity is only a minor subject in his procurement process.
In addition to the positive feedback, suggestions for improvements and changes were also made. To get a clear overview of the suggestions and improvements made by the experts, the interviews are analyzed. The process of analyzing the eight transcripts is shown in Figure 35.

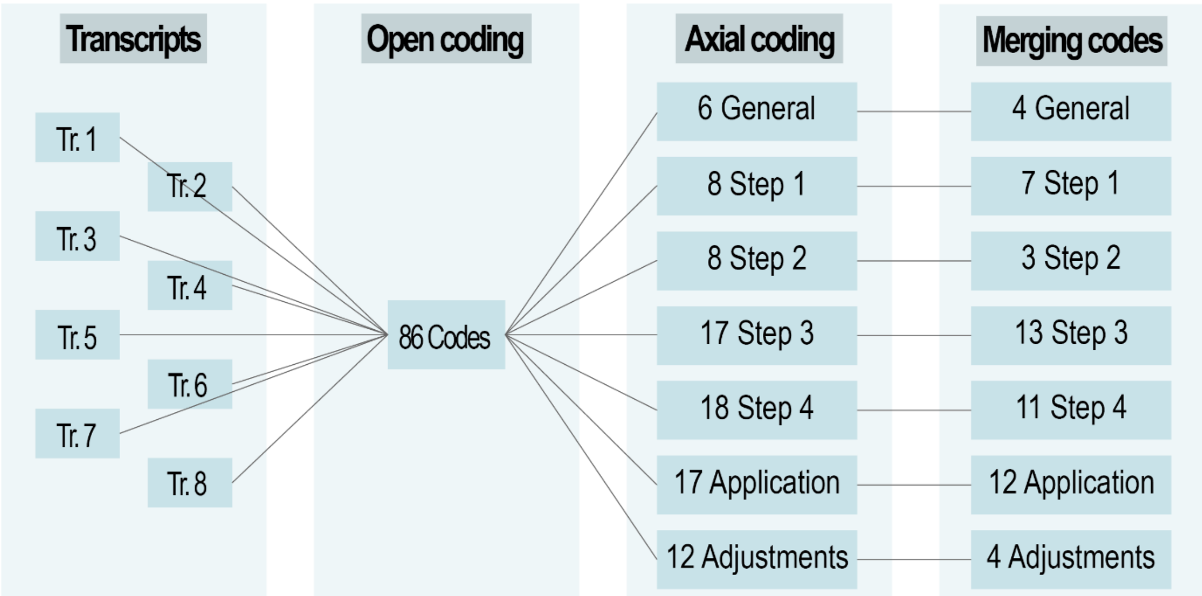

Figure 35; Process of analyzing the eight interview transcripts of the framework validation

Each step in Figure 35 is briefly explained, and the elaborated result of the feedback per code group can be found below. The first step in analyzing the interviews is to transcribe all interviews in Atlas.ti. After all interviews are transcribed, codes are created for all transcripts using open coding. A total of 86 codes were derived from the eight interviews. The next step is to apply the axial coding technique, in which the open codes are divided into code groups. Based on the feedback from the experts, seven groups were created using axial coding. These groups are:

- **General**: general feedback
- **Step 1**: feedback on the project characteristics
- **Step 2**: feedback on the circular material strategies
- **Step 3**: feedback on the circular economy criteria
- **Step 4**: feedback on the impact of strategies
- **Application**: feedback on the applicability of the framework
- **Adjustments**: feedback for general adjustments to the framework

The results of axial coding can be found in Appendix I. After axial coding, the next step is to merge duplicates and comparable codes per code group. In addition, codes that do not fit the purpose of this research or codes that are too vague to use in this research are deleted. The result of merging the codes is a final list of feedback per code group. The total feedback per code group is discussed in more detail below.

General feedback

General feedback provided by experts on the framework included the use of a case study to validate the framework in practice. By applying the framework in practice, the final ambiguities and errors become visible and can be improved and corrected. Furthermore, advice was given to link the framework with already existing tools, for example 'het ambitieweb' or 'het nieuwe normaal'. This avoids creating many separate instruments that end up not being used because of the high supply. The last general comment concerned the consideration of innovations related to the circular economy in the framework.

Feedback step 1 – project characteristics

The feedback on the project characteristics is to have a general interpretation of circularity, in order to give substance to the project characteristics. Therefore, the definition of circularity within this research should be added to the framework. Thereby, step 1 could be further elaborated on in general, as governments lack the knowledge to define suitable and feasible circular ambitions, visions and motives themselves. One expert suggested including specific targets for the ambitions and visions. Thereby, some experts noted a distinction between the defined project characteristics. Some project characteristics could be considered project boundaries, namely budget and willingness and acceptance. On the other hand, the project characteristics ambition, vision and circular motives could be considered as objectives or motivators. It was suggested that the project characteristics be changed to objective determination that distinguishes between the objectives and the boundaries of a project. Another expert suggested changing the project characteristics to clients characteristics. Finally, one expert wondered to what extend the willingness and acceptance could already be determined at the beginning of the building project.

Feedback step 2 – circular material strategies

In step 2, there was confusion about the extent to which circular material strategies can be combined or one strategy should be used, since in practice multiple strategies are combined within a building project. In this regard, the experts mentioned that there are more strategies than the four included in my framework. Therefore, it was suggested to explain why these four strategies are included for circular materials and to mention that there are more circular material strategies.

Feedback step 3 – circular economy criteria

Feedback was provided on Step 3 regarding the content of the step in general and the content of the CE- criteria. In general, it was mentioned that more knowledge about the circular economy is needed to apply and understand the CE criteria. For example, the average client is not familiar with the Building Circularity Index. Therefore, the percentage for reuse and demountability does not mean anything to them. Additional information should be given about the bci tool. Other measurement tools for reuse and demountability should also be considered. In addition, the framework distinguishes between quantitative and qualitative criteria, but experts suggest that the criteria can be both quantitative and qualitative. Thereby, suggestion should be given to implement the CE- criteria in the procurement process and ways to assess the CE- criteria in the procurement process. Finally, two experts see the CE- criteria as the final step of the framework, as since the final step of publishing the tender is also setting the criteria.

Regarding the content of the CE- criteria, it was expressed that avoiding toxic materials is difficult because some products are manufactured and accepted only with toxic materials. Regarding the reduce criteria, it was expressed that the reduction of materials in a building is usually not approached layer by layer, but the building in general. Thereby, reducing materials in the structural work should be the basis ambition level, since the greatest impact comes from reducing material use in the structural work. Finally, it was asked whether reused materials are accepted by users of newly built single-family homes.

Feedback step 4 – impacts of strategies

In connection with the feedback in step 3 to move the CE criteria to the last step, the feedback in step 4 is to move the impacts to an earlier step. However, experts have different opinions on which step the impacts should be moved to. Two experts agreed on leaving the impacts on the last step to use as a final check for their ambitions. Two experts suggested that the impacts should be placed between the circular material strategies and the CE- criteria, since the impacts are the basis for setting the CE- criteria. On the other hand, two experts suggested the impacts between the project characteristics and circular material strategies, as the impacts are an interpretation of the ambition. The last two experts did not mention any shift in the impacts.

In addition to locating the impacts, feedback is also provided on the content of the impacts. First, it is suggested that the impact information be expanded to better distinguish between impacts. For example, a five-point scale should be used instead of a three-point scale. Impacts per ambition level should be indicated. For the costs, all the costs associated with the strategies should be indicated, rather than not supported, as costs are an important factor for many parties. In addition, CO_2 emissions should include CO_2 storage. Finally, impacts should be justified and validated in practice and presented quantitatively.

Feedback on applicability

In addition to applying the framework to newly built single-family homes, the experts suggest that the framework could also be applicable to other sectors, such as apartments and utility buildings. In fact, it may be easier to apply to other sectors because the procurement process for newly built single-family homes is more complex and less common. In addition, the circular material strategies suggested in the framework are only a small part of the tender inquiry, more attention is given to the program of housing and related investments. The application of the framework to multiple sectors is an added value because it makes the application of the circular economy comparable across sectors. Thereby, the framework could besides the government also be applied by developers and clients. However, more context is needed to apply the framework, such as project characteristics. Now the framework is only applicable to experts, as a certain level of knowledge is required to understand and apply the framework. Overall, it is concluded that the applicability of the framework becomes clear only when the framework is applied in practice.

Feedback for adjustments

In addition to the suggestions for adjustments given for each step of the framework, additional suggestions for adjustments are given. The first suggestion is to explain all the concepts of the framework. Thereby, it is suggested to translate the framework into Dutch and to change the design a bit, since not everything is easy to read. Finally, it would be a positive contribution to make the framework digital and interactive. The framework could be made interactive by allowing people to click on components to get additional information or by creating a digital roadmap of the framework.

7.2 Improvements framework

In general, the setup of the framework is good based on the input from the expert interviews. The framework is clear and structured, inviting to read and provides concrete and applicable information. The four different steps are clearly recognizable and serve as a roadmap for integrating the circular economy into the procurement process. Thereby, the circular economy criteria provide clear guidelines for circular criteria that can be applied in the procurement process. The combination of the roadmap with the circular economy criteria distinguishes this framework from other frameworks such as ‘het nieuwe normaal’, the EU GPP criteria and the Ambitieweb.

However, based on the interviews and interview analysis, several improvements could be made to the framework. The first improvement is to swap the circular economy criteria (step 3) and the impacts of strategies (step 4) in the framework. This means that the impacts of the strategies becomes the third step and the circular economy criteria becomes the fourth and final step. The steps are swapped to increase the applicability of the framework. In the old situation, the project characteristics determined the circular material strategy and thus the circular economy criteria. Impacts were used as additional information to see if the impact of a strategy matched the defined project characteristics. In this way, the order of steps provided governments with insight into circular options and the practicality and value of those options. In the new setup, the link between the project characteristics and the strategies ultimately determines the impact of the strategies, and based on the impact of the strategies, a suitable ambition level for the circular economy criteria can be determined. Now, the impact of the strategies are used as reasoning for the ambition level of the circular economy criteria. In this way, the order of steps provides practical information for governments to apply the circular economy criteria in public procurement. Thus, by changing the order of the steps, the framework shifts from providing knowledge to being applicable in practice.

In step 4, the costs were further examined based on the knowledge within Alba Concepts. It can be said that the cost of a demountable construction are higher compared to a traditional construction. This increase in cost can be explained by the higher material costs for demountable constructions, since a large part of demountable constructions is made of wood. On the other hand, demountable constructions are made of prefabricated elements. Prefabricated elements also have higher construction costs. Thereby, there are additional costs for the design of the demountable constructions. However, this is only considering the investments costs. If the residual value of demountable constructions is taken into account, the price becomes lower. The cost of non-toxic materials and their reduction is still undetermined based on current knowledge in the literature and knowledge within Alba Concepts.

A third improvement is that the distinction between quantitative and qualitative criteria has been removed, as strategies can be both quantitative and qualitative based on expert suggestions.

As fourth improvement the layout of the framework has been changed somewhat in terms of color scheme and structure to improve the readability of the framework. In addition, the steps within the framework and the content are further elaborated to make it clearer.

Finally, an additional page explaining the concepts used in the framework has been added to the framework. The definition of circular economy and circular economy in the building sector is also added to ensure that users have the same interpretation of circular economy. The Building Circularity Tool is also briefly elaborated and suggestions for other measurement tools are made.

The final framework with all improvements is shown in Figure 36 and Figure 37 on the next page. Any feedback from the interviews that could not be included in the improvement of the framework due to prioritizations will be included in the future recommendations of this study. The future recommendations are mentioned in Section 8.4.

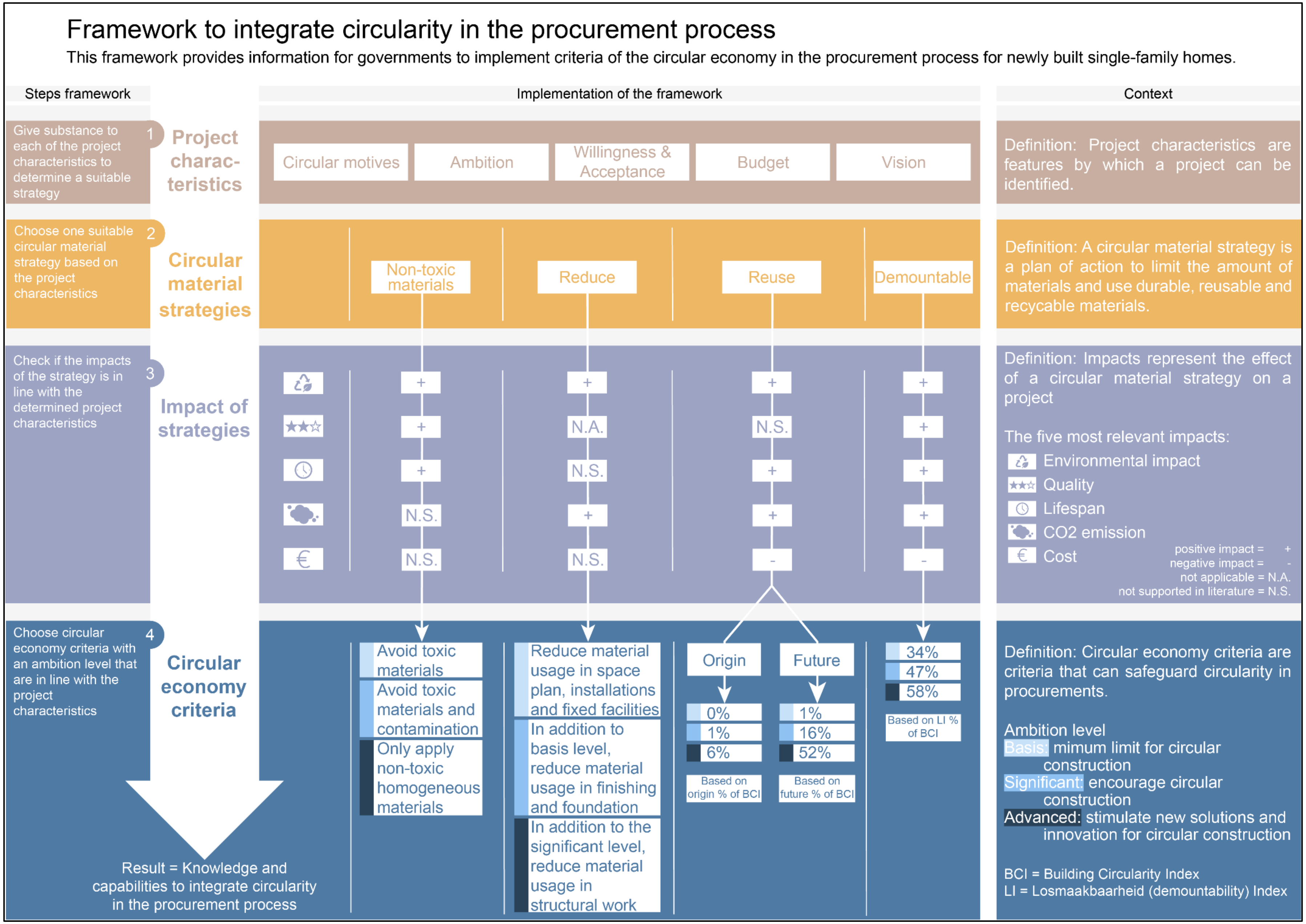

Figure 36; Framework final design evaluation phase – page 1

Framework Definitions

+ Circular economy

Circular economy

“A circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the end-of-life concept with restoration, shift towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse and return to the biosphere, and aims for the elimination of waste through the superior design of materials, products, systems and business models” (EMF & McKinsey & Company, 2014).

Circular construction economy

“the development, use and reuse of buildings, area’s and infrastructure, without avoidable depletion of natural resources, pollution of the environment or negatively impacting ecosystems. Construction which is economically responsible and contributes to wellbeing of humans and animals, now and in the future” (Rijksoverheid, 2018).

1 Project characteristics

Circular motives
The reasons why a person or company want to achieve certain circular goals. E.g. image, finance, residual value, material scarcity, impact on climate and social motives.

Ambition
Striving for specific goals within a building project.

Willingness & Acceptance
The benevolence of the client, contractor and consumer to implement and use circular measures.

Budget
The total financial resources available to finance the building project, from initiative to realization.

Vision
Your organization's view of the (future) world and the role of your organization in that world.

2 Circular material strategies

Non-toxic materials
Replacing toxic and hazardous materials with regenerative sources.

Contamination
The application, combination or mixing of different materials and resources in a way that makes reuse difficult or impossible.

Reduce
Reducing the use of raw materials, water and energy and reducing the amount of waste generated.

Toxic materials
Materials that can be poisonous or cause health effects.

Reuse
The reuse of products or components for the same function.

Origin reuse
The percentage of materials that is reused from another project, thus secondary materials.

Future reuse
The percentage of materials that can be reused at another building after the end of life in the current building.

Demountable
Designing products or buildings of multiple parts that can be easily separated and reassembled.

3 Impacts of strategies

Environmental impact
The influence of a building on the natural environment and ecosystems of the planet, think of pollution, deforestation, and so on.

Quality
The extent to which a building, and products within a building, meet established standards.

Lifespan
The period of time in which a product or building is used, from purchase till disposal.

CO2 emission
The total amount of CO2 produced during the realization of a building.

Costs
The total financial resources needed to finance the building, from initiation till realization.

4 Circular economy criteria

Criteria types in which you can gaurantee circularity:

- Suitability requirements
- Selection criteria
- Award criteria
- Minimum requirements
- Contract provision

The Building Circularity Index is a measuring method to determine the degree of circularity and the circular potential of real estate objects in an objective and uniform manner. To determine the BCI, the origin of materials, the future scenario of materials and the demountability of materials and elements are considered. More information can be found at: bcigebouw.nl

Other measuring tools
- GPR materiaal
- Building Circularity tool
- Circularity Indicator
- MPG gebouw
- BREEAM, etc.

Figure 37; Framework final design evalution phase - page 2

7.3 Conclusion evaluation phase

In the evaluation phase, the framework is validated using expert interviews. Eight experts were interviewed. Of these four experts have experience as contracting authority and the other four experts have experience as both contracting authority and contractor. In general, the experts provided positive feedback on the framework. The framework is clear and structured, inviting to read and provides concrete and applicable information. The four different steps serve as a roadmap for integrating the circular economy into the procurement process and the circular economy criteria provide clear guidelines for circular criteria that can be applied in the procurement process. In addition, seven of the eight experts agreed that the framework is applicable to the procurement process of newly built single-family homes and seven experts would apply the framework themselves. The two experts who disagreed mentioned that the framework can only be applied by experts and that the framework is only applicable to a small part of their procurement process.

In addition to the positive feedback, suggestions were also made to improve the framework. The most important feedback was related to conducting a case study to verify the framework and its content, changing the order of steps, elaborating the project characteristics in more detail and combining the framework with existing frameworks. In addition, some general suggestions were made to elaborate in more detail the content of the steps and the concepts used in the framework. Thereby, it was mentioned that the framework could only be used by experts due to the high level of knowledge required to apply the framework. On the other hand, the framework could be applied to building types other than newly built single-family homes.

The framework is improved based on the experts input from the interviews. The biggest improvement was changing the order of steps, in which the circular economy criteria (step 3) is swapped with the impacts of strategies (step 4). The steps are swapped to increase the applicability of the framework. By changing the order of the steps, the framework shifts from providing knowledge to being applicable in practice. Any feedback from the interviews that could not be included in the improvement of the framework due to prioritizations will be considered in the future recommendations of this research. The result of the evaluation phase is a validated framework that is supported by the market and governments.

8. Conclusion

This chapter contains the general conclusions of this research by answering the main research question. In addition, the scientific and societal relevance and provides recommendations for further research are also described.

8.1 Answering the research question

A circular economy can realize a transition by reducing the consumption of raw materials and the production of waste, thus counteracting climate change, the loss of biodiversity and the depletion of the earth.
Public procurement is an important tool for governments to stimulate and realize a circular transition. To do so, governments must have clear ambitions and formulate clear criteria for the circular economy. However, governments do not have sufficient knowledge about circular economy and circular criteria that can be applied in the procurement process. They need a tool to help them identify circular options and determine the practicality and value of these options. Therefore, this research has provide a tool and set boundaries for the circular economy by creating a framework for governments to realize a circular transition. The framework proposes strategies and CE- criteria to integrate the circular economy into public procurement. The framework focusses on newly built single-family homes, as one million additional homes are needed by 2030, 70 percent of which are for single-family homes.
The main research question answered is:

How can a framework be designed and validated for governments to improve the capabilities and knowledge to achieve a circular transition for newly built single-family homes with public procurement?

A design science research approach (DSR) is used to answer the main research question. The DSR approach used in this research consists of four steps: exploration, synthesis, creation, and evaluation.

In the exploration phase information is gathered through a literature study and expert interviews. In the literature study boundaries are created for the circular economy concept and the procurement process. In addition, a list of 3 project goals, 29 circular material strategies, and 5 impacts are determined to be considered for the framework. The expert interviews are used to validate the project goals, circular material strategies, and impacts of the literature study. Based on the expert interviews, the project goals are transformed into project characteristics. In addition to the results of the literature study, 15 additional project characteristics, 3 additional circular materials strategies and 20 additional impacts are identified to consider for the framework. The result of the exploration phase is a list of 18 project characteristics, 32 circular material strategies, and 25 impacts to be considered for the framework based on literature study and expert interviews.

The synthesize phase is used to translate the results of the exploration phase into meaningful project characteristics, circular material strategies, CE- criteria, and impacts for the framework. Using the Fuzzy Delphi Method 5 project characteristics, 5 circular material strategies and 5 impacts are considered for the framework. Those are:

- The project characteristics: Circular motives, ambition, willingness & acceptance, vision and budget.
- The circular materials strategies: Demountable, material efficiency, reuse, non-toxic materials and reduce.
- The impacts: Environmental impact, quality, lifespan, CO_2 emission and costs.

The next step is to determine the CE-criteria for each circular material strategy. The CE-criteria are divided into the three ambition levels basis, significant and advanced. For the determination of the CE-criteria, the circular material strategy material efficiency is combined with the circular material strategy reduce, since these two circular material strategies are very similar. The result of determining the CE-criteria is a list of CE-criteria, divided into three ambition levels, that can be applied to the circular material strategies of reuse, demountable, reduce and non-toxic materials. In which reuse and demountable are classified as quantitative criteria and reduce and non-toxic materials are classified as qualitative criteria. The final step is to determine the impact of each circular material strategy. Each impact is classified as positive, negative, not applicable, or not supported in relation to the circular material strategy. The result of determining the impact of each circular material strategies is an overview that provides information on the impact of cost, quality, CO_2 emissions, lifespan and environmental impact for the circular material strategies of reuse, demountable, reduce and non-toxic materials. The overall result of the synthesize phase is a list of 5 project characteristics, 4 circular material strategies, and 5 impacts to consider for the framework. In addition, the CE-criteria for each circular material strategy are defined in three ambition levels and the impacts of each circular strategy are given.

The creation phase is used to create the framework with the results of the synthesize phase. The content of the framework created in the synthesize phase and the sketches resulted in an infographic in A4 format. The framework presents the project characteristics, circular material strategies, circular economy criteria, and impact of strategies in the order to follow. Following the steps in this order will provide governments with insight into circular options and the practicality and value of those options. Furthermore, it explains each step and provides additional information on how to apply each step. The result of the creation phase is a framework in the form of an infographic that helps governments identify circular options and determine the practicality and value of those options.

In the evaluation phase, the framework is validated using expert interviews. In general, the experts provided positive feedback on the framework. The framework is clear and structured, inviting to read and provides concrete and applicable information. The four different steps serve as a roadmap for integrating the circular economy into the procurement process and the circular economy criteria provide clear guidelines for circular criteria that can be applied in the procurement process. In addition, seven of the eight experts agreed that the framework is applicable to the procurement process of newly built single-family homes and seven experts would apply the framework themselves. The two experts who disagreed mentioned that the framework can only be applied by experts and that the framework is only applicable to a small part of their procurement process.
In addition to the positive feedback, suggestions were also made to improve the framework. The most important feedback was related to conducting a case study to verify the framework and its content, changing the order of the steps, elaborating the project characteristics in more detail and combining the framework with existing frameworks. In addition, some

general suggestions were made to elaborate in more detail the content of the steps and the concepts used in the framework. Thereby, it was mentioned that the framework can only be used by experts due to the high level of knowledge required to apply the framework. On the other hand, the framework could be applied to building types other than newly built single-family homes.
The framework is improved based on the experts input from the interviews. The biggest improvement was changing the order of steps, in which the circular economy criteria (step 3) is swapped with the impacts of strategies (step 4). The steps are swapped to increase the applicability of the framework. By changing the order of the steps, the framework shifts from providing knowledge to being applicable in practice. Any feedback from the interviews that could not be incorporated into the improvement of the framework due to prioritizations will be considered in the future recommendations of this research. The result of the evaluation phase is a validated framework that is supported by the market and governments.

By following the four steps of the Design Science Research methodology, a framework is designed and validated that improves the capabilities and knowledge of governments to achieve a circular transition for newly built single-family homes with public procurement.

8.2 Scientific contribution

The government lacks knowledge to implement the circular economy in the procurement process. The framework developed in this research provides a contribution to this knowledge gap by providing a roadmap for implementing the circular economy in procurement. A roadmap for implementing the circular economy in procurement in itself is not new, but a roadmap combined with concrete CE-criteria and impacts to consider had not been seen before. The framework provides in four steps insight into the information needed to choose a circular option, the circular options, the impact of a circular option, and how to implement the circular option using CE-criteria. In this framework, those steps are described as the project characteristics, circular materials strategies, impacts and CE-criteria. In this research, the link between the four steps is considered. It is explained why and what project characteristics are needed to determine a circular material strategy. Insight are provided on the four major circular materials strategies and how these circular material strategies impact the five major impact categories. The impact of a circular material strategy provides insight into whether the circular material strategy is consistent with the previously established project characteristics. Knowing that the circular material strategy and impact are consistent with the determined project characteristics, a suitable CE-criteria can be selected with an ambition level that is in line with the project characteristics. Using these four steps, this research provides insight into the steps to consider when determining the CE-criteria for the procurement process. In this way, the framework contributes to enhancing the capacity and knowledge of governments to achieve a circular transition for newly built single-family homes with public procurements.
In addition, this research contributes by providing insights into the project characteristics, circular material strategies and impacts to consider for a circular transition with procurement. Thereby, the relevance of the identified project characteristics, circular material strategies, and impacts is determined using the Fuzzy Delphi Method and expert opinions. This contributes to providing insight into which project characteristics, circular material strategies, and impacts are considered most relevant for a circular transition.

8.3 Societal contribution

Several studies highlight the lack of knowledge on the part of the government as a problem in implementing the circular economy in the procurement process. Several manuals on integrating circular economy in the procurement process can be found in the literature. However, these manuals are often guidelines that lack specific information on how to establish circular criteria. As a result, governments still do not know how to incorporate realistic circular criteria into their tenders. In addition to procurement manuals, there are also tools for creating criteria. However, these tools are not specific to residential buildings or, in particular, single-family homes. As a result, the tools do not provide insight into the practicality and value of the circular criteria. The lack of circular criteria for single-family homes, combined with the lack of knowledge among governments on how to implement the circular economy in the procurement process, leads to the demand for a circular framework for governments to implement a circular transition with procurement. The framework created in this research contributes to this knowledge gap by presenting circular options with the corresponding CE-criteria and providing insight into the practicality and value of these circular options for newly built single-family homes.

In addition to governments, the framework could also be applied by other parties seeking to improve their knowledge and capabilities to achieve a circular transition through procurement. Other parties that could use the framework include housing corporations, contractors, developers, and project managers. In addition, the framework could be applied in other sectors beside newly built single-family homes. For example, other sectors where the framework could be applied include multifamily housing and the utility sector.
Overall, the framework can be used to improve the capabilities and knowledge to achieve a circular transition in public procurement. In this way, the framework contributes to the Dutch national goals to have a fifty percent reduction of primary raw materials by 2030 and achieving a 100 percent circular economy by 2050.

8.4 Recommendations

Based on the results of this research recommendations for further research can be made. First of all, this research does not include the elaboration of the project characteristics. Since this step is the basis for the next step, it is important to give substance to the project characteristics in the right way. In doing so, the content of the project characteristics should be further elaborated. Thereby, the relationship between the individual steps is not elaborated in detail. This is especially true for the project characteristics related to the circular material strategies. Further research could explore how to define the project characteristics and how the project characteristics relate to the choice of a circular material strategy. For the other steps within the framework, a detailed elaboration of the relationship between the step and their implementation could also be undertaken. In addition, the steps in the framework are examined individually. This means that the CE-criteria and impacts of each circular material strategy are defined individually. Further research could explore how the circular material strategies can be combined and the impact of this combination on the CE-criteria and impacts.
The dataset for the circular material strategy reuse in this research was small and scattered. For future research, it is preferred to have more and less scattered data to create a proper boxplot. In addition, the determination of the CE-criteria for reuse and demountability could be approached differently. In this research, the CE-criteria are based on current data.

However, the CE-criteria could also be a prediction to further stimulate the circular economy. Thereby, the reuse and demountability CE-criteria could be presented as a range instead of a value, since a value gives an apparent accuracy.
The results of the framework are a snapshot of the current situation in the construction sector. However, the construction sector is constantly changing and evolving over time. Therefore, the framework needs to be updated from time to time to keep pace with developments in the construction sector. The timespan for this update will depend on the developments within the market, but it is expected that the framework will be reviewed for relevance at least every six months and updated as necessary.

Suggestions for improvement were also made during the expert interviews. Based on those suggestions, additional recommendations are made. First and foremost, the framework and the CE-criteria and impact of the framework should be validated through a case study. By applying the framework in practice, the last ambiguities and errors will become visible and can be improved and corrected. Furthermore, the framework should be linked with already existing tools, e.g. 'het ambitieweb' or 'het nieuwe normaal'. This avoids creating many separate instruments that end up not being used because of the large supply. Furthermore, it would be a positive contribution to make the framework digital and interactive. The framework could be made interactive by allowing people to click on components to get additional information or by creating a digital roadmap of the framework.
Considering the CE-criteria, suggestions on how to implement the CE-criteria in the procurement process and ways to assess the CE-criteria in the procurement process could be included. With regard to the impacts, the scale of the impacts can be expended from a three-point to a five-point scale. Thereby, it would be complementary to determine the impact per ambition level of the CE-criteria and present the impacts quantitatively.
Regarding the application of the framework, it could be applied by other sectors and users. However, more context is needed to apply the framework. Currently, the framework is only applicable to experts, as a certain level of knowledge is required to understand and apply the framework.

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A. Appendix – Literature study circular strategies

Reference	Strategy
Wegwijzer Circulair inkopen (n.d.)	Design for durability
	Design for standardization
	Design for repairability
	Design for flexibility
	Design for disassembly
Rahla, Mateus & Braganca (2021)	Recycled or recovered content
	Recyclability
	Reusability
	Ease of deconstruction
	Maintainability
	Durability
	Energy recoverability
	Upcycling potential
	Biodegradability
	R0 Refuse
	R1 Rethink
	R2 Reduce
	R3 Reuse
	R4 Repair
	R5 Refurbish
	R6 Remanufacture
	R7 Repurpose
	R8 Recycle
	R9 Recover
Goodwin Brown, et al. (2021)	Rain water usage
	Reuse water
	Water efficiency
	Biobased
	Ruese
	Non-toxic
	Non-critical materials
	Efficient use in production process
	Renewable energy
	Energy efficiency
	Electrification
	Regeneration and maintaining nature
	Design out waste
	Refurbish
	Remanufacture
	Reuse (or shared)
	stretching the lifetime of biological products through management, preservation and conservation Recycling
Bocken, et al. (2016)	Design for attachement and trust

	Design for reliability and durability
	Design for ease of maintenance and repair
	Design for upgradability and adaptability
	Design for standardization and compatibility
	Design for dis- and reassembly
	Design for technological cycle
	Design for biological cycle
	Design for dis- and reassembly
Circle Economy (2021)	Sharing/rental models
	Material lightweighting
	Multifunctional products/buildings
	Energy efficiency
	Digitisation
	Durable material use
	Modular design
	Design for disassembly
	repair
	remanufacturing
	refurbishing
	renovation
	remodelling
	Regenerative material use
	Renewable energy
	Regenerative agriculture
	Design for recyclability
	Design for disassembly
	Recycling
	Biomass waste-to-energy
Kubbinga, et al. (2018)	Accountability and substantiation of building volume
	Design for flexibility
	Design for resilience
	Design reassembly
	Checks and balances on evironmental impact (prerequisite)
	Maximise amount of reused materials
	Maximise amount of reused components
	Maximise amount of reused elements
	Future use
	Maximise amount of renewable materials
	Minimize use of toxic/scarce/critical materials
	building design contains and uses minimal amount of energy
	Energy matching (space and time)
	Minimise environmental impact on energy source
	building design contains and uses minimal amount of water
	Grey water system
	Rainwater collection system
	Resource/nutrient recovery
	Building design caus- es minimal loss of biodiversity through embodied and use- phase ecosystem impacts

	Ecosystem elements provide biodiversity and building func- tions
	Building design strengthens local bio- diversity, especially for rare species
	Building design embodies no or minimal toxicity
	Prevent pollution during the construction, use-phase and deconstruction
Knowledge Hub (n.d.)	Bio-based
	Reusable
	Non-toxic
	Material efficiency
	Non-critical materials
	Replace fresh water with less impactful alternatives (rainwater, fogwater, seawater)
	Water efficiency measures
	Electrification (fossil fuel to electric)
	Energy efficiency measures
	Renewable eneryg, fuels (solar, wind, biomass)
	Upgrade
	Repair
	Maintenance
	Give products and parts another life after their end-of-use
	Ensure that biological products are properly managed and preserved
	Reuse
	Repurpose
	Recycle
	Generating energy from waste
	Processing waste into fuel
	Recovery and reuse of waste energy
	Design for minimal waste
	Design for resource efficiency
	Design for bio-degradability
	Design for disassembly
	Design for modularity
	Design for recycling
	Design for recycling (mono-materials)
	Design for repair
	Design for reuse
	Design for physical durability
	Design for product attachment, emotional durability
Potting, et al. (2017)	Refuse
	Rethink
	Reduce
	Re-use
	Repair
	Refurbish
	Remanufacture
	Repurpose

	Recycle Recover
Circle Economy (2020)	Long-life products with durable materials Material use efficiency Regenerative resources No toxic No fossil fuels Reuse
Lieder and Rashid (2016)	Reduce Reuse Recycle
Kirchherr, et al. (2017)	Reduce Reuse Recycle Recover
Li (2011)	Rethink Reduce Reuse Recycle Repair
Yan & Feng (2014)	Reduce Reuse Recycle Recover Remanufacture Redesign
Xing, et al. (2017)	Reduce Reuse Recycle Recover Rethink Resilient Regulate
Maia, et al. (2019)	Rethink Redesign Reduce Reuse Return Repair Recycle/recovery Refuse
van Buren, et al. (2016)	Refuse Reduce Reuse Repair Refurbish Remanufacture Repurpose

	Recycle Recover
Ghisellini, et al. (2016)	Reduction Reuse Recycle Appropriate design Reclassification of materials into 'technical' and 'nutrients' Renewability
Gerding, et al. (2021)	Reduce Prevention Reduction Reuse Repair & maintenance Reuse & redistribution Refurbishment & remanufacturing Recycling Cascading & repurpose Organic feedstock
Amory (2017)	Refuse/Reduce input Maintain/prolong use Reuse/redistribute Refurbish/remanufacture Recover output Design for light-weighting/miniaturising Design out waste Design for eliminating yield loses Design to fit Design for sharing Design for longevity/reliability/durability Design for repair/maintenance Design for reuse/resell Design for reassemble/redistribute Design for PSS (product-service-system)/leasing Design for refurbish/restoration Design for remanufacture/renovation/upgradability Design for modularity/adaptability Design for disassembly/reversibilty/reverse logistics Design for resource conservation Reuse materials Optimise manufacture process Durable materials Recyclable/renewable materials Materials for recycling infrastructure/separability
Elia, et al. (2017)	Reducing input and use of natural resources Increasing share of renewable and recyclable resources Reducing emmissions Reducing valuable material losses Increasing the value durability of products

	Recover & Recycle
	Reuse
Alivojvodic, et al. (2020)	Design for attachment and trust
	Design for durability
	Design for standardization and compatibility
	Design for ease of maintenance and repair
	Design for adaptability and upgradability
	Design for di- and reassembly
	Reduce or eliminate the need for materials and packaging
	Use recycled/renewable materials and remanufactured components
	Choose alternative, less resource-intensive, and nontoxic materials
	Design to eliminate or minimize waste during production processes
	Design for durability, modularity, repair/upgradeability, and efficiency while in use
	Design to avoid single use and obsolescence
	Deploy technologies to extend product use and enable recovery (e.g. for asset monitoring)
	Design for end of use disassembly, refurbishment and remanufacture (upcycling)
	Choose materials that are recyclable or compostable at end of use
Gerding (2018)	Design for resource efficiency
	Design for long-life components/buildings
	Design for component/building life extension
	Design for technical cycles
	Design for biological cycles
	Reduce
	Reuse
	Prevention & reduction
	Repair & maintenance
	Reuse & Redistribution
	Refurbishment & remanufacturing
	Recycling
	Cascading & repurposing
	Organic feedstock
	Reduce component & material imput & output
	Retain component value
	Retain material value
van Stijn & Gruis (2019)	Material reduction
	Energy reduction
	Design for attachment
	Design for long-life
	Design for standardisation and compatiblity
	Design for easy maintenance and repair
	Design for upgrades and adjustments

	Design for disassembly Design for recycling
Ingemarsdotter, et al. (2019)	Efficiency in use Increased utilization Product lifetime extension Reuse Remanufacturing Recycling Material efficiency
Ellen MacArthur foundation (2013)	Share Maintain/prolong Reuse/redistribute Refurbish/remanufacture Recycle
Bakker, et al. (2014)	Material efficiency Longer product life Product repair Product refurbishment Product remanufacturing Product/material recycling
Balkenende, et al. (2017)	Durability Upgrading Adapting Repair Refurbishment Parts harvesting Remanufacturing Recycling
Moreno, et al. (2016)	Design for resource conservation Design for multiple cycles Design for long life use of products Design for system change
den Hollander, et al. (2017)	Design for long use Design for extended use Design for recovery Design for recycling
Cheshire (2016)	Retain Refit Refurbish Reclaim/reuse Remanufacture Recycle/compost Building layers Designing out waste Design for adaptability Design for disassembly Selecting materials
Verberne (2016)	Design for disassembly

	Design for adaptability Refuse Reuse Repair Refurbish Remanufacture Repurpose Recycle Energy recovery Incineration Landfill

B. Appendix – Circular material and design strategies

Loops	Category	Strategy	Definition used in this research
Regenerating	Material strategy	Rain/grey water usage	Reusing water and replacing freshwater use with rainwater, fog water, seawater, etc. (Knowledge Hub, n.d.)
		Biobased materials	Using bio-based materials such as bioplastics, mushroom-based materials, etc. (Knowledge Hub, n.d.)
		Non-toxic materials	Replace toxic and hazardous materials with regenerative sources (Knowledge Hub, n.d.)(Kubbinga, et al., 2018)(Circle Economy, 2020)
		Non-critical materials	Using materials that are not considered critical (Knowledge Hub, n.d.)
		Non-fossil fuels	Replace fossil fuels with regenerative sources (Circle Economy, 2020)
		Renewable energy	Using renewable energy like solar, wind, etc. or renewable fuels like biomass, etc. (Knowledge Hub, n.d.)
		Electrification	Converting fossil fuel based operations to electric (Knowledge Hub, n.d.)
	Design strategy	Df resource conservation	A preventative approach in which products are designed with minimal resources and resources are reused through cascading hierarchical levels by designing easy end-of-life cleaning, collection and transport (Moreno, et al., 2016)(Amory, 2017)
Narrowing	Material strategy	Refuse	Preventing the use of raw materials, water and energy (Amory, 2017)(van Buren, et al., 2016)
		Reduce	Reduce the use of raw materials, water and energy and reducing the amount of waste generated (van Buren, et al., 2016)(Xing, et al., 2017)(Yan & Feng, 2014)(Ghisellini, et al., 2016)
		Rethink	Reconsider the options regarding material, energy and water usage and consider the impact on the environment (Xing, et al., 2017)
		Redesign	To design something again or differently through innovative techniques to make more sustainable (Yan & Feng, 2014)
		Water efficiency	Optimize water usage by doing more with less or using less water (Garding, 2018)(Knowledge Hub, n.d.)
		Material efficiency	Optimize material usage by doing more with less or using less materials and fewer resources (Garding, 2018)(Knowledge Hub, n.d.)
		Energy efficiency	Optimize energy usage by doing more with less or using less energy (Garding, 2018)(Knowledge Hub, n.d.)
	Design strategy	Design out waste	Designing to reduce waste (Knowledge Hub, n.d.)(Goodwin Brown, et al., 2021)
		Df resource efficiency	Designing products so they use as little materials, water and energy as possible (Knowledge Hub, n.d.)
		Df light-weight /miniaturizing	Design to save material through weight-saving strategies and size reduction strategies (Amory, 2017).
		Df eliminating yield loses	Design strategies to reduce and eliminate resource losses (Amory, 2017)
		Design to fit	Designing on demand or on availability as a way of optimizing systems rather than component (Amory, 2017)
		Df sharing	Design strategies to increase the utility of the object of design, by more intense use (by multiple users) and flexible functions (Amory, 2017).
Slowing	Material strategy	Retain	Keeping the existing product
		Reuse	The reuse of products or components for the same function (Rahla, Mateus & Braganca, 2021)(Potting, et al., 2017)(Yan & Feng, 20141)(Gerding, 2018)(Ghisellini, et al., 2016)
		Repair	Fix a defective product so it can be used with its original function (Potting, et al., 2017)(Rahla, Mateus & Braganca, 2021)
		Refurbish	Renovate an outdated product to provide an appropriate physical condition (Rahla, Mateus & Braganca, 2021)(Potting, et al., 2017)(Gerding, 2018)
		Remanufacture	Make a new product by using parts of a discarded product with the same function (Rahla, Mateus & Braganca, 2021)(Potting, et al., 2017)(van Buren, et al., 2016)
		Resilient	The ability of materials and components to withstand difficult conditions
		Durable	The resistance of materials and components to deterioration over time while maintaining the minimal requirements (Rahla, et al., 2021)(Amory, 2017)
		Maintain	Prolong use of materials and components through maintenance (Rahla, et al., 2021)
		Upgrade	Raising products to a higher standard by adding or replacing components

		Multifunctional products/building	Fulfilling multiple functions within one product/building
	Design strategy	Df attachment and trust	The design of timeless aesthetics, pleasure experience and meaningful design (Monero, et al., 2016)
		Df long-life, durability & reliability	Designing to last and to ensure longer use of products and components with limited need of maintenance and materials (Amory, 2017)(Moreno, et al., 2016)(Bocken, et al., 2016)(Wegwijzer Circulair inkopen, n.d.)(Gerding, 2018)(Knowledge Hub, n.d.)
		Df maintenance & repair	Design for easy restoring a product after decay or damage and maintenance to retain the functional capabilities of a product and extend the lifetime (Amory, 2017)(Bocken, et al., 2016)
		Df upgradability & adaptability	Design for the ability to use products under changing conditions by improving the product (upgradability) and designing products that could be converted to other uses (adaptability)(Bocken, et al., 2016)(Cheshire, 2016)
		Df standardization & compatibility	Designing products with components that fit other products as well (Bocken, et al., 2016)
		Df dis- & reassembly	Designing products of multiple parts that can be easily separated and reassembled (Knowledge Hub, n.d.)(Bocken, et al., 2016)(Wegwijzer Circulair inkopen, n.d.)(Cheshire, 2016)
		Df modularity	Designing for standardization in which parts of products can be easily used for changing conditions, changing uses or reused elsewhere (Amory, 2017)(Knowledge Hub, n.d.)
		Df flexibility	Design for easy changes (Wegwijzer Circulair inkopen, n.d.)
		Df reuse	Designing the product to be reused for the same or different purposes (Knowledge Hub, n.d.)
		Df remanufacture	Designing products for disassembly and recovery and reusing the components in new products (Amory, 2017)
		Df refurbish & restoration	Designing products for anticipation of replacing or repairing major components and making cosmetics changes to update the appearance (Amory, 2017)
Closing	Material strategy	Repurpose	Make a new product by using parts of a discarded product with a different function (Rahla, Mateus & Braganca, 2021)(Potting, et al., 2017)(van Buren, et al., 2016)
		Recycle	The reprocessing of waste materials into new products or materials with the same, higher (upcycling) or lower (downcycling) qualities for original or other functions (Ghisellini, et al., 2016)(Rahla, Mateus & Braganca, 2021)(Potting, et al., 2017)(Gerding, 2018)
		Recover	The incineration of non-recyclable materials with retrieving heat, electricity or fuel (Rahla, Mateus & Braganca, 2021)(Potting, et al., 2017)(van Buren, et al., 2016)
		Renewable	The usage of renewable resources, such as biobased materials and renewable energy (Ghisellini, et al., 2016)(Elia, et al., 2017)
		Biodegradable	The disintegration of products into the natural environment without ecological damage (Rahla, Mateus & Braganca, 2021)
	Design strategy	Df technological cycle	Designing products so that the materials (technical nutrients) can be continuously and safely recycled into new materials or products (Bocken, et al., 2016)
		Df biological cycle	Designing products to be capable of being degraded by biological activity (Bocken, et al., 2016)
		Df recyclability	Designing products to be easily, efficiently and effectively looped back into the economic system (Knowledge Hub, n.d)(den Hollander, et al., 2017)

C. Appendix – Interview questions exploration phase

English questions

Part 1: Introduction
Every interview will start with an introduction. In the introduction the researcher will introduce the research and the aim of the interview.

Part 2: Warm-up
1. What is your function within the company?
2. How many years of experience do you have with working with circularity?
3. In what way does circularity play a role in your work?

Part 3: Main body

A circular strategy is defined as a plan of action designed to achieve circular goals. With respect to circular buildings this means how circularity could be implemented. Based on this definition:
4. What are circular material strategies for new build single-family homes projects?

Building new single-family homes is done by using a project. A characteristic of a project is that it concerns a unique situation. This means that every project for new-single family homes differs in their project goals.
The project results determines whether a circular strategy is suitable for a project.
5. You named several circular material strategies, which project goals influence the implementation of these circular strategies?

On the other hand when a circular strategy is implemented it has an impact on the project (project impacts).
Impacts provide insight into the impact of a circular strategy on a project.
6. You named several circular material strategies, to what impacts does these circular strategies lead?

Within this research different circular strategies, project goals and impacts have been determined based on a literature study. The question to you is whether you agree with the results from the literature study.

Show the list of circular material strategies.
7. Do you agree with the list of circular material strategies?
8. Are there strategies missing that should be added?

Show the list of project results.
9. Do you agree with the list of project goals?
10. Are there project goals missing that should be added?

Show the list of impacts.

11. Do you agree with the list of impacts
12. Are there impacts missing?

Part 4: Cool-off

The aim of this research is to develop a framework that can be used to implement circularity with the aid of procurement.

13. What are according to you the success factors of the framework?
14. What are according to you the failure factors of the framework?
15. What would be the optimal end results of my research for you?

Part 5: Closure

16. Is there anything that remained undiscussed during the interview that could be important for my research?

Thank you for participating in my research.

Dutch questions

Deel 1: Introductie

Elk interview zal starten met een introductie. In de introductie introduceert de onderzoeker het onderzoek en het doel van de interviews.

Deel 2: Warm-up

1. Wat is uw functie binnen het bedrijf?
2. Hoeveel jaar ervaring heeft u met het werken met circulariteit?
3. Op welke manier speelt circulariteit een rol in uw werk?

Deel 3: Main body

Een circulaire strategie is gedefinieerd als een plan van aanpak om circulaire doelen te behalen. Met betrekking tot circulaire gebouwen betekent dit hoe circulariteit kan worden geïmplementeerd. Gebaseerd op deze definitie:

4. Wat zijn circulaire materiaal strategieën die je kunt inzetten bij nieuwbouwprojecten van eengezinswoningen?

Het bouwen van nieuwe eengezinswoningen gebeurt aan de hand van een project. Kenmerkend voor een project is dat het een unieke situatie betreft. Dit betekent dat elk project voor nieuwbouw eengezinswoningen anders is in hun project doelstellingen.
De project doelstellingen bepalen in hoeverre een circulaire strategie past binnen een project.

5. U noemde verschillende circulaire materiaal strategieën, welke project doelstellingen beïnvloeden de implementatie van deze circulaire strategieën?

Aan de ander kant wanneer een circulaire strategie wordt toegepast heeft dat effect op een project (dat zijn de impacts).

Impacts geven inzicht in de effecten van een circulaire strategie op een project.

6. U noemde verschillende circulaire materiaal strategieën, tot welke impacts leiden deze circulaire strategieën?

In dit onderzoek zijn verschillende circulaire strategieën, project doelstellingen en impacts bepaald aan de hand van een literatuuronderzoek. De vraag aan u is in hoeverre u het eens bent met de uitkomsten van het literatuuronderzoek.

Laat de lijst met circulaire materiaal strategieën zien.

7. Bent u het eens met deze lijst circulaire materiaal strategieën?
8. Missen er circulaire materiaal strategieën die naar uw mening toegevoegd moeten worden?

Laat de lijst met project doelstellingen zien.

9. Bent u het eens met deze lijst project doelstellingen?
10. Missen er project doelstellingen die naar uw mening toegevoegd moeten worden?

Laat de lijst met impacts zien.

11. Bent u het eens met deze lijst impacts?
12. Missen er impacts die naar uw mening toegevoegd moeten worden?

<u>Deel 4: Cool-off</u>

Het uiteindelijke doel van mijn onderzoek is het ontwikkelen van een framework dat gebruikt kan worden om circulariteit uit te vragen in aanbestedingen.

13. Wat zijn volgens u de succesfactoren voor het framework?
14. Wat zijn volgens u de faalfactoren voor het framework?
15. Wat zou voor u een optimaal eindresultaat zijn van mijn onderzoek?

<u>Deel 5: Afsluiting</u>

16. Is er nog iets onbesproken gebleven tijdens het interview wat van belang kan zijn voor mijn onderzoek?

Bedankt voor uw deelname aan mijn onderzoek.

D. Appendix – Expert interview codes of exploration phase

In the exploration phase nine interviews have been conducted to validate the literature study. All interviews are held in Dutch, therefore the transcribing, coding and analyzing of the interviews is conducted in Dutch. In total 192 codes have been derived from the nine interviews. By applying the axial coding technique, the codes are divided in the code groups the project characteristics, project goals, circular material strategies and impacts. In total 39 project characteristics, 27 project goals, 51 circular material strategies and 75 impacts are identified, as shown in the pictures below.
Each picture shows two colors, in which one color represent the opinion of the expert without knowing the results of the literature study in this research. The other color represents the opinion of the expert while knowing the results of the literature study in this research. Some words contain a number, this number indicates that the phrase is also present in another code group.

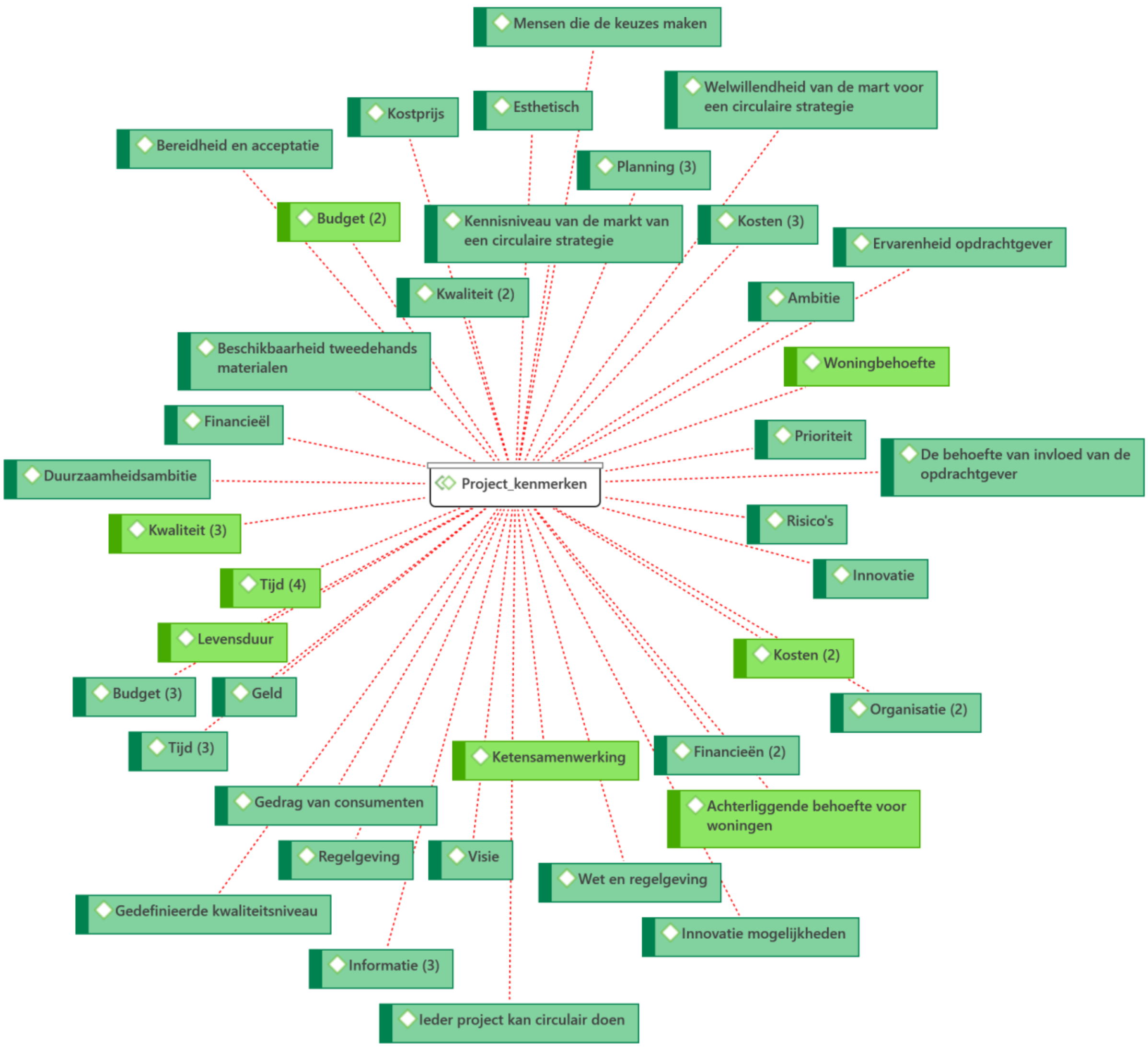


Figure 38; Project characteristics derived from expert interviews. Dark green is the opinion of the expert without knowing the results of the literature study and light green is the opinion of experts while knowing the result of the literature study.

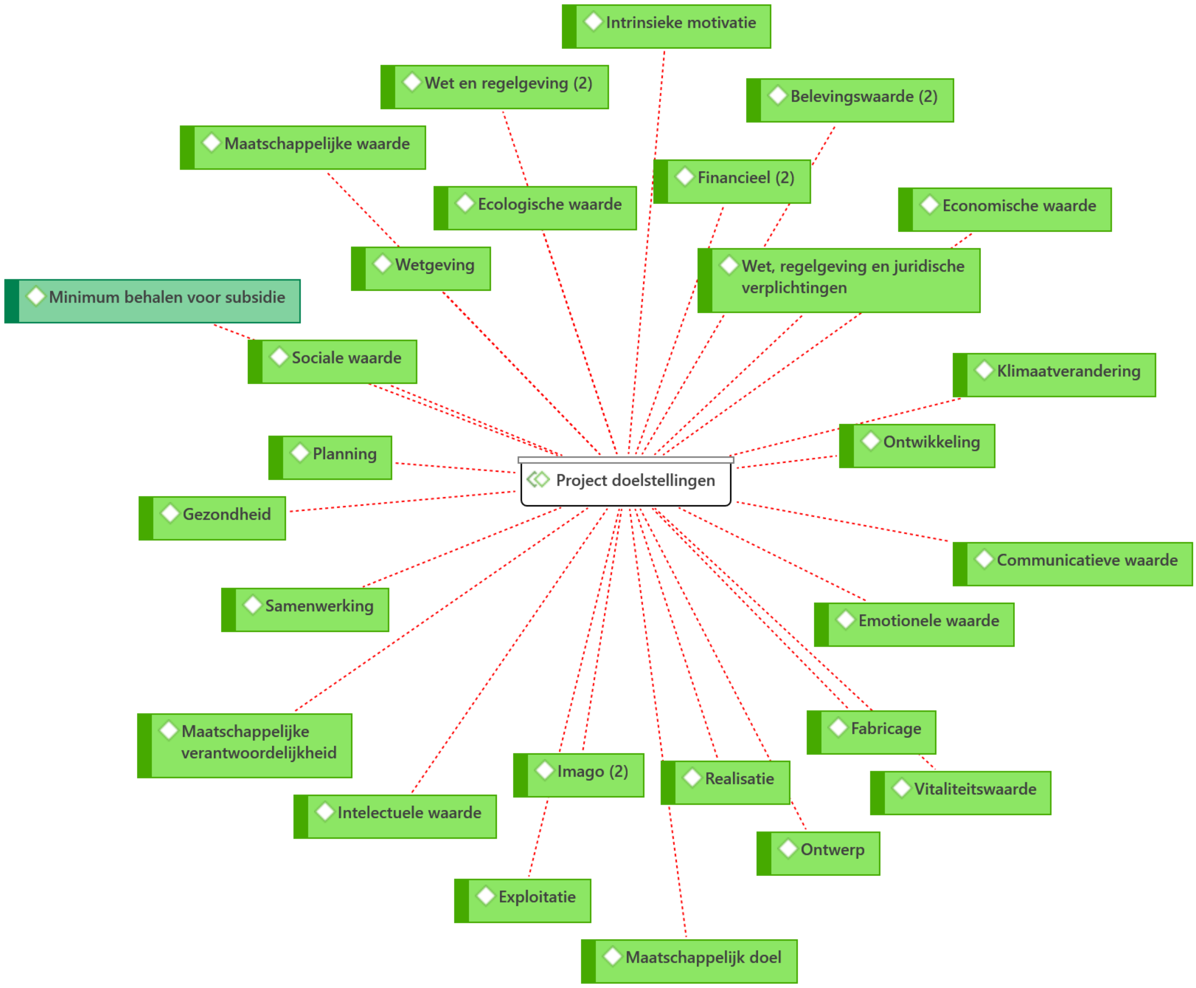


Figure 39; Project goals codes derived from expert interviews. Dark green is the opinion of the expert without knowing the results of the literature study and light green is the opinion of experts while knowing the result of the literature study.

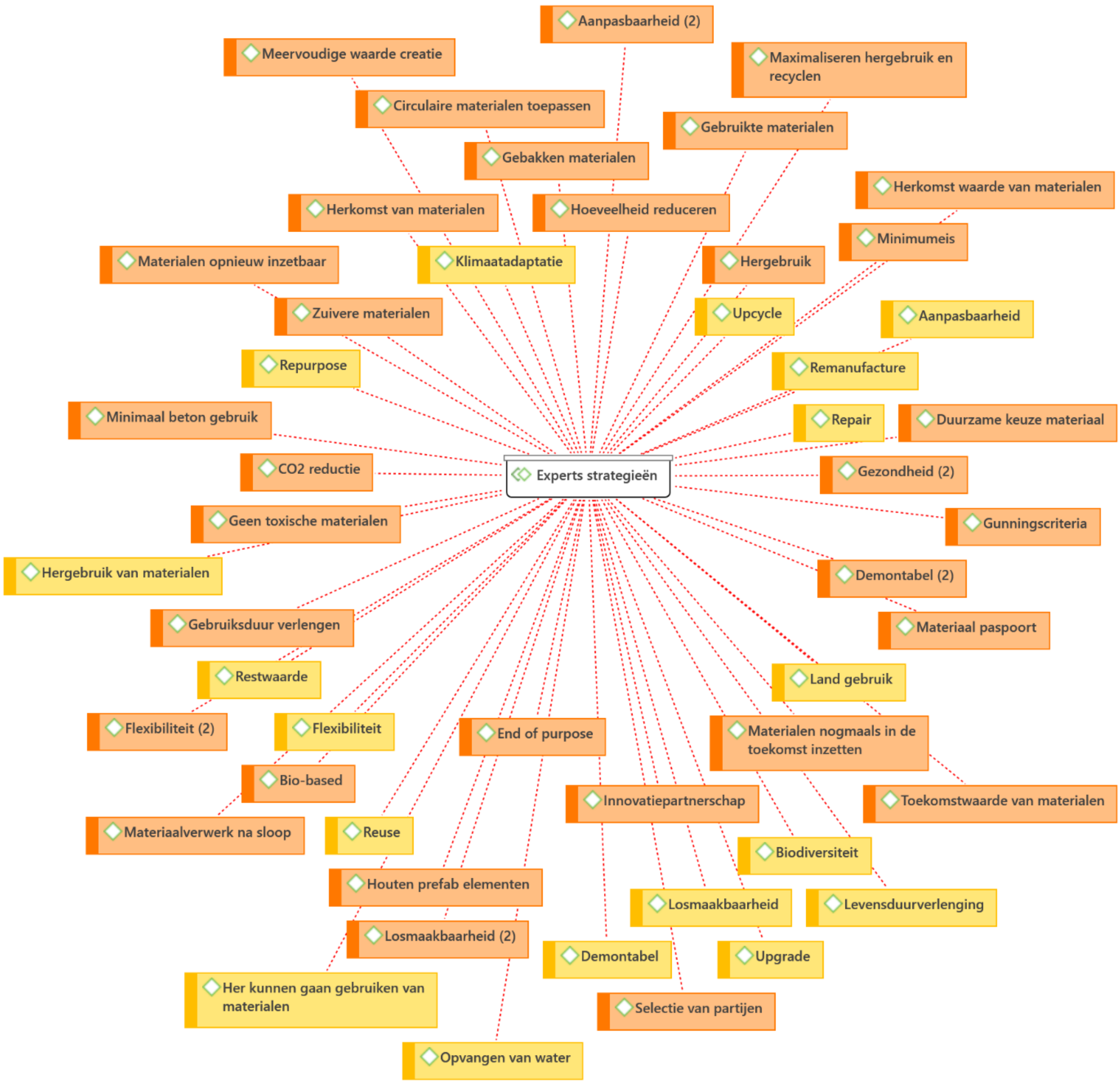


Figure 40; Circular strategy codes derived from expert interviews. Orange is the opinion of the expert without knowing the results of the literature study and yellow is the opinion of experts while knowing the result of the literature study.

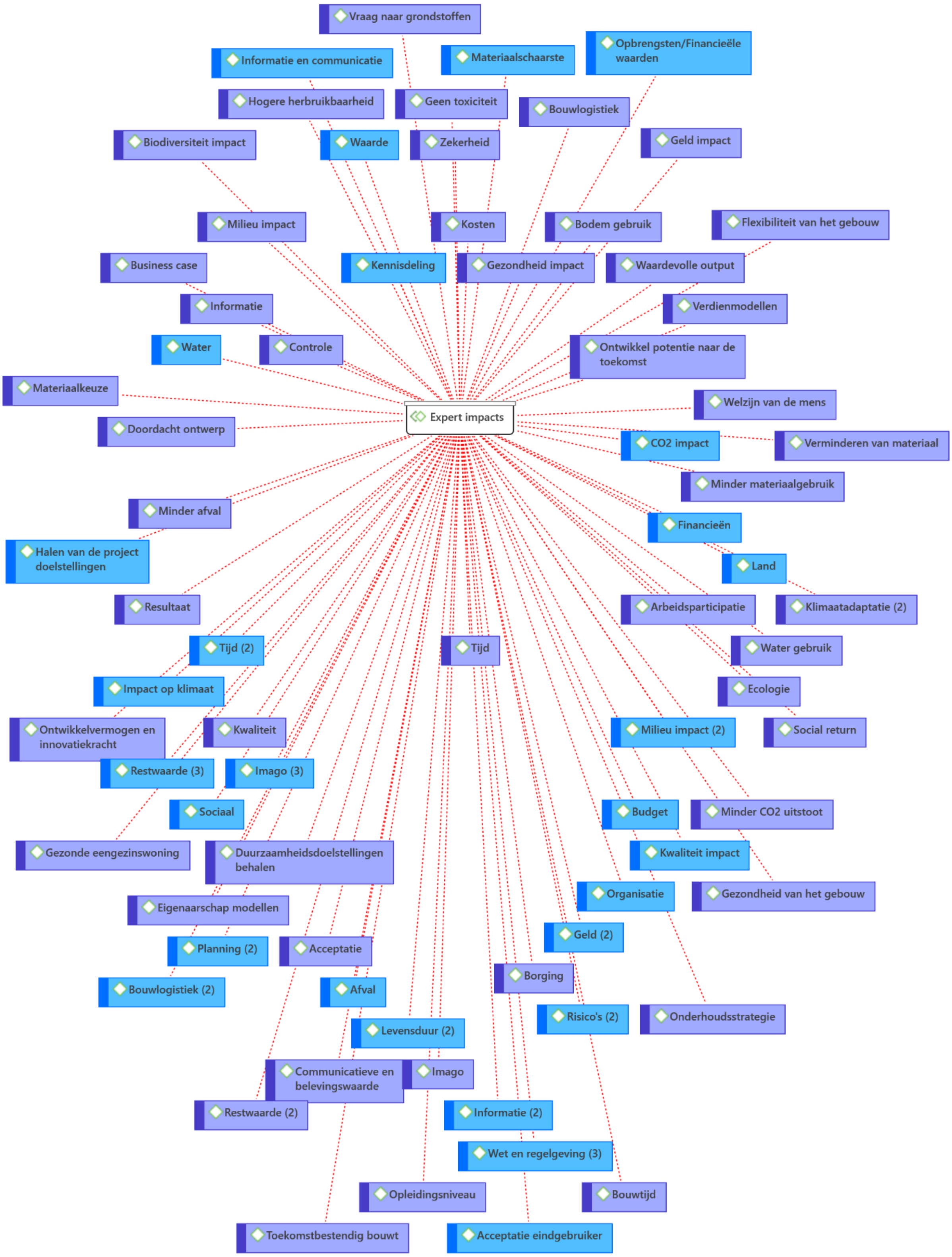
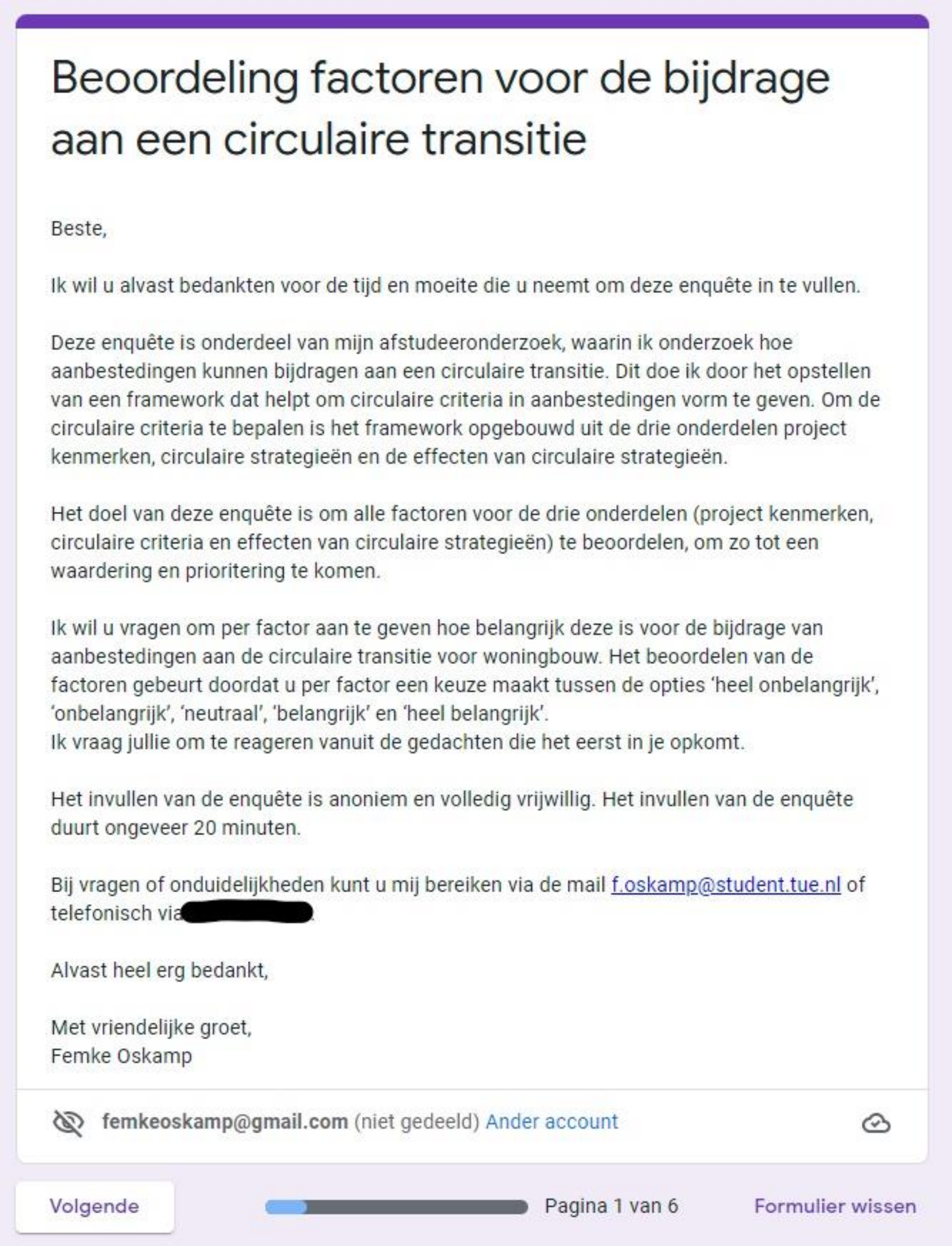


Figure 41; Impact codes derived from expert interviews. Dark blue is the opinion of the expert without knowing the results of the literature study and light blue is the opinion of experts while knowing the result of the literature study.

E. Appendix – Fuzzy Delphi Method questionnaire

The questionnaire consist of six sections. Each section will be shown. For the project characteristics, circular material strategies and impacts not the entire sections will be shown, because every question in these section is the same only the factor that is requested changes.



Beoordeling factoren voor de bijdrage aan een circulaire transitie

Beste,

Ik wil u alvast bedankten voor de tijd en moeite die u neemt om deze enquête in te vullen.

Deze enquête is onderdeel van mijn afstudeeronderzoek, waarin ik onderzoek hoe aanbestedingen kunnen bijdragen aan een circulaire transitie. Dit doe ik door het opstellen van een framework dat helpt om circulaire criteria in aanbestedingen vorm te geven. Om de circulaire criteria te bepalen is het framework opgebouwd uit de drie onderdelen project kenmerken, circulaire strategieën en de effecten van circulaire strategieën.

Het doel van deze enquête is om alle factoren voor de drie onderdelen (project kenmerken, circulaire criteria en effecten van circulaire strategieën) te beoordelen, om zo tot een waardering en prioritering te komen.

Ik wil u vragen om per factor aan te geven hoe belangrijk deze is voor de bijdrage van aanbestedingen aan de circulaire transitie voor woningbouw. Het beoordelen van de factoren gebeurt doordat u per factor een keuze maakt tussen de opties 'heel onbelangrijk', 'onbelangrijk', 'neutraal', 'belangrijk' en 'heel belangrijk'.
Ik vraag jullie om te reageren vanuit de gedachten die het eerst in je opkomt.

Het invullen van de enquête is anoniem en volledig vrijwillig. Het invullen van de enquête duurt ongeveer 20 minuten.

Bij vragen of onduidelijkheden kunt u mij bereiken via de mail f.oskamp@student.tue.nl of telefonisch via [redacted].

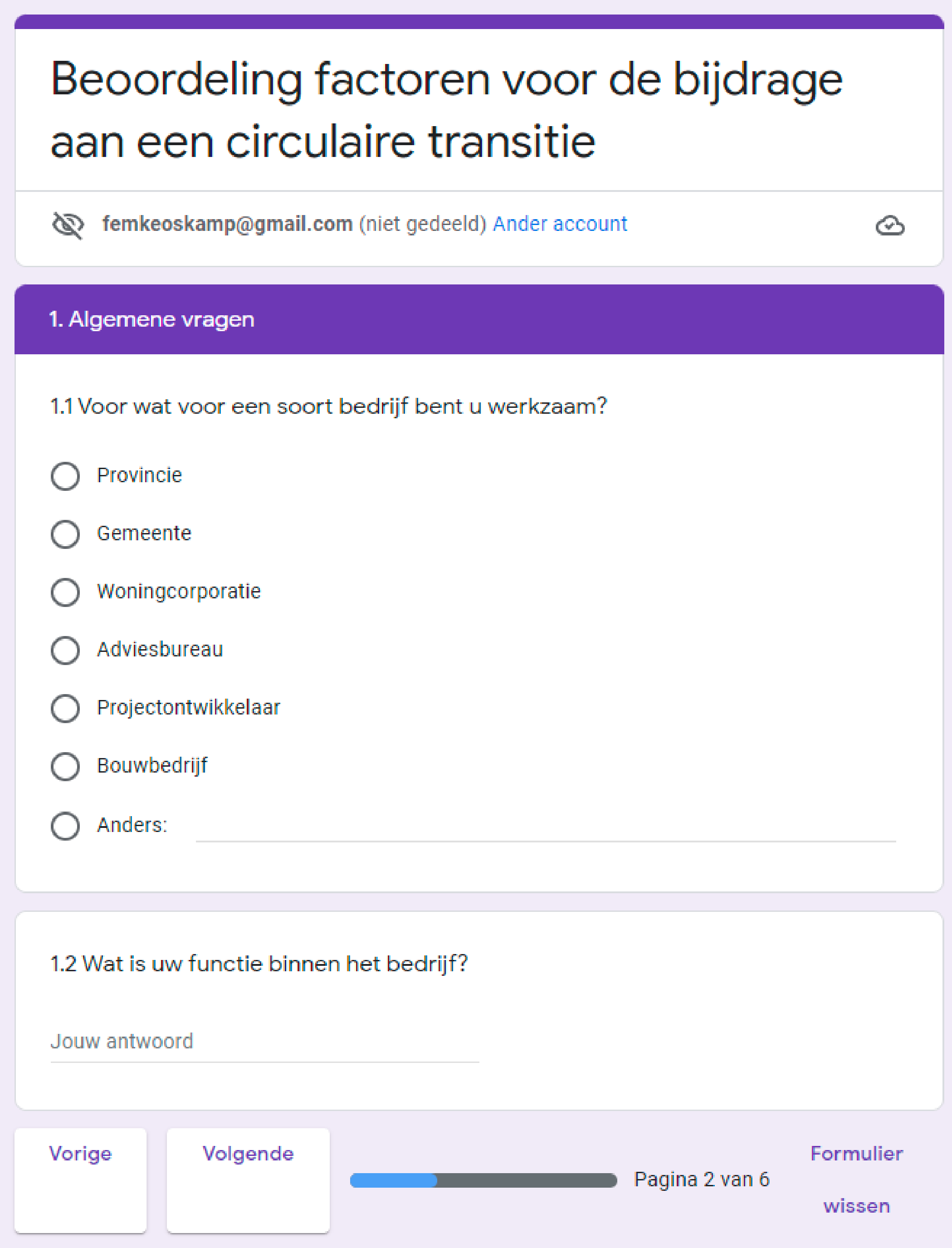
Alvast heel erg bedankt,

Met vriendelijke groet,
Femke Oskamp

femkeoskamp@gmail.com (niet gedeeld) Ander account

Volgende | Pagina 1 van 6 | Formulier wissen

Figure 42; Section 1 introduction



Beoordeling factoren voor de bijdrage aan een circulaire transitie

femkeoskamp@gmail.com (niet gedeeld) Ander account

1. Algemene vragen

1.1 Voor wat voor een soort bedrijf bent u werkzaam?

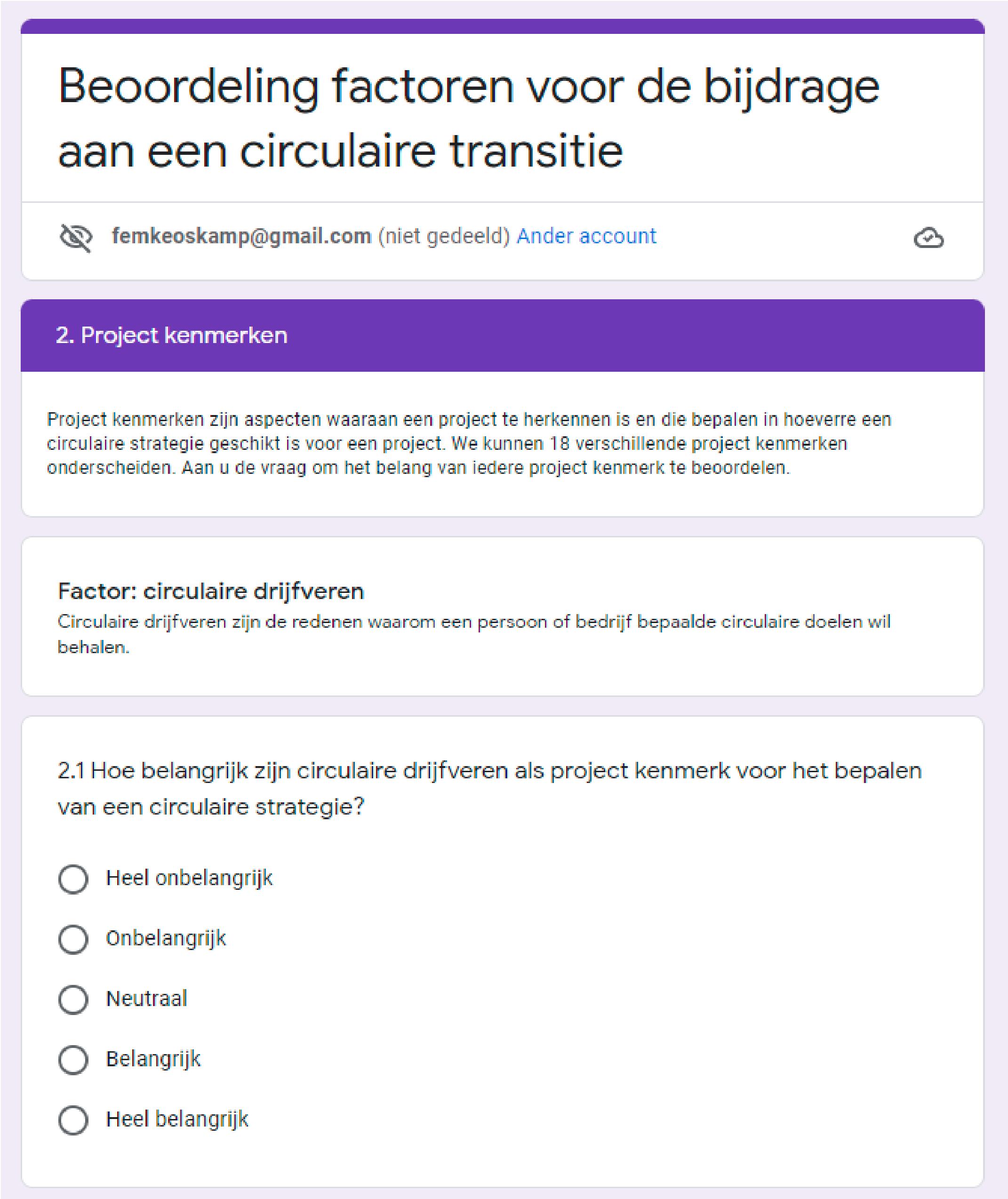
- Provincie
- Gemeente
- Woningcorporatie
- Adviesbureau
- Projectontwikkelaar
- Bouwbedrijf
- Anders: ____

1.2 Wat is uw functie binnen het bedrijf?

Jouw antwoord

Vorige | Volgende | Pagina 2 van 6 | Formulier wissen

Figure 43; Section 2 general information



Beoordeling factoren voor de bijdrage aan een circulaire transitie

femkeoskamp@gmail.com (niet gedeeld) Ander account

2. Project kenmerken

Project kenmerken zijn aspecten waaraan een project te herkennen is en die bepalen in hoeverre een circulaire strategie geschikt is voor een project. We kunnen 18 verschillende project kenmerken onderscheiden. Aan u de vraag om het belang van iedere project kenmerk te beoordelen.

Factor: circulaire drijfveren

Circulaire drijfveren zijn de redenen waarom een persoon of bedrijf bepaalde circulaire doelen wil behalen.

2.1 Hoe belangrijk zijn circulaire drijfveren als project kenmerk voor het bepalen van een circulaire strategie?

- Heel onbelangrijk
- Onbelangrijk
- Neutraal
- Belangrijk
- Heel belangrijk

Figure 44; Section 3 project characteristics

Beoordeling factoren voor de bijdrage aan een circulaire transitie

femkeoskamp@gmail.com (niet gedeeld) Ander account

3. Circulaire materiaal strategieën

Een circulaire materiaal strategie wordt gedefinieerd als een plan van aanpak om circulaire doelen te bereiken. We kunnen 32 verschillende circulaire materiaal strategieën onderscheiden. Aan u de vraag om het belang van iedere circulaire materiaal strategie te beoordelen.

Factor: regen/grijs watergebruik

Water hergebruiken en zoetwatergebruik vervangen door regenwater, mistwater, zeewater, etc.

3.1 Hoe belangrijk is regen/grijs watergebruik als circulaire materiaal strategie voor het bereiken van circulaire doelen?

- ◯ Heel onbelangrijk
- ◯ Onbelangrijk
- ◯ Neutraal
- ◯ Belangrijk
- ◯ Heel belangrijk

Figure 45; Section 4 circular material strategies

Beoordeling factoren voor de bijdrage aan een circulaire transitie

femkeoskamp@gmail.com (niet gedeeld) Ander account

Concept opgeslagen

4. Effect van circulaire strategieën

Een effect van circulaire strategieën laat zien wat het effect van een circulaire materiaal strategie op een project is. We kunnen 25 verschillende effecten onderscheiden. Aan u de vraag om het belang van ieder effect te beoordelen.

Factor: kosten

De totale financiële middelen die nodig zijn om het project te financieren, van initiatief tot realisatie.

4.1 Hoe belangrijk is kosten als effect van een circulaire strategie op een project?

- Heel onbelangrijk
- Onbelangrijk
- Neutraal
- Belangrijk
- Heel belangrijk

Figure 46; Section 5 impacts of circular strategies

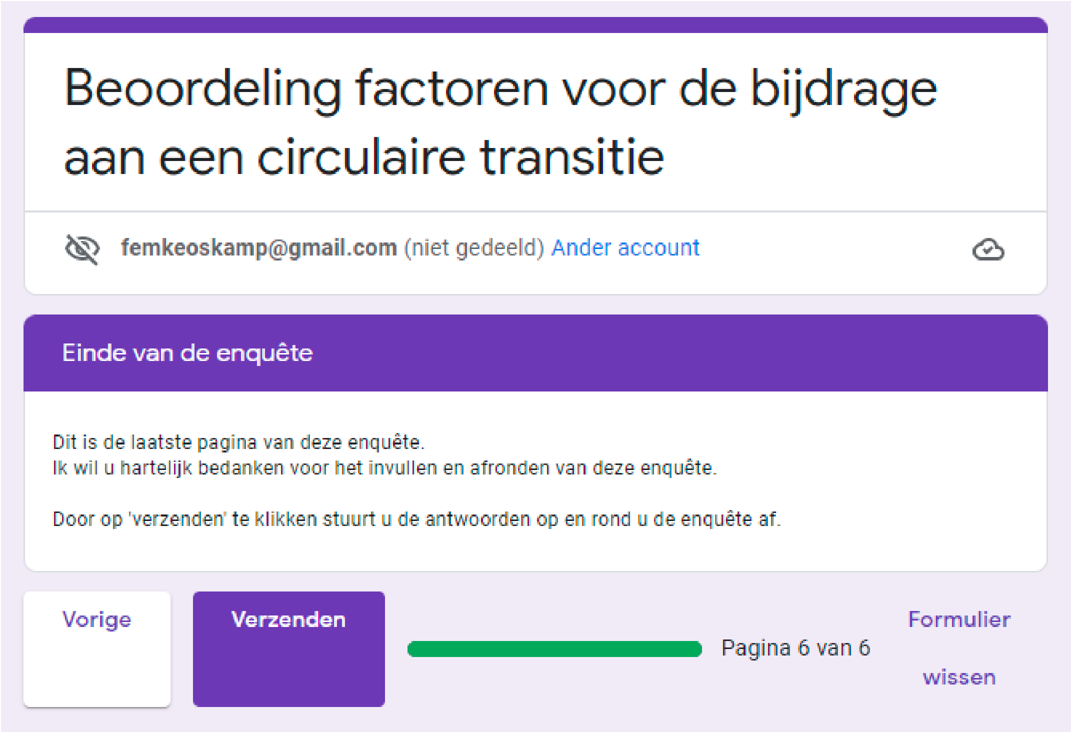


Figure 47; Section 6 closure

F. Appendix – Calculation sheet Fuzzy Delphi Method

Number	Project Characteristic	Single real number S_j	Normalized value	Result
1	Circular motive	0,80555556	1	Accepted
2	Implementation term	0,68376068	0,46729	Rejected
3	Lifecycle phase	0,74145299	0,719626	Rejected
4	Chain collaboration	0,73931624	0,71028	Rejected
5	Priority	0,73717949	0,700935	Rejected
6	Ambition	0,7991453	0,971963	Accepted
7	Willingness and acceptance	0,79059829	0,934579	Accepted
8	Availability of second-hand materials	0,60042735	0,102804	Rejected
9	Budget	0,77350427	0,859813	Accepted
10	Innovation	0,73076923	0,672897	Rejected
11	Knowledge level	0,74145299	0,719626	Rejected
12	Quality	0,71581197	0,607477	Rejected
13	Lifespan	0,73931624	0,71028	Rejected
14	Organization	0,57692308	0	Rejected
15	Risks	0,66452991	0,383178	Rejected
16	Time	0,61324786	0,158878	Rejected
17	Vision	0,77777778	0,878505	Accepted
18	Laws and regulations	0,70940171	0,579439	Rejected

Table 25; Calculation FDM project characteristics

Number	Circular material strategy	Single real number S_j	Normalized value	Result
1	Rain/grey water usage	0,57051282	0,092308	Rejected
2	Biobased materials	0,7457265	0,723077	Rejected
3	Non-toxic materials	0,77350427	0,823077	Accepted
4	Non-critical materials	0,61111111	0,238462	Rejected
5	Non-fossil fuels	0,71367521	0,607692	Rejected
6	Renewable energy	0,74358974	0,715385	Rejected
7	Electrification	0,62393162	0,284615	Rejected
8	Pure materials	0,54487179	0	Rejected
9	Refuse	0,63675214	0,330769	Rejected
10	Reduce	0,77136752	0,815385	Accepted
11	Rethink	0,76282051	0,784615	Rejected
12	Redesign	0,7542735	0,753846	Rejected
13	Water efficiency	0,57905983	0,123077	Rejected
14	Material efficiency	0,78846154	0,876923	Accepted
15	Energy efficiency	0,71581197	0,615385	Rejected
16	Retain	0,74358974	0,715385	Rejected
17	Reuse	0,78205128	0,853846	Accepted
18	Repair	0,67307692	0,461538	Rejected
19	Refurbish	0,66880342	0,446154	Rejected
20	Remanufacture	0,70940171	0,592308	Rejected
21	Resilient	0,6474359	0,369231	Rejected
22	Durable	0,70940171	0,592308	Rejected
23	Maintain	0,75854701	0,769231	Rejected
24	Upgrade	0,65811966	0,407692	Rejected
25	Multifunctional products/building	0,69230769	0,530769	Rejected

26	Flexible	0,75213675	0,746154	Rejected
27	Demountable	0,82264957	1	Accepted
28	Repurpose	0,71367521	0,607692	Rejected
29	Recycle	0,7008547	0,561538	Rejected
30	Recover	0,58333333	0,138462	Rejected
31	Renewable	0,75641026	0,761538	Rejected
32	Biodegradable	0,66025641	0,415385	Rejected

Table 26; Calculation FDM circular material strategies

Number	Impacts	Single real number S_j	Normalized value	Result
1	Costs	0,76068376	0,793478	Accepted
2	Time	0,72008547	0,586957	Rejected
3	Quality	0,79273504	0,956522	Accepted
4	Construction waste	0,66880342	0,326087	Rejected
5	Material consumption	0,75	0,73913	Rejected
6	Acceptance	0,70940171	0,532609	Rejected
7	Biodiversity	0,7008547	0,48913	Rejected
8	Land use	0,60470085	0	Rejected
9	Construction logistics	0,63247863	0,141304	Rejected
10	CO2 emission	0,78418803	0,913043	Accepted
11	Flexibility of a building	0,71153846	0,543478	Rejected
12	Image	0,63888889	0,173913	Rejected
13	Information and communication	0,7457265	0,717391	Rejected
14	Climate adaptation	0,68589744	0,413044	Rejected
15	Lifespan	0,78846154	0,934783	Accepted
16	Material scarcity	0,7542735	0,76087	Rejected
17	Environmental impact	0,80128205	1	Accepted
18	Development capacity and innovation power	0,72863248	0,630435	Rejected
19	Organization	0,68589744	0,413044	Rejected
20	Residual value	0,75213675	0,75	Rejected
21	Risks	0,73076923	0,641304	Rejected
22	Social	0,64957265	0,228261	Rejected
23	Future proof construction	0,75213675	0,75	Rejected
24	Water consumption	0,60470085	0	Rejected
25	Certainty	0,70299145	0,5	Rejected

Table 27; Calculation FDM impacts of circular strategies

G. Appendix – Interview question evaluation phase

English questions

Part 1: Introduction
Every interview will start with an introduction. In the introduction the researcher will introduce the research and the aim of the interview.

Part 2: Warm-up
1. What is your first reaction to the framework?

Part 3: Main body
The framework consist of four steps. For each step the content is discussed.
2. Is the content of step 1 clear?
3. Is the content of step 2 clear?
4. Is the content of step 3 clear?
5. Are the CE-criteria applicable for newly built single-family homes?
6. Is the content of step 4 clear?

Part 4: Cool-off
7. Is the framework applicable for the procurement process of newly built single-family homes?
8. Would you use the framework in practice?
9. Would you like to make adjustments to the framework?

Part 5: Closure
10. Is there anything that remained undiscussed during the interview that could be important for my research?

Thank you for participating in my research.

Dutch questions

Deel 1: Introductie
Elk interview zal starten met een introductie. In de introductie introduceert de onderzoeker het onderzoek en het doel van de interviews.

Deel 2: Warm-up
1. Wat is uw eerste reactie op het framework?

Deel 3: Main body
Het framework bestaat uit vier stappen. Voor iedere stap wordt de inhoud besproken.
2. Is de inhoud van stap 1 duidelijk?
3. Is de inhoud van stap 2 duidelijk?
4. Is de inhoud van stap 3 duidelijk?

5. Zijn de CE-criteria toepasbaar voor nieuwbouw eengezinswoningen?
6. Is de inhoud van stap 4 duidelijk?

Deel 4: Cool-off

7. Is het framework toepasbaar in het aanbestedingsproces voor nieuwbouw eengezinswoningen?
8. Zou u het framework in de praktijk gebruiken?
9. Zou u aanpassingen willen maken aan het framework?

Deel 5: Afsluiting

10. Is er nog iets onbesproken gebleven tijdens het interview wat van belang kan zijn voor mijn onderzoek?

Bedankt voor uw deelname aan mijn onderzoek.

H. Appendix – Framework sketches

To create the framework, four layout sketches were made. In these sketches, the relationship between the four steps and the content of each step was visualized. The sketch with the clearest and most understandable layout was selected to develop into a final design. This is sketch 4, which is shown in Figure 52.

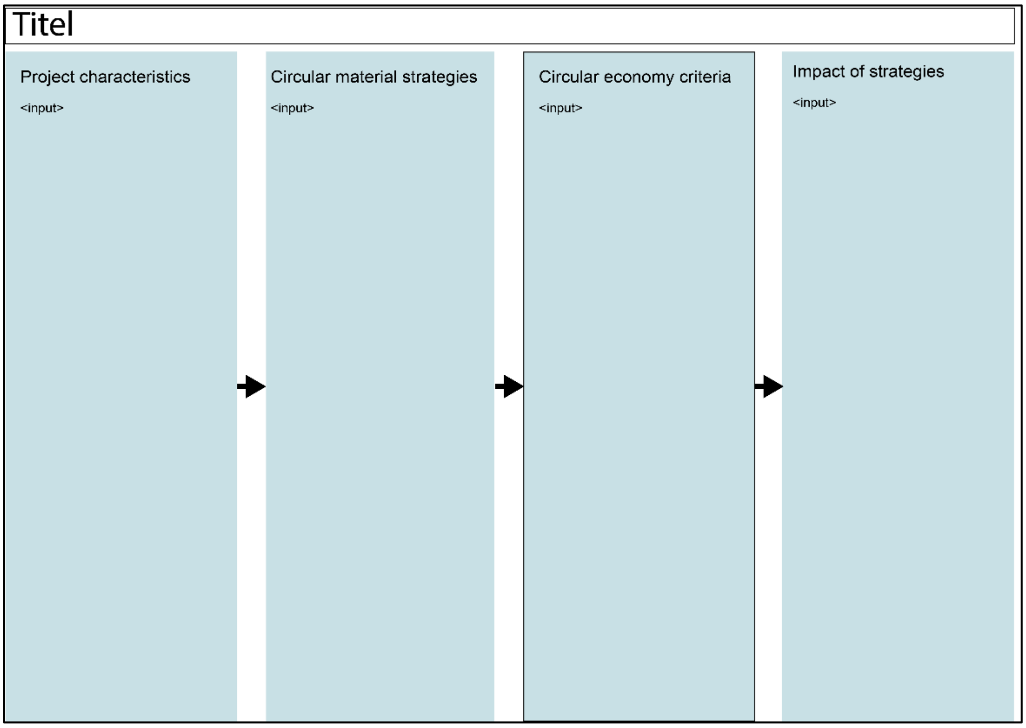


Figure 48; Framework sketch 1

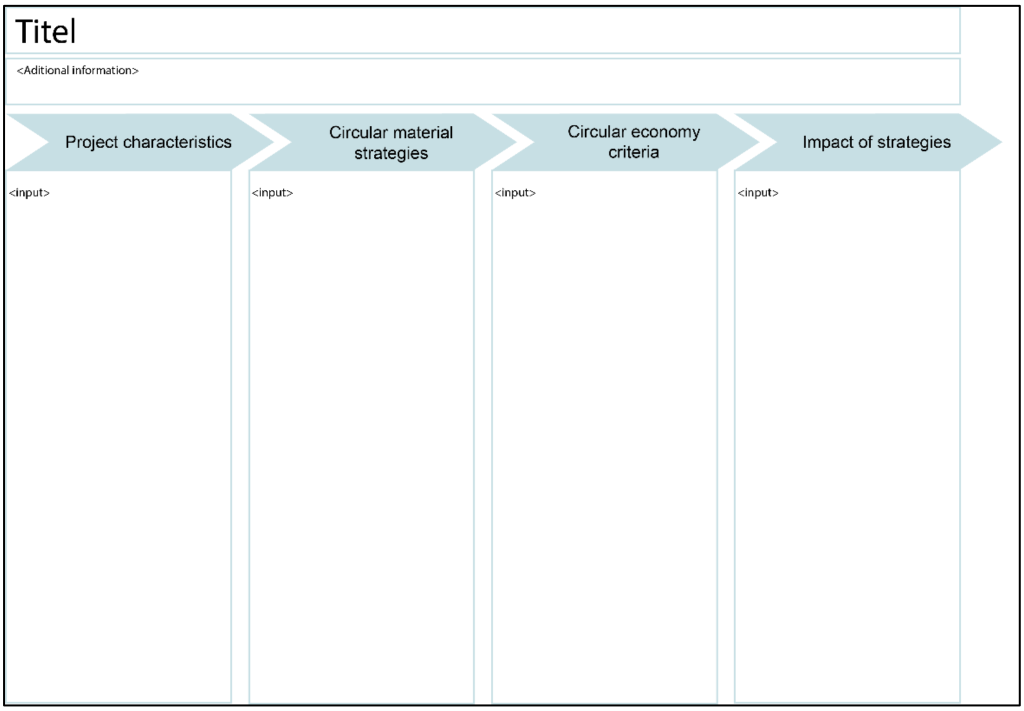


Figure 49; Framework sketch 2

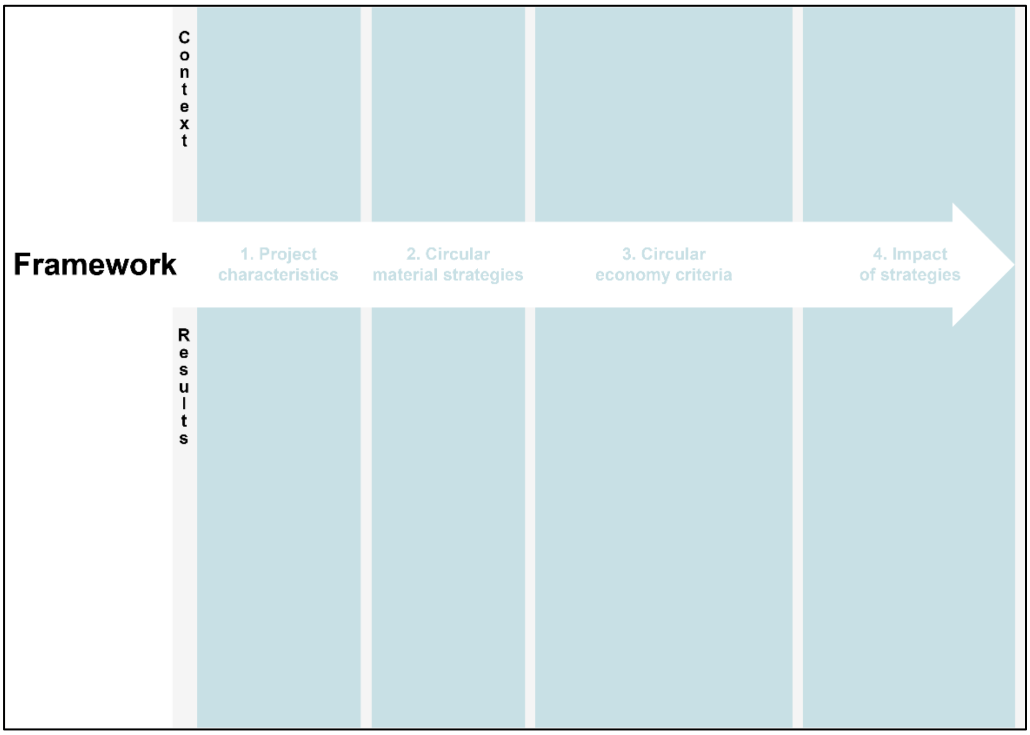


Figure 50; Framework sketch 3

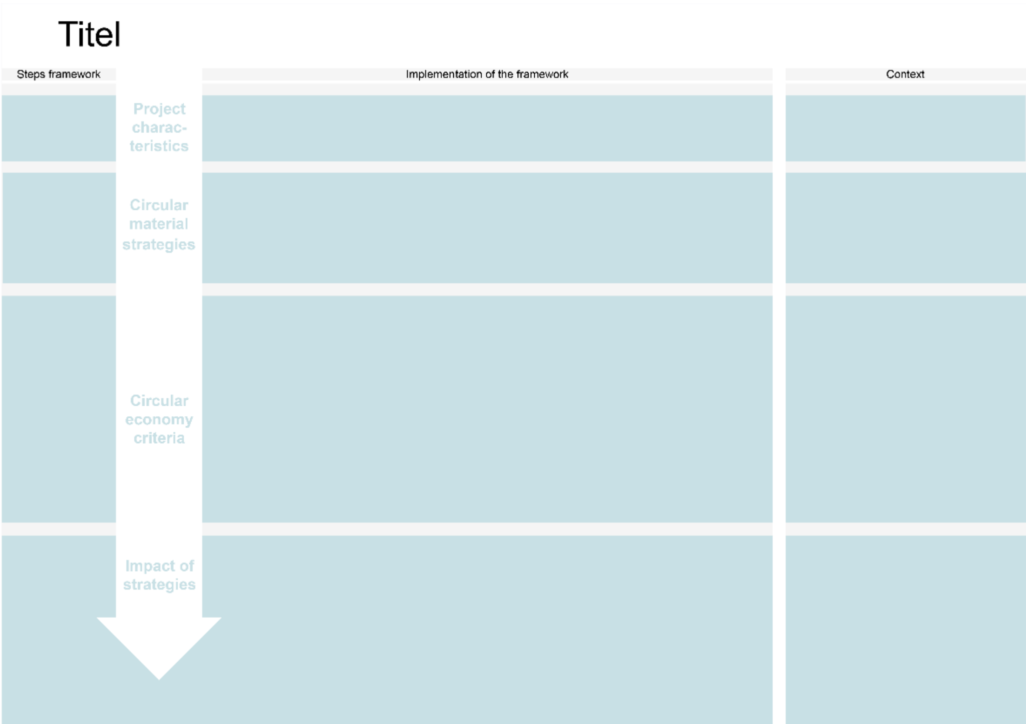


Figure 51; Framework sketch 4

I. Appendix – Expert interview codes of evaluation phase

In the evaluation phase eight interviews have been conducted to validate the framework. All interviews are held in Dutch, therefore the transcribing, coding and analyzing of the interviews is conducted in Dutch. In total 86 codes have been derived from the eight interviews. By applying the axial coding technique, the codes are divided into the seven code groups: general, step 1, step 2, step 3, step 4, application and adjustments. The results of the axial coding technique for each code group is given in the Figures 53 till 59.

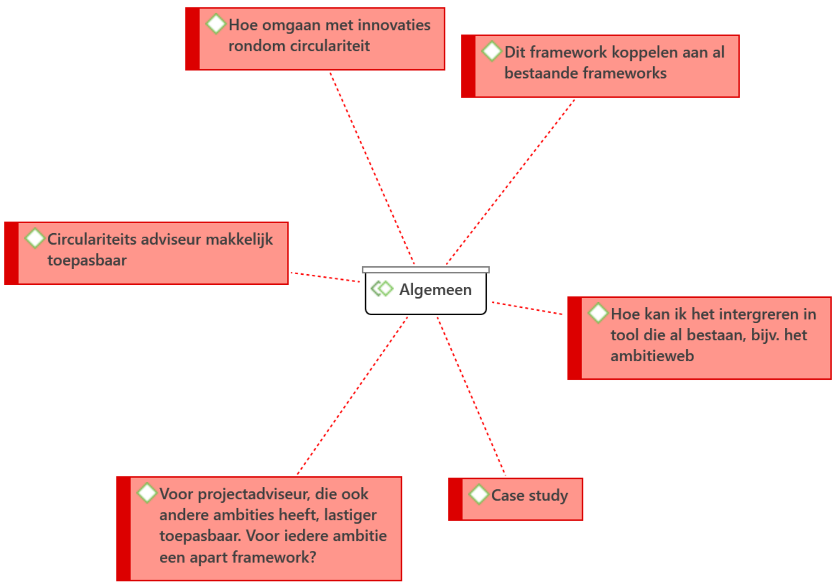


Figure 52; General feedback derived from the expert interviews

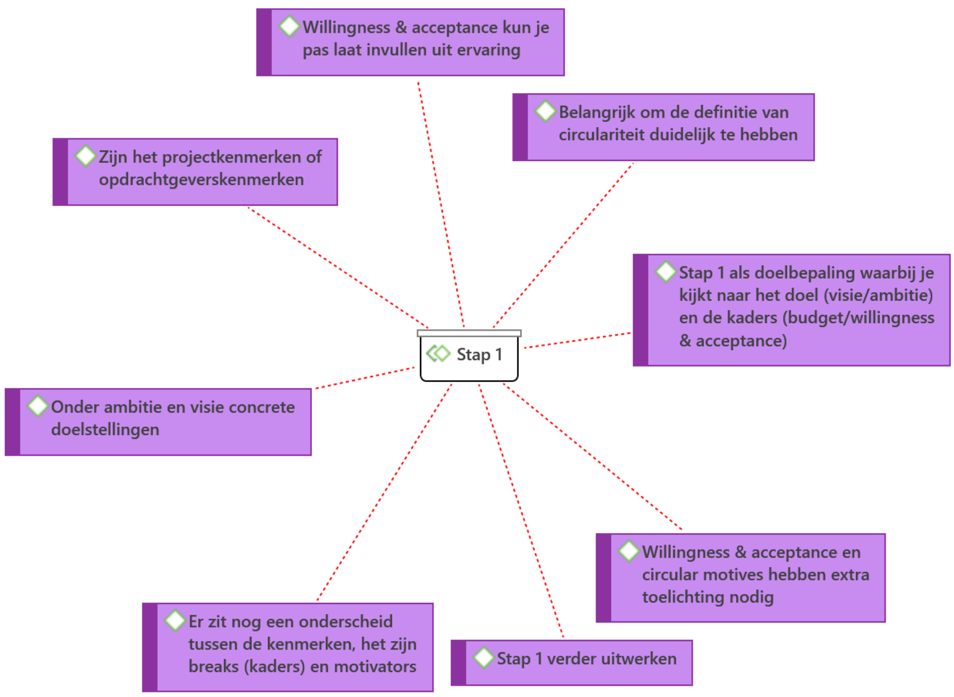


Figure 53; Feedback for step 1 derived from the expert interviews

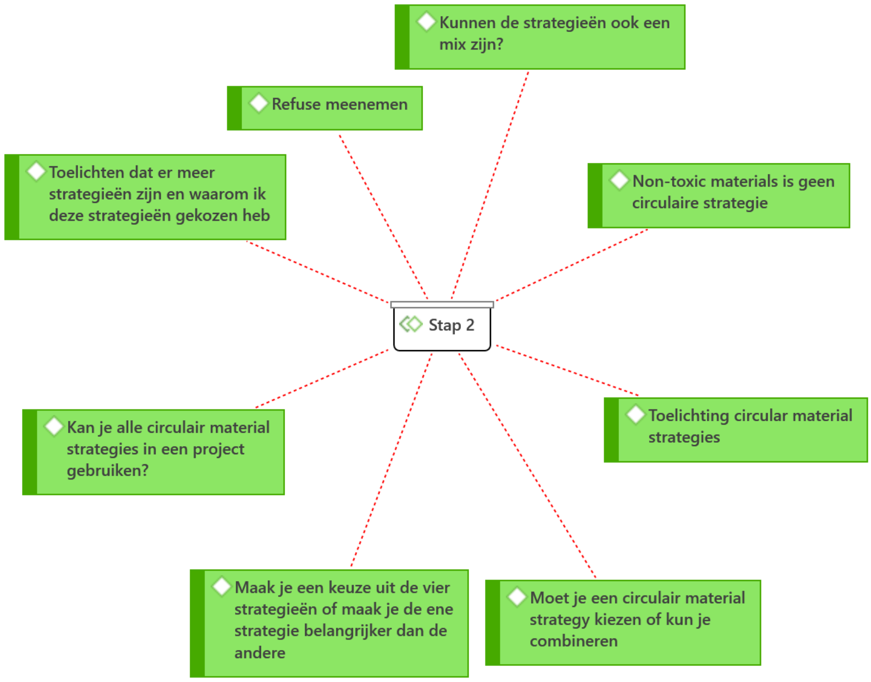


Figure 54; Feedback for step 2 derived from the expert interviews

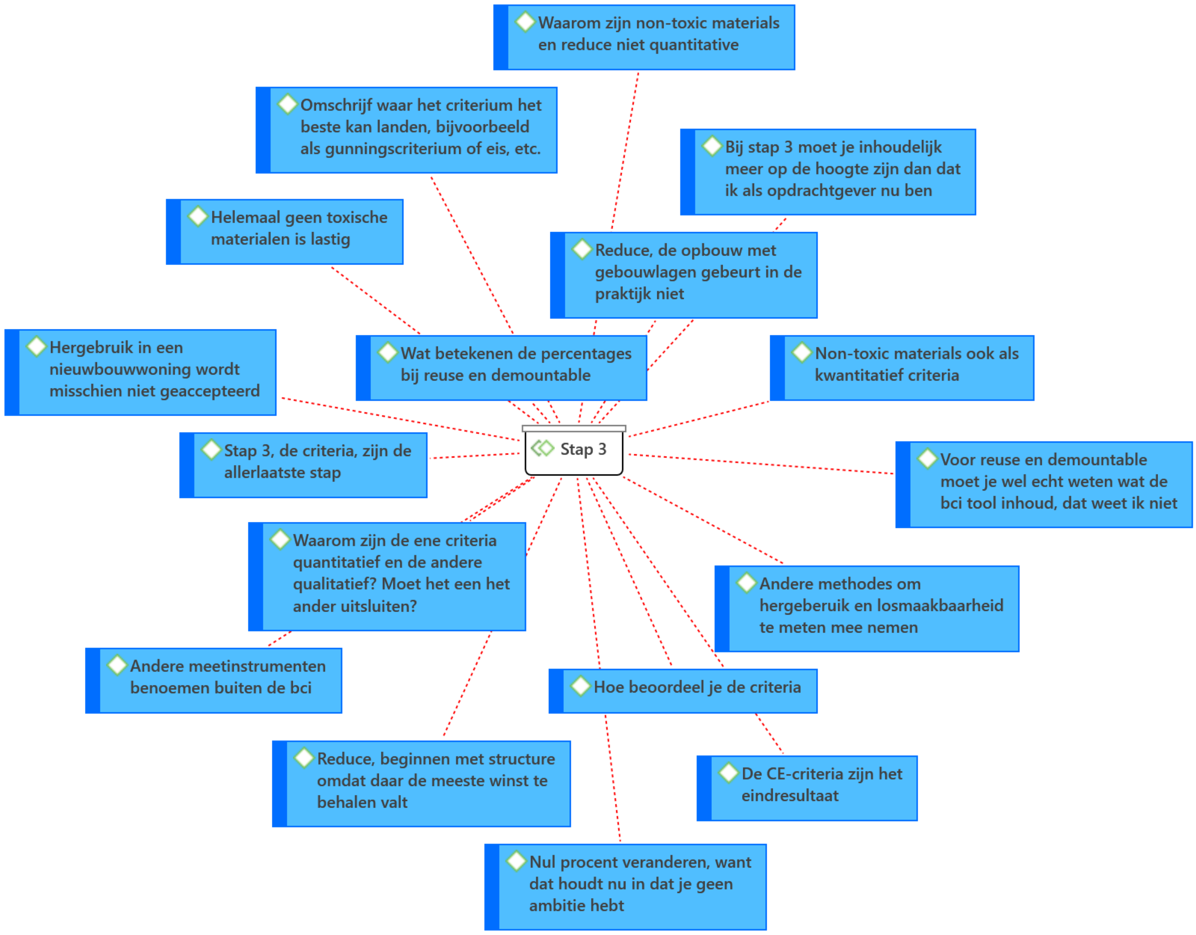


Figure 55; Feedback for step 3 derived from the expert interviews

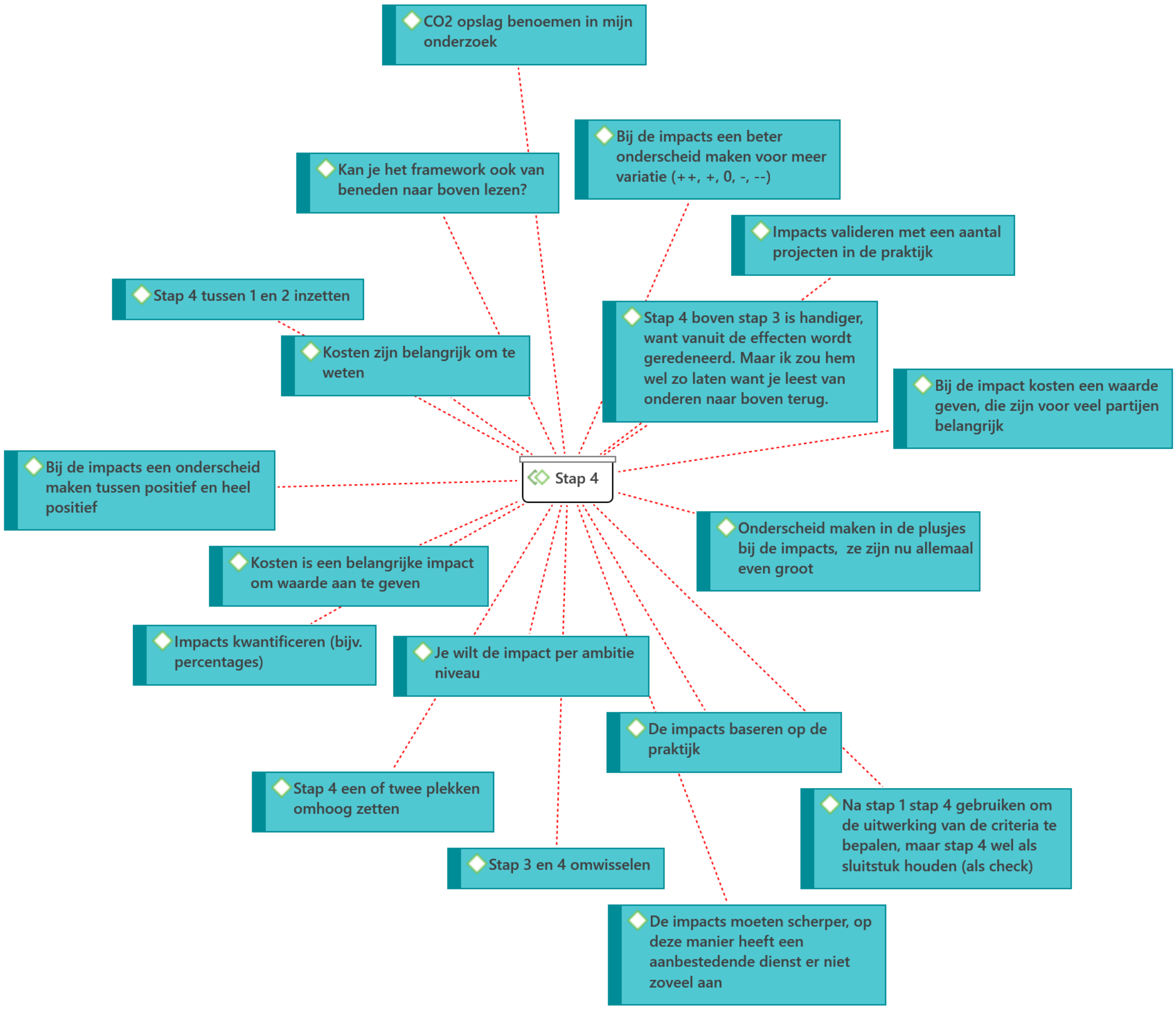


Figure 56; Feedback for step 4 derived from the expert interviews

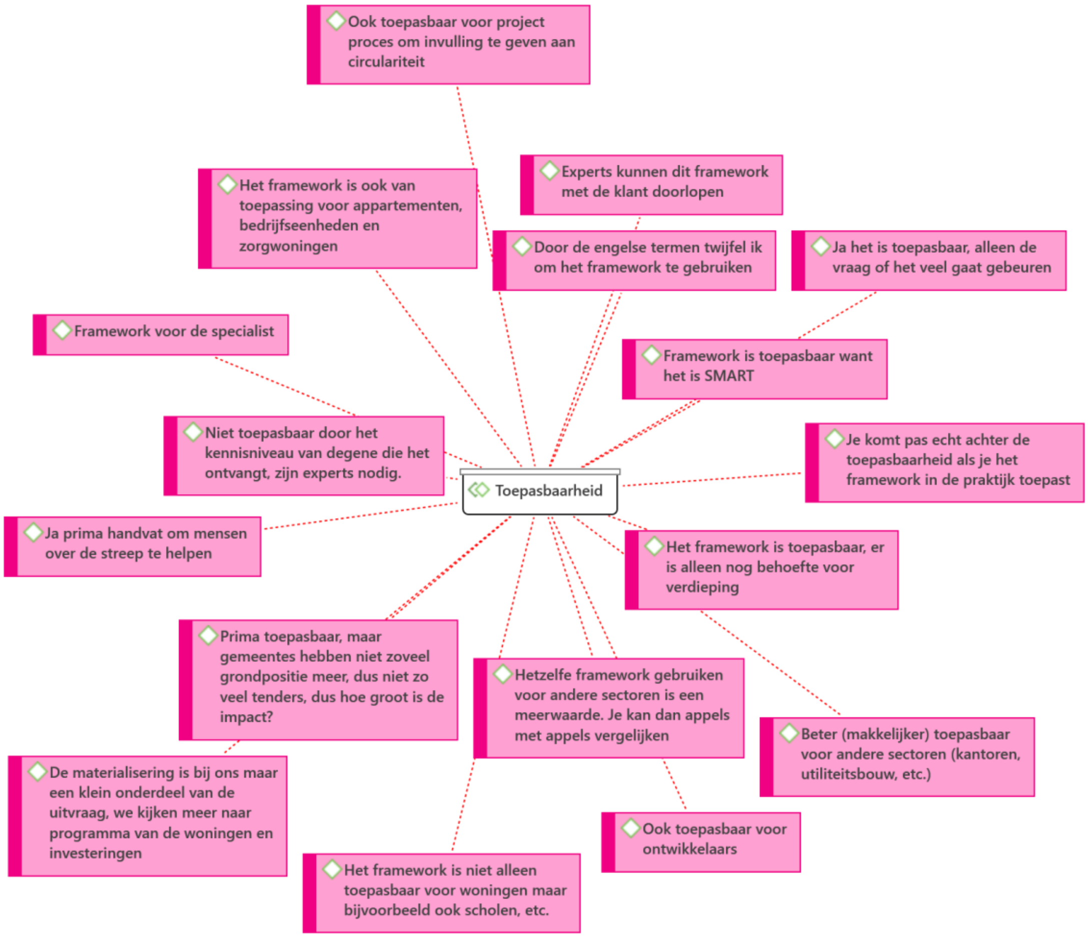


Figure 57; Applicability feedback derived from the expert interviews

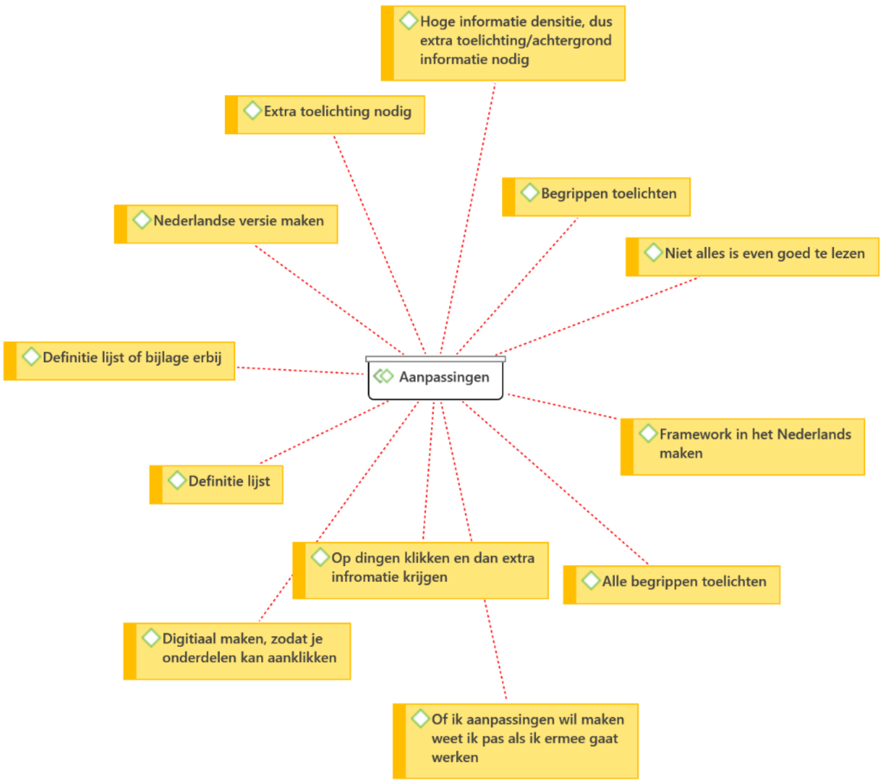


Figure 58; Adjustment feedback derived from the expert interviews