

# **A system thinking perspective on accelerating circular construction**

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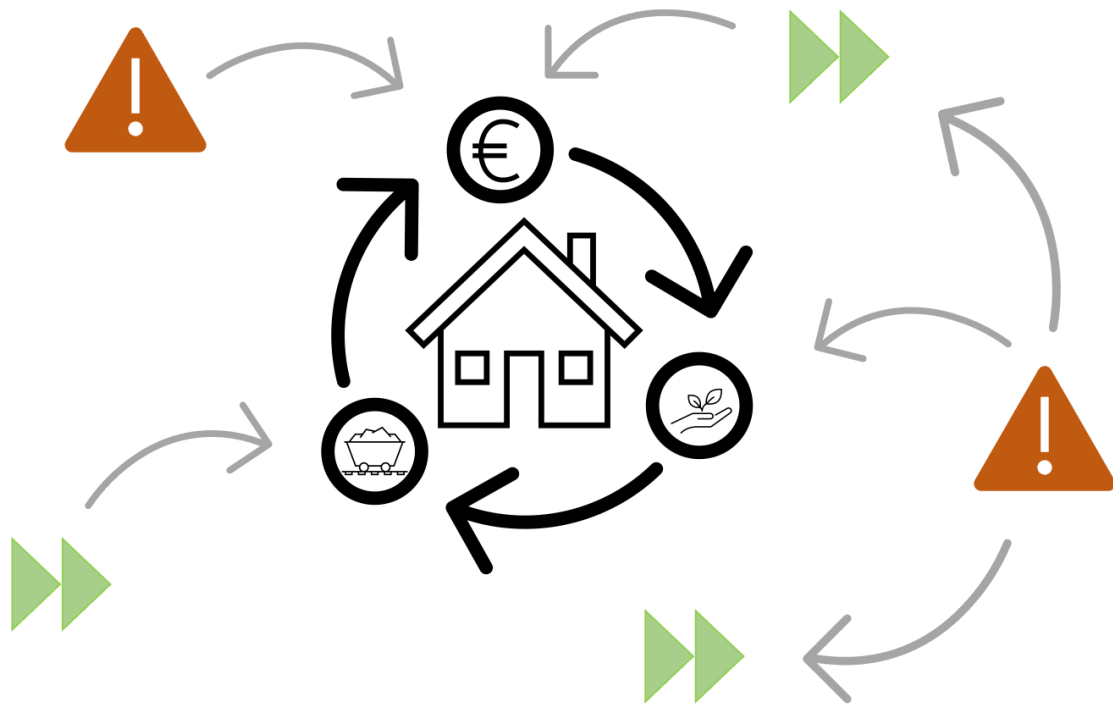
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*How drivers and barriers for circular construction create feedback mechanisms, to identify actions for increased secondary material use.*



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**Abstract:** The purpose of this study is to create insight into feedback mechanisms and actions, on a socio-technical regime (meso) level, created by barriers and drivers for circular construction, that can help the Dutch construction industry increase the use of secondary materials and consequently contribute to a more environmentally friendly way of building.

Developing these actions and feedback mechanisms is done by creating a causal loop diagram via a participatory research method called group model building. This research shows that organizations are currently driven to implement circular construction because of either internal motivation to reduce the environmental impact of construction, or due to the increasing number of governmental targets. However, these targets are unambiguous and therefore give insufficient guidance to the direction of the transition. Furthermore, the housing shortage causes an increasing important of cost which is another barrier since costs of circular construction are higher. The feedback mechanisms uncovered in this study relate to giving direction to the transition by learning-by-doing, creating acceptance by improving certification of secondary materials and creating market mechanisms by improving continuity of supply and demand.

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## 1 Introduction

With an annual waste output of 23.630 kilotons, the construction industry is the biggest waste producer in the Netherlands (Rijkswaterstaat, 2020). Around 97% percent of this waste is used for low grade recycling (Nelissen et al., 2018), meaning that the resulting reusable materials have less functional and economical value (Ellen MacArthur Foundation, 2015a). In order to reduce waste and therefore ecological damage, the Dutch government is committed to transform the Dutch economy into a circular economy (CE) by 2030. The CE can reduce CO<sub>2</sub> emissions by 48%, while providing an additional net economic benefit of 1.8 trillion euros and creating 2 million additional jobs within the European Union (Ellen MacArthur Foundation, 2015a; European Commission, 2014). The construction sector has been marked as one of five crucial sectors, by the Dutch government, in the transition to a CE (Nelissen et al., 2018).

Despite its benefits and the strong commitments from governmental organisations, circular construction is most frequently found in pilot projects and has not landed in common practice yet. The transition is constrained by what Coenen, van der Heijden, and van Riel (2018) call dynamic complexity. This dynamic complexity can be understood by studying systems feedback mechanisms (Sterman, 2000). As de Jesus and Mendonça (2018) describe, keeping a systems perspective on such a multidimensional problem is important to help us understand the interactions, linkages, trade-offs and mismatches between the different elements, accordingly increasing the ability to influence the system into its transition (Coenen et al., 2018).

This master thesis seeks to contribute to a more sustainable society by helping the application of circularity in the build environment accelerate. For this purpose, the current study aims at creating insight into feedback mechanisms and actions, on a socio-technical regime (meso) level, created by barriers and drivers for circular construction that can help the Dutch construction industry increase the use of secondary materials and consequently contribute to a more environmentally friendly way of building. All the above leads to the following main research question: *What actions should be taken to enhance the implementation of secondary materials in de Dutch construction industry, when looking at the feedback mechanisms that are created by barriers and drivers for circular construction?*

To answer this main question, the sub questions below will be addressed in this study.

1. *A: What drives do companies in the Dutch construction industry experience when implementing circular principles into their business activities?*  
*B: What barriers do companies in the Dutch construction industry experience when implementing circular principles into their business activities?*
2. *What feedback mechanisms do the drivers and barriers create in the Dutch construction industry?*
3. *Which actions should be implemented according to actors to enhance the use of secondary materials in the Dutch construction industry?*

The following chapter discusses the theoretical background to develop a conceptual framework that places the study in the context of relevant literature. Therefore, creating synthesising concepts that guide the interpretation and explanation of the found data. Thereafter, chapter three (methodology) discusses the research strategy and how data is collected and analysed. Chapter four describes the results and lastly, chapter five is concerned with the conclusions and discussion of this study.

## 2 Theoretical background

### 2.1 Circular construction

The circular economy is a system in which re-use and maintaining the value of material plays a central role but it is not yet a completely crystalized concept as shown by Kirchherr, Reike, and Hekkert (2017). They discovered 114 different definitions for the circular economy. The prominent Ellen MacArthur Foundation (2015b) defined it as follows: “*The circular economy is an economic and industrial system that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles.*”. In order to build in such a way that aligns with the above definition, a new way of building is required (Icibaci, 2019).

As shown by Pinder, Schmidt, Austin, Gibb, and Saker (2017) a building is made of several systems, which consist of different elements. These elements are, at the same time, made of various products. which are produced using diverse materials. Likewise, these materials are obtained from assorted raw materials. This creates a hierarchy of elements, products and materials (EMPs) that is represented horizontally in Figure 1. In order to re-use the EMPs, Potting, Hekker, Worrell, and Hanemaaijer (2017) have developed the R-ladder which contains 10 ordinal strategies for circular use of EMPs. These strategies are shown in appendix 2.

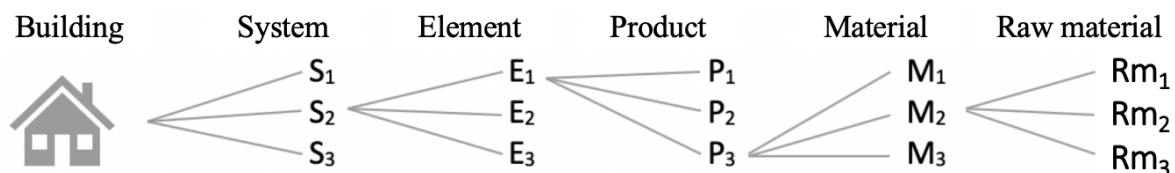


Figure 1 – The hierarchical composition of a building.

To apply these circular strategies for re-use in the construction sector, it is important that the building and it's EMPs are decomposable. Only then, layers or EMPs with a short life span can be replaced without destroying value in the layers or EMPs higher in the 'hierarchy' shown in Figure 1. However, changing how we build houses is not enough to become circular, a shift from a rather linear supply chain towards a closed loop supply chain (CLSC) is needed. A linear supply chain is primarily concerned with activities in the process of converting raw materials into finished products (Kocabasoglu, Prahinski, & Klassen, 2007). However CLSCs also contain return flows and are described by Ferguson and Souza (2010, p. vii) as follows: *Closed-loop supply chains are supply chains where, in addition to the typical forward flow of materials from suppliers to end customers, there are flows of products back (post-consumer*

*touch or use) to manufacturers.* This shift from the incumbent linear supply chain towards a CLSC is considered a transition (Nelissen et al., 2018).

## **2.2 Understanding transitions**

A transition is a transformation process in which society establishes fundamental new system structures by innovating not only technological but also economic, political and cultural (Suurs, 2009). Transitioning towards a closed loop supply chain is particularly difficult in the construction sector, because the lifetime of the product (the building) is long (Coenen, van der Heijden, & van Riel, 2019). For example, it is uncertain whether a circular designed roof will be compatible or economically complete for re-use after 50 years. Additionally, Unruh (2000) shows, in his research on transitioning the energy sector, that systems ‘lock-in’ because they create reinforcing feedback mechanisms. Scale economies, accumulation of knowledge and technology, network externalities and habits cause a system to reinforce its current way of working and therefore counteract change. In order to understand how systems transition, first some key takeaways from the multi-level perspective theory are addressed. Thereafter, the dynamics in a transition are described based on a typology from the technological innovation systems (TIS) literature.

### *2.2.1 A multi-level perspective*

Geels (2002) develop the multi-level perspective as a tool for the analysis of transitions in socio-technical systems. Therein it distinguishes three levels, shown in Figure 2. The **socio-technical landscape** contains structural trends that influence the interactions between actors such as economic growth, broad political coalitions or cultural- and normative values. In the context of this research, environmental problems such as pollution, climate change and loss of biodiversity are developments that urge the search for new socio-technical systems such as the circular economy (Geissdoerfer, Savaget, Bocken, & Hultink, 2017). Moreover Geissdoerfer et al. (2017) describes that economic developments also play a role. Financial and economic instabilities occur more often within companies and entire economies, due to problematic ownership structures, deregulated markets and supply risk. This supply risk for example, is caused by political instability, export restrictions, scarcity and oligopolistic markets (de Groot et al., 2012).

A **socio-technical regime** is the semi-coherent set of rules carried by different social groups, embedded in a complex system of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems; all of them embedded

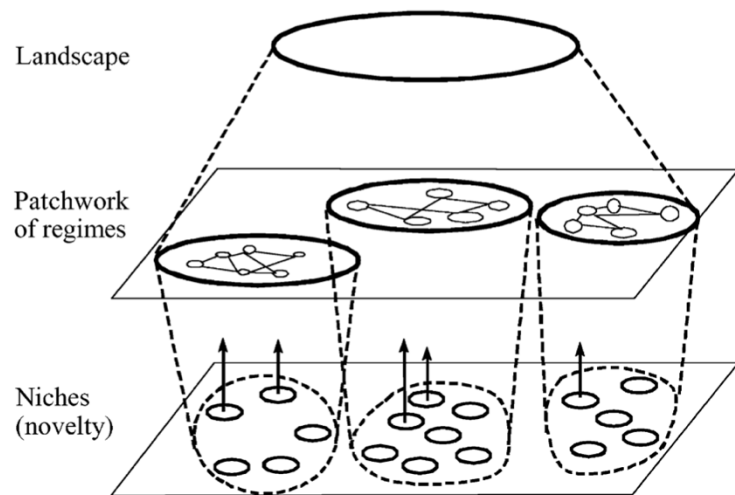


Figure 2 - The nested layers in the multi-level perspective (Geels, 2002).

in institutions and infrastructure. It is the framework that contains the core assumptions, ways of thinking and doing of a sector (Fuenfschilling & Truffer, 2014)

**Niches** are ‘incubation rooms’ where (mostly) radical innovations can develop because they are protected from incumbent market selection, originating from the socio-technical regime. In this research these innovations can entail circular building in a pilot project. A good example in the context of this research is the building of 24 apartments called Strobouw IEWAN, in Lent. A circular construction in which its success was co-determined by the help of two hundred volunteers and financial support of governmental bodies. The niche can also entail a specific development that improve the ability to build circular. For example, Madaster, which seeks to improve the information provision about buildings to facilitate re-use of materials or the innovative ClickBrick, that allows for the building of walls without any form of glue and therefore is completely dismountable.

The main point of the multi-level perspective is that the success of a transition is not solely determined by the success within niches but also by the way the socio-technical regime and the socio-technical landscape develop. It is the alignment between the three that will determine whether a transition will occur (Geels, 2002). The interplay between the developments in the three different levels creates internal dynamics. Changes in the slowly changing socio-technical landscape, such as cultural changes, demographic trends or broad political changes, can put pressure on the current socio-technical regime. Consequently, the connections in the regime loosen up and this creates opportunities for innovations to rise above the niche-level and be included in the social-technical regime.

### 2.2.2 *Driving dynamics in socio-technical transitions*

Suurs (2009) has developed a typology of how technological systems can transition despite their lock-in. A technological system can be defined as a “...network(s) of agents interacting in a specific technology area under a particular institutional infrastructure for the purpose of generating, diffusing, and utilizing technology...” (Carlsson & Stankiewicz, 1991, p. 21). The typologies are applicable in this research, since the construction sector consists of lots of different agents that operate in varying compositions (*networks*), to build (*technology*) according to habits and directed by legislation such as the building decree (*institutions*). However, the technological innovation systems (TIS) literature originally focusses on the innovation system around a particular technology (Bergek et al., 2015). Nonetheless, Markard, Hekkert, and Jacobsson (2015) argue that the functions of TIS (described below) are generic and can therefore be applied to the transitions of socio-technical regimes as well.

The typology consists of four so-called motors of sustainable innovation, which are reinforcing feedback mechanisms that eventually create the same effects that kept the incumbent system locked in. These mechanisms are built up from seven functions that are necessary for TIS and are described below.

- F1 Entrepreneurial activities - These activities are orientated at transferring knowledge into new business opportunities by experimenting in a commercial environment. The activities are necessary to overcome the uncertainty around the new technology and create change in the systems and its surrounding institutions.
- F2 Knowledge development - The system function entails learning activities in two forms. Learning by searching (R&D or academic research) and learning by doing (laboratory experiments or pilot projects).
- F3 Knowledge diffusion - This function is aimed at sharing knowledge between actors and networks, especially when these are heterogeneous.
- F4 Guidance of the search - This function entails activities that give direction to the transition. Individual choices regarding the technology or policy targets are examples of these activities. Additionally, the exchange of promises and expectations between actors in the system is a core element of creating that direction.

F5 Market formation - For the new technology to stand a chance in the locked-in system, the creation of artificial (niche) markets is required, to create demand for the new technology. This is (mostly) done by governmental activities that support the emerging technology to eventually support the creation of an independent market mechanism.

F6 Resource mobilization - This function refers to the allocation of material, human and financial capital to the development of the innovation. These activities are vital since a transition cannot take place if there are no means available.

F7 Support from advocacy coalitions - These activities involve persuasion and the use of political power to create structural change. They are relevant since the actors in the incumbent system will generate resistance towards the innovation.

These functions are the bases for the four motors of innovation in TIS. The first motor is the ‘**Science and technology push motor**’. The development of knowledge (F2) leads to an innovative technology (or socio-technical system in this case), that is then picked up by a governmental organisation that wants to support R&D (F4) and therefore allocates resources(F6). This increases the amount of research that is done (F2) but also leads to the involvement of firms and research institutes in pilot projects (F1). When these pilots show positive results the reinforcing mechanism will cause an increase in knowledge, resources and consequently, exponential growth appears. A negative result can lead to the decline of ‘guidance of the search’ and therefore decrease resources.

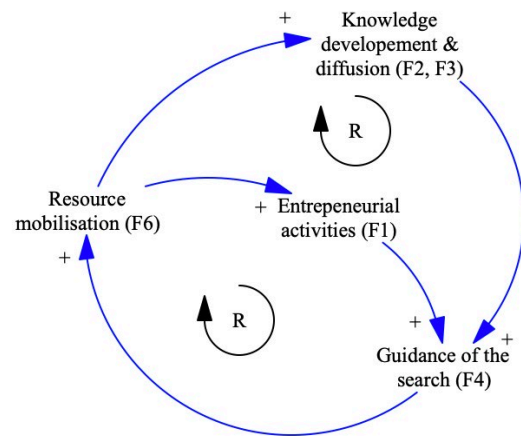


Figure 3 - The science and technology push motor.

This mechanism is shown in Figure 3.

The second motor is the ‘**entrepreneurial motor**’ and is shown in Figure 4. This motor is initiated when organisations start to develop pilot projects (F1). When these show positive results, the perceived opportunities increase (F4), consequently increasing the involvement of actors (F4) who then lobby to get funding (F7) because they require recourses (F6). These resources allow for new projects (F1) and their performance once again determines the direction of the feedback mechanism. In this stage, the presence of niche markets (F5) also improves the perceived opportunities and direction. Note that the feedback mechanisms of the

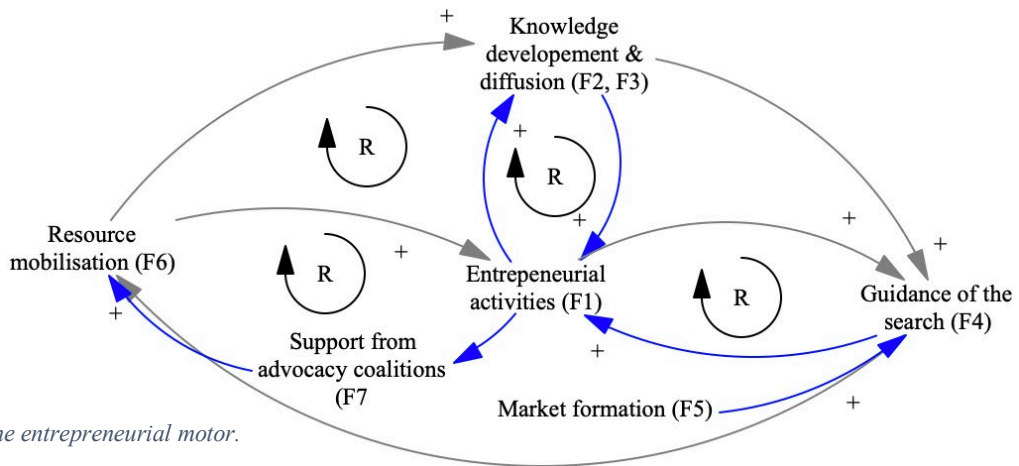


Figure 4 - The entrepreneurial motor.

‘Science and technology push motor’ are also present in this motor (grey arrows). The difference is that now the projects produce knowledge via learning-by-doing and therefore a feedback mechanism between F1 and F2, F3 arises.

When the entrepreneurial motor has created a broad base of involved actors, the ‘**system building motor**’ arises (Figure 5). The biggest difference compared to the entrepreneurial motor is that entrepreneurs are starting to organise themselves in networks with government, intermediaries and interest groups (F1). They shift their focus towards lobbying (F7) resources (F6) and change of regulations for the technology as a whole (F4), to create more momentum for the growth of mass markets (F5).

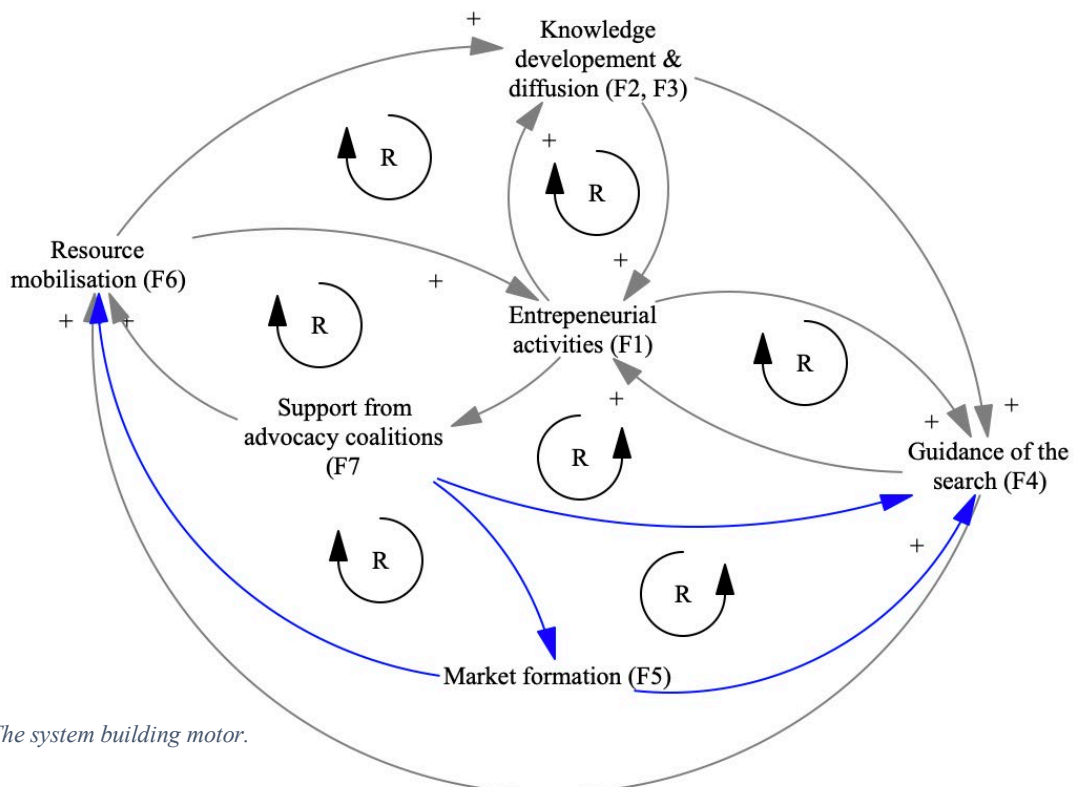


Figure 5 - The system building motor.

The last motor is the ‘**market motor**’, shown in Figure 6. The system building motor has created a market demand that is big enough that it has proven its legitimacy and therefore support by advocacy coalitions, is no longer necessary to maintain momentum.

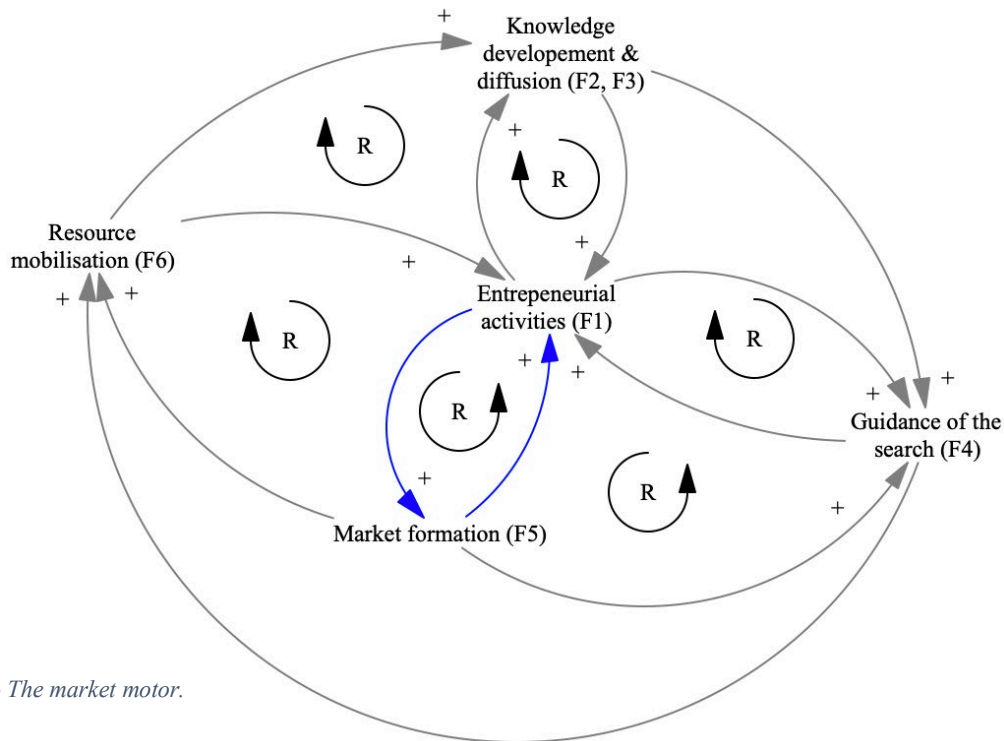


Figure 6 - The market motor.

These motors contain generic positive feedback mechanisms that describe how innovative (socio-technical) systems emerge and lock in. However, these motors do not create insight in to limiting factors that prevent socio-technical systems from transitioning. In the following section, some of the known barriers and drivers that prevent or simulate the emerging of circular construction, as a new socio-technical system, are described.

### 2.3 Drivers and barriers in the transition towards a circular construction supply chain

A driver is defined as a variable of feedback mechanism that enables and encourages the transition towards CLSC in construction. On the other hand, a barrier is a variable or feedback mechanism that restrains the transition towards CLCS in construction (de Jesus & Mendonça, 2018). Barriers and drivers for the transition towards CLCS in general can be described in four categories: Technological, social/cultural, institutional and economic (de Jesus & Mendonça, 2018; Kirchherr et al., 2018).

### *2.3.1 Technological*

As mentioned before, a core technical aspect of circular construction is dismantability. The extent to which the products and materials are dismantable, determines the amount of damage that is done to the materials when extracted from the construction and additionally reduces the costs of deconstruction (Nußholz, Nygaard Rasmussen, & Milios, 2019, p. 312). Limiting the amount of damage is essential for the material chances to be reused (Chebli, 2016). Improving the certification of secondary materials is also mentioned by Nußholz et al. (2019) as an important development to reduce uncertainty around the quality of the secondary materials and increase trust in these materials.

### *2.3.2 Economic*

Even when the necessary technologies and materials are present, there are economic limitations that prevent organizations from implementing them. The investment costs of sustainable innovation have been proven to be one of the main barriers for CE implementation (Rizos, Behrens, Kafyeke, Hirschnitz-Garbers, & Ioannou, 2015). Even though circular construction focusses on increasing future material value, consequently lowering the long-term costs of construction. Geraedts (2008) also argues that it is hard to determine whether the extra initial investment to create more dismantable and flexible construction would pay off in the future. Moreover, insufficient liquidity or market uncertainty regarding the value and demand of materials are mentioned as barriers. This indicates the need of new financial instruments, particularly helpful for small and medium-sized enterprises (SMEs) (Kirchherr et al., 2018).

Economic factors such as market mechanisms and financing are not only barriers but also drivers. As the depletion of resources continues, the availability and price will increasingly fluctuate which is an important driver for an organization to go circular (de Groot et al., 2012; Kirchherr et al., 2018). By having 'increased producer ownership' as one of its core indicators, the circular economy drives companies to maintain ownership over its materials which results in lower vulnerability to price volatility and -shocks (Junnilla, Ottelin, & Leinikka, 2018).

As already mentioned in paragraph 2.3.1, the dismantability of a building is an important element of circular construction. This is not only because of the quality of the materials. The improved quality increases the value of the materials (Leising, Quist, & Bocken, 2018; Nußholz et al., 2019). Additionally, the adjustability of a building is also improved by dismantability and this is proven to positively influence the value of a building (Greden,

2005). These increases of value should act as driver by improving the perceived pay off of circular construction.

Adams, Osmani, Thorpe, and Thornback (2017) argue that a ‘lack of market mechanisms to aid recovery’ is another important barrier in the construction sector. One barrier in this respect is the low price of virgin resources. Currently, secondary materials are not able to economically compete with virgin alternatives (Kirchherr et al., 2018). This does not only influences the use of secondary materials but also their production as argued by Preston (2012, p. 10) in the following statement: *“The recycling of many materials does not occur because it is uneconomical relative to the production of virgin material”*. Another factor that preserves a lack of market mechanism is the number of companies involved in the production of secondary materials. When more companies engage in the recovery and sale of secondary materials, the diversity of offers increases as well as the competition (Nußholz et al., 2019, p. 312).

### 2.3.3 Institutional

Policy measures are one of the main drivers for a CE. The adjustment and addition of legal frameworks and taxes can help to establish market mechanisms and a healthy environment for innovation and entrepreneurship. Yet they also form barriers when legal systems are not flexible and incentives are not properly aligned (Kirchherr et al., 2018). For example, current environmental policies define what is waste and, because of that definition, a lot of material is qualified as waste. Consequently, that material is not used in recycling/reuse processes although it is fit for recycling/reuse. A practical example in the construction industry is described by Berghuis (2019). He shows that the requirements for construction materials are sometimes so precise and strict that they do not allow for the reuse in construction. An old doorpost can be in good shape but 1 centimeter shorter than what is required, or an insulation material cannot be reused because it has lost its CE-mark.

In a predominantly linear sector, in which externalities of waste generation and resource extraction are insufficiently internalised in prices, companies still encounter numerous barriers to using secondary materials (Mont, Plepys, Whalen and Nußholz, 2017). Increasing the uptake of circular economy principles in public procurement is of the drivers that can increase the use of these secondary materials (Nußholz et al., 2019, p. 312).

#### *2.3.4 Social/cultural*

Kirchherr et al. (2018) describes customer demand as an important social/cultural driver for CE. The extent to which customers demand circular products/business models determines attractiveness of the market, but also relates to reputational gains of producing circular. Moreover, information sharing between organizations in the supply chain is also essential. But still the collaboration in the construction supply chain is currently insufficient, as shown by Icibaci (2019). This information management is an important tool to improve the ability to construct circular (Icibaci, 2019). The qualitative and quantitative information of the used materials in buildings allows for planning and design of circular buildings by architects and developers (Honic, Kovacic, & Rechberger, 2019b). Namely, only when the specifications, age, amounts, timing of release and quality of the materials in the build environment are known, one can plan and design a new building with circular materials. However, nowadays this knowledge is still insufficient (Honic, Kovacic, & Rechberger, 2019a).

#### **2.4 Conceptual model**

To conclude this chapter, the concepts described in this chapter are connected in the perceived conceptual model in Figure 7. It shows how the described barriers and drivers relate as a socio-technical regime and recognizes the influence of developments from the socio-technical landscape and niche level.

## Structural trends that influence the adoption of circular construction.

*Socio-technical landscape*

e.g., increased awareness about environmental problems, increased economic instability and supply risks due to scarcity, volatile resource prices and the political instability of resource producing countries.

*Socio-technical regime*

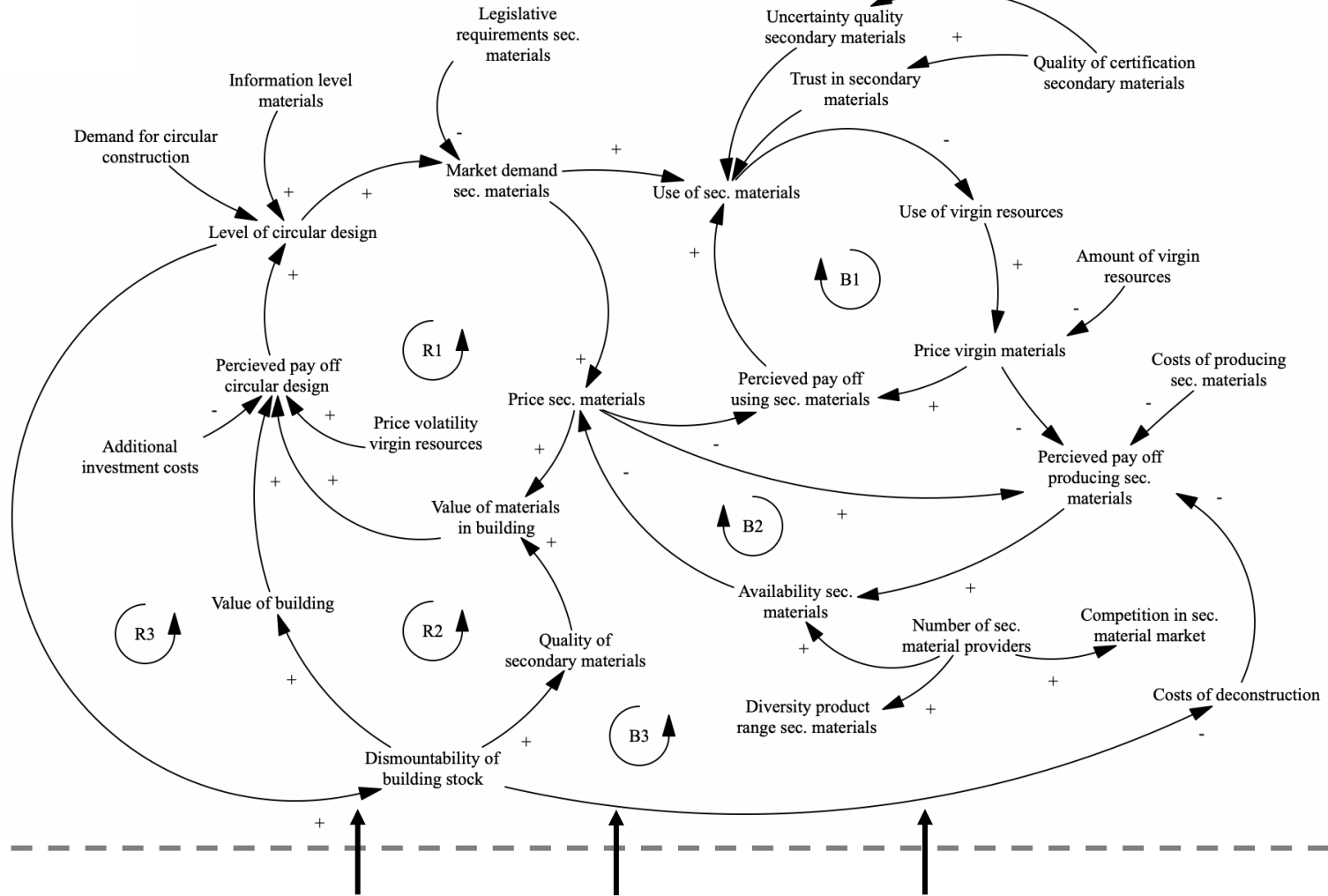


Figure 7 - Perceived conceptual model

*Socio-technical niche*

**Niche innovations that support circular construction**

e.g., Successful pilot projects, ClickBrick & Madaster

#### 2.4.1 Feedback mechanisms

Two different types of feedback mechanisms exist (Sterman, 2000). Reinforcing (positive) feedback mechanisms are drivers for exponential growth or decay. They consist of only positive causalities or an even number of negative causalities is present within the feedback mechanism (e.g., minus and minus is plus). However, a quantity cannot grow or decay infinitely because balancing (negative) feedback mechanisms create limits to the levels of growth and decay. The balancing feedback mechanisms consist of an odd number of negative causalities and cause goal seeking behaviour. The combination of positive and negative feedback mechanisms are present in every system and the way they interact determines the systems behaviour (Sterman, 2000). The feedback mechanisms in the perceived conceptual model are explained below.

R1<sup>1</sup> starts with the assumption that when the *perceived pay off of circular design* increases, the *level of circular design* by the construction supply chain also increases. It is then assumed that the *demand of secondary materials* increases which increases *the price of secondary materials*. This price increase then leads to an increased *perceived pay off circular design* because the *value of materials in buildings* become higher.

An increase in *level of circular design* also increases the *dismountability of the building stock* which increases the *quality of secondary materials* because less damage is done to the materials when they are dismantled from the building. Therefore, the *value of the materials in buildings* increases which leads to a higher perceived pay off circular design (R2). Additionally, an increase in *dismountability of the building stock* leads to a higher *value of the building* due to its flexibility, consequently increasing the *perceived payoff circular design* (R3). The *perceived payoff circular design* is also influenced by the *additional investment costs of circular design* and the *price volatility of virgin resources*.

When *market demand for secondary materials increases*, it is assumed that the *use of secondary materials* also increases. This leads to a reduced *use of virgin materials* and therefore the *price of virgin materials* drops. Consequently, the *perceived pay off of using secondary*

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<sup>1</sup> The reinforcing mechanisms are marked with an R and balancing mechanisms with a B.

*materials* compared to virgin materials decreases, which leads to a reduced use of secondary materials. This effect is shown as feedback mechanism B1 in the conceptual model @@.

B2 is a balancing effect caused by the *perceived pay off producing secondary materials*. This variable is determined by the *price of virgin materials, price of secondary materials, the costs of producing secondary materials and the costs of deconstruction*. When the *perceived pay off producing secondary materials* increases, the *availability of secondary materials* also increases. This lowers the *price of secondary materials* and therefore reducing the *perceived pay off producing secondary materials*.

The last feedback mechanism is B3. When *decomposability of the building stock* increases due to an increased *level of circular design*, the *costs of deconstruction* decrease. This increases the *perceived pay off producing secondary materials* which leads to a higher *availability of secondary materials* and therefore decreases the *price of secondary materials*. This will decrease the *perceived pay off of circular design* and with that create a balancing feedback mechanism. Apart from the feedback mechanisms, the model contains some exogenous variables based on the described theory in this chapter. Appendix 1 – Explanation causal loop diagram, contains a description of all the causal relations in the model.

Note that the perceived conceptual model only touches upon some central factors that influence circularity in the construction industry and does not incorporate all interactions. This research seeks to discover feedback mechanisms on the level of the socio-technical regime by developing a model based on the experienced drivers and barriers of actors in the Dutch construction sector. The next chapter addresses the applied methodology to develop such a model.

### **3 Methodology**

#### **3.1 Research strategy**

The current study takes an inductive case study approach to develop a causal loop diagram. The use of a case study is suitable as the research seeks to explain why a phenomenon is happening in its real life context (Yin, 2008). It takes an interpretivism approach because the research collected the experiences, understandings and perceptions of practitioners. This is well-suited with the multi stakeholder perspective of the issue at hand since interpretivism accepts the existence of multiple perceptions (Thanh, 2015).

First the study addressed transition theory which explained what functions within systems are crucial for a new system to beat the incumbent one. Furthermore it addressed the know barriers and drivers that currently influence the transition towards a closed loop supply chain in construction (chapter 2). This chapter gave guidance to the researcher during the collection of data via Group Model Building (GMB), which is a method that requires the facilitation of discussions. Therefore, it is important that the researcher has sufficient knowledge on the topic, to be able to guide these discussions. Additionally, the literature chapter supported the interpretation and explanation of the data as the described literature was used as synthesizing concepts, more on this later.

#### **3.2 Case description**

The case that is studied in this research is the construction sector, concerned with the building of residential buildings, in and around Nijmegen. This region is currently ranked 3rd when it comes to housing shortage in the Netherlands, after Amsterdam and Utrecht, with a current deficit of 5.565 houses (Friedrichs, 2019). To close this gap, the Nijmegen-region plans to build 10.000 houses before 2030. Due to the commitment of the national government towards a circular economy, circular goals have been set for the construction of these houses. Parties that are involved with existing building plans are required to seek the inclusion of 10% circular materials new building plans need to thrive towards 25% circular material use. This percentage is increased towards 50% by 2050 (Rijksoverheid, 2020).

### 3.3 Research questions

The main research question is: *What actions should be taken to enhance the implementation of secondary materials in de Dutch construction industry, when looking at the feedback mechanisms that are created by barriers and drivers for circular construction?*

To answer this question, the following sub questions have been formulated:

4. A: What drives do companies in the Dutch construction industry experience when implementing circular principles into their business activities?  
B: What barriers do companies in the Dutch construction industry experience when implementing circular principles into their business activities?
5. What feedback mechanisms do the drivers and barriers create in the Dutch construction industry?
6. Which actions should be implemented according to actors to enhance the use of secondary materials in the Dutch construction industry?

### 3.4 A system thinking perspective

To address these research questions, the study took a system thinking perspective. The categories of barriers and drivers, addressed in chapter two, are nested, and interaction between them is present, which makes the transition dynamically complex (Coenen et al., 2018; Kirzherr et al., 2018). Therefore, this research aimed to study circular construction, via System Dynamics (SD), creating a holistic understanding on how barriers and drives influence each other. Sterman (2000, p. 5) states that SD helps us to *'learn about dynamic complexity, understand the sources of policy resistance, and design more effective policies.'* In contrast to regular social science, SD does not narrow down the context, but focusses on the larger system in which the issue occurs. However, a SD model does have a so called 'closed boundary'. This means that the boundary is set in such a manner that the model entails all the elements that are significant for understanding the systems behaviour. Nonetheless, this boundary does not imply that there is no interaction with the systems environment but rather that the elements outside the boundary are judged as non-essential to explain the problem at hand (Vennix, 1996). Since the CE is a heterogeneous and multidimensional concept (de Jesus & Mendonça, 2018), such a closed boundary increases the chances of solving the right problem and designing the right actions (Vennix, 1996). The current study sets this boundary by using GMB to build the model.

### 3.5 Group model building

GMB is a method from the operational sciences that allows for the development of a model by multiple stakeholders, creating a perspective on a problem that represent multiple viewpoints. GMB allows the participants (the system actors) to set the closed boundary there where they deem appropriate. This approach also aligns with the fact that socio-technical systems are broad unit of analysis that make it hard to draw precise boundaries (Geels, 2011). Thus, due to the involvement of multiple stakeholders around the problem addressed in the current research and the difficulty of setting boundaries, GMB is suitable.

In a publication by the World Business Council for Sustainable Development and Circle Economy, a collection of core stakeholders for the transition in the build environment is described (Thelen et al., 2018). The ‘ Kenniscentrum Circulair Bouwen ’ (KCCB) selected actors from this collection based on heterogeneous purposive sampling (see Table 1). This form of sampling is based on personal judgment to select respondent that can best represent the population based on different characteristics (in this case: different positions in the supply chain). Besides, it focussed on the selection of actors, which are individuals who have the power to make decisions that can influence the system (Coenen et al., 2018), since they are the ones that need to make the transition happen. In order to maintain a manageable group during the GMB, the selection aimed to create a group of 8 to 10 participants (Vennix, 1996).

*Table 1 - Selection of stakeholders for the GMB sessions and argumentation of their relevance.*

Actor	Relevance	Session presence			
		1	2	3	4
Regulator and legislator	The regulator and legislator is the actor that can implement legislations and requirements to stimulate circular construction (Kirchherr et al., 2018). This actor was represented by a Policy advisor sustainability and an intern.	x	x	x	x
Developer	A project developer has a central role in building projects, as he balances the interests of financial stakeholders, construction companies, governments and customers. This actor was represented by a technical developer.	x	x	x	

Real estate inventor	They are one of the biggest customers in the building industry. They need quality housing for financially affordable prices and their vision on circular building is therefore essential. A policy officer and a purchasing employee were present during the sessions. This actor was represented by a policy advisor sustainability and procurement advisor.	x x x x
Demolition company	The demolition company is relevant since it stands at the start of the product lifecycle, as well as at the end. This actor was represented by the director.	x x x
Knowledge institute	This institute plays a role in the development and distribution of knowledge in the region. Two of the founders were present during the sessions.	x x x x

### 3.6 Data collection & analysis

The GMB was executed online in four sessions of two hours each. To facilitate the online sessions, electronic meeting systems were used: Zoom was used as the tool for communication, while Miro was used to facilitate divergent activities. The tool mentioned last is easy-to-use and allows for the creation of individual workspaces that helped participants with the execution of divergent scripts. Creating the causal loop diagram was done using the modelling program Vensim. These meetings were supported by Annemijn Besselink. She is a business analysis & modelling student as well and therefore has experience to support the GMB. To ensure structured and valid data collection, validated scripts were used from Scriptapedia<sup>2</sup>. This an opensource platform on which practitioners of GMB can share their scripts. The dotted arrows in Figure 8 show to which data collection each script contributed. The grey squares represent the data that was used to answer the corresponding research question. A further elaboration of the data collection and analysis is described below.

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<sup>2</sup> <https://en.wikibooks.org/wiki/Scriptapedia>

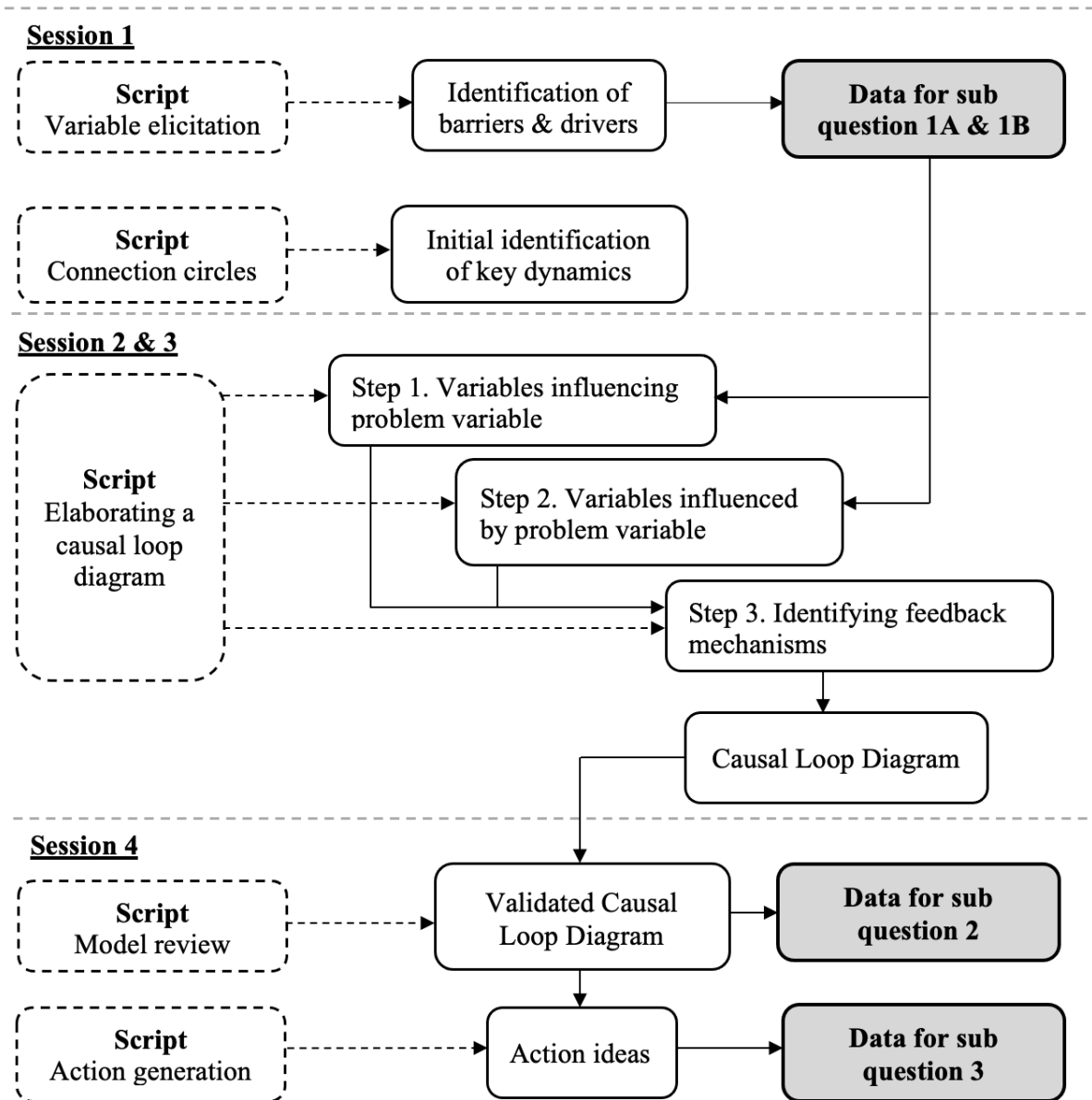


Figure 8 - Cohesion between the different sessions, applied scripts and the sub questions.

Session 1 – 11<sup>th</sup> of May 2021

First the research and its relevance were introduced, and the participants received a crash course in group model building. This entailed explaining the process of group model building and introducing the participants to the way models are drawn in the field of system dynamics. Then we moved to the Miro platform to execute the first script: ‘id. This script is used to get an initial collection of central concepts that revolve around the problem at hand and collect the data to answer sub question 1A & 1B. During this script the participants were asked the following question: “What are the key variables limiting the extent to which you can apply circular

construction?”. They were given around 10 minutes to write down as many variables that came to their mind on the red post-its. Then the participants were asked (one at a time) what their most relevant variable is they wrote down and explain it, if necessary. After each explanation, the post-it was dragged to the main screen and categorized. When everyone had shared their barriers, the above steps where repeated while addressing the following question: ‘What are the key variables driving you to apply circular construction?’. Once all drivers and barriers where shared, the facilitators reviewed the variables and categories that arose on the center of the board (see Figure 9).



Figure 9 - Miro board filled with drivers and barriers.

The second script that was executed is called ‘connection circles’. This script is used to create an initial idea on dynamics between key variables. Additionally, it was used to showcase how to think in feedback mechanisms. The participants were asked to think of causalities between the mentioned variables in the

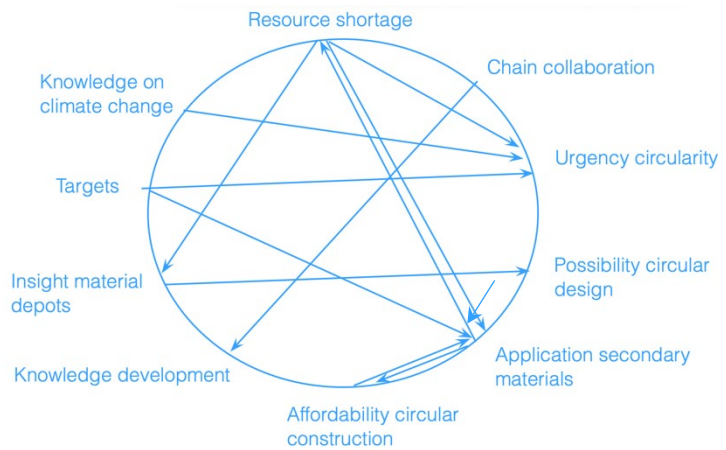


Figure 10 - Connection circle made in session 1.

previous script. The participants then pick a set of two variables and add them on the circle and draw an arrow that shows their causality. This step is then repeated, while the participants also try to find causalities between the variables in Miro and ones that were already placed in the circle. By repeating this process, a circle arose that shows causalities between a broad array of variables that were mentioned in the first script (see Figure 10). When ending the session, the found feedback mechanisms where explained.

### 3.6.1 Session 2 – 18<sup>th</sup> of May 2021

Not all the post-it's from the first sessions contained variables. To support a productive second session, the post-it's from the first session were translated into specific variables. This list was shared with the participants in advance of the second session. Additionally, these variables were categories and label based on the synthesising

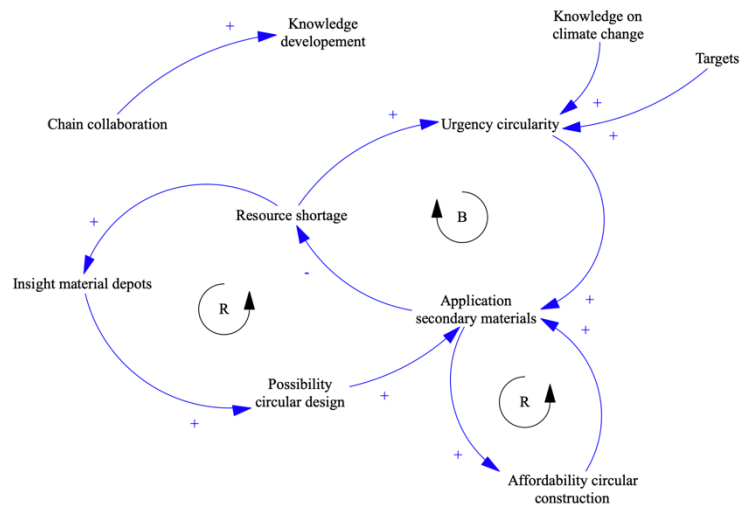


Figure 12 - Causal loop diagram resulted from connection circle.

concepts to support interpretation of the data and the answering of sub questions 1A & 1B. During categorization and labelling the recordings were used to ensure appropriate translation and categorisation of the post-its. Appendix 3 contains the content of the post-its, including the corresponding derived variable, category and TIS-function. Furthermore, the connection circle was translated into a causal loop diagram as shown in Figure 11. This CLD was used as the starting model for the second session. To scope the start of the second session, the participants

#### Poll results: Importance of variable categories

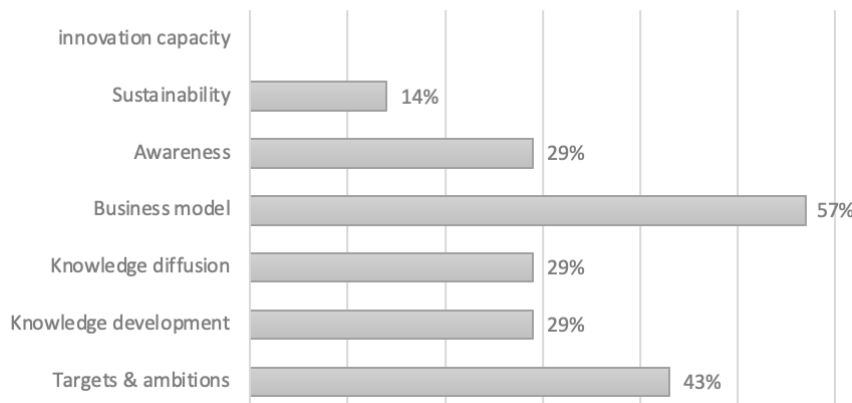


Figure 11 - Steps of 'elaborating a causal loop diagram'.

were asked to vote for the two most pressing categories of barriers and drivers (based on the labelling in appendix 3). The categories and their received votes are shown in Figure 12.

Thereafter, the script 'elaborating a causal loop diagram' was started. This script entails three steps as shown in Figure 13. During the first step, the participants were asked to look at the variables that belonged to the category 'business model' and determine if/which variables had an influence on the problem variable (application of secondary materials). This was followed by adding variables from the 'targets & ambitions' categories, followed by the remaining

categories. Thereafter the session was closed by summarising the executed activities and results of the session and by addressing the program of the following session.

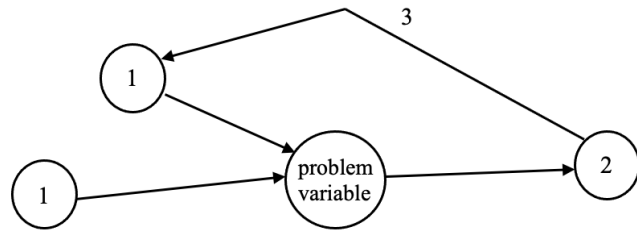


Figure 13 - Distribution of votes by participants on variable categories.

### 3.6.2 Session 3 – 25<sup>th</sup> of May 2021

After the second session the recordings were listened to adopt any elements that were mentioned but not inserted into the model yet. Additionally, the model was restructured to create a clear representation of the feedback mechanisms. The third session started with a recap and clarification of the progress made so far. Thereafter the causal structure was refined by continuing with the ‘*elaborating a causal loop diagram*’ script. This meant the identification of variables that were affected by the problem variable (step 2), followed by the identification of feedback mechanisms (step 3).

### 3.6.3 Session 4 – 1<sup>st</sup> of June 2021

Once again, the recordings were listened and the model was restructured. In the fourth session the ‘model review’ script and the ‘generating action ideas’ scripts were used. First the model review script was executed to evaluate the model and note any limitations and missing elements perceived by the participants. The participants were provided with an image of the model and were asked to make notes during the explanation of the model. Then each causal relationship and feedback mechanism was described. After that, each participants was asked to explain his/her notes and adjustments and additions based on their comments were made.

Thereafter the ‘action ideation’ script was executed. The participants were asked to write down as many actions as they could think of, that could improve the use of secondary materials in the construction sector. For every action the participant had to think of where the action would impact the model, grade the ease of implementation, and grade the impact if successfully implemented. After 15 minutes, each participant was asked to

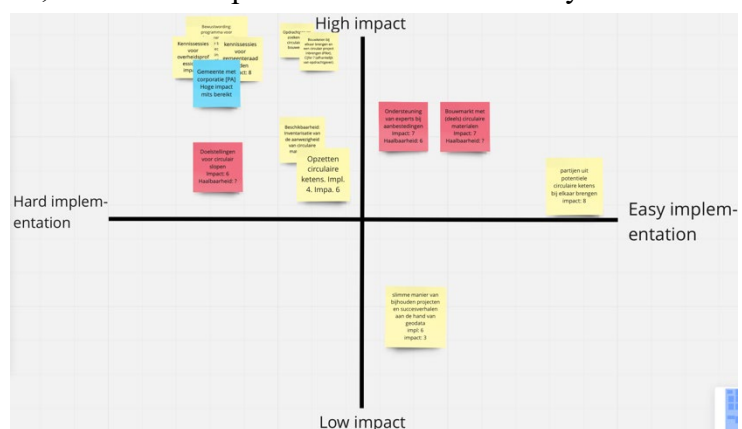


Figure 14 - The impact vs implementation matrix in Miro

explain their actions and place the post-it on the matrix as shown in Figure 14. The closing minutes of the session were used to make arrangements between participants based on the list of inventoried actions.

After the fourth session, the developed actions were also labelled based on the systems functions from the TIS-typology, to support the answering of sub question 3. Furthermore, the causal loop diagram was restructured to ensure a clear representation of the causal relationships. Thereafter the feedback mechanisms were marked and categorised, based on the synthesizing concepts if applicable.

### **3.7 Ethics**

This research adhered to the ethics code of the Chartered association of business schools. The following direct measures were taken to make sure no ethical principles were violated. The respondents were informed on the research goal, the methodology, how they could contribute to the research and how their contribution would be used, to ensure informed consent. Additionally, the respondents are anonymized to minimize the risk of harm and protect anonymity and confidentiality and they could withdraw from the research at any time. Permission to record the GMB was asked, and the recordings were not shared, except with the thesis supervisor. The collected data is neither critical or sensitive and therefore does not require extra secured storage than usual. Furthermore, the researcher was independent at all times and used peer reviewed studies in the literature study to ensure scrupulousness. A whitepaper is developed to share the results with the participants. If requested, the participants are provided with a copy of the thesis.

## 4 Results

First the drivers and barriers for the implementation of secondary material use are addressed. The complete list of drivers and barriers that were mentioned by the participants can be found in Appendix 3. Thereafter, the developed causal loop diagram is described, including its feedback mechanisms.

### 4.1 Drivers and barriers

#### 4.1.1 Sub question 1A: Drivers

As shown in Figure 15, the vast majority of drivers is related to guidance of the search. Almost all participants mentioned the growing (governmental) targets as a driver. As stated by one of the participants: *‘The legislation and targets are an important motivator. From the moment that governments start posing targets, you’ll see movement. In moments where it stays unclear what to do, only a small group will be intrinsically motivated but when you want to scale up it is convenient to have governmental targets as a threat’*<sup>3</sup>. Also, internal motivation to contribute

to a more sustainable construction sector was written down, as well as mentioned multiple times during the session. One of the participants explained: *‘Eventually, we do it to reduce our environmental impact and we see circularity as one of our core pillars to do so’*. Where another participant made the same claim by mentioning that *‘I not only want to develop a full bank account, but I also want to be able to tell my kids that I used my company to do something good for the world’*. This corresponds to the significant amount of post-its relating to the sustainable element of circular construction as a motivator i.e., *‘reduce CO2’*, *‘reduce environmental impact’* or *‘realization that current way of working is not sustainable’*.

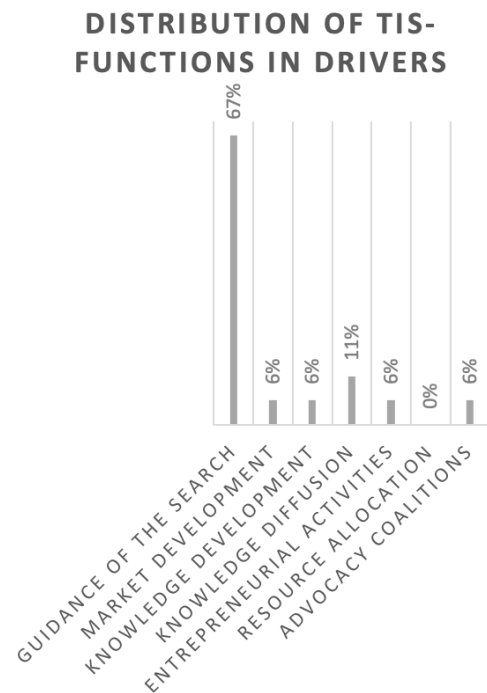


Figure 15 - Distribution of TIS-function in drivers.

<sup>3</sup> The quotes are translated to English while consciously trying to maintain the wording used by the participants.

Partly, it is the growth governmental targets that creates the next prominent motivator for the participants to develop circular production. Getting actively involved in the development of circular construction is a way to secure continuity for the organization. As stated by one of the participants: *‘I believe I need to change my organization to acquire the right for existence in the new economy’*. Additionally, the scarcity of resources and economic dependency on resource producing countries was also mentioned as part of that organizational continuity.

#### 4.1.2 Sub question 1B: Barriers

Contradictory to what is described in the previous section, guidance of the search is also the main barrier for the implementation of circular construction (see Figure 16). Even though the growing targets by governments motivate the sector to act, it was mentioned that: *‘There is no clear guideline from the government on how we can measure circularity and there is no clear definition...This makes it difficult to speak the same language.’* Therefore, the direction of the transition is unambiguous which makes it hard for organisation, within the construction chain, to set targets and goals. Additionally, it was discussed that most of the organisations lack a sense of urgency to uptake circularity into their operations. *‘What you need is a sense of urgency and the will to work together, which are both missing from the linear economy because that is what profit maximization is all about.’*

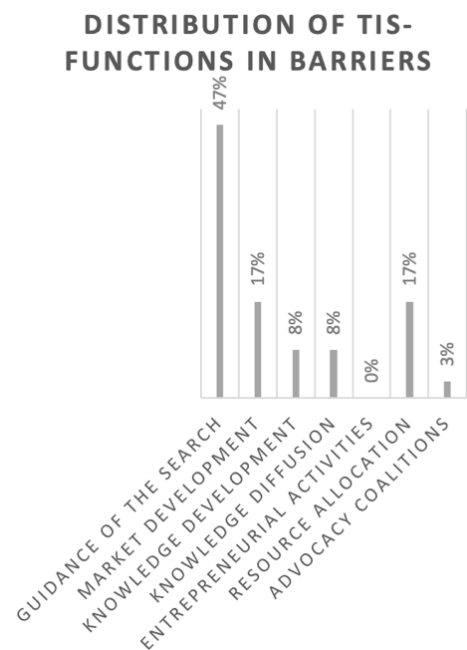


Figure 16 - Distribution of TIS-function in barriers

Apart from guidance of the search, resource allocation and market development are currently perceived as a limiting function of Technological Innovation Systems (TIS). First of all, the costs of circular construction are higher, causing a barrier especially at times of housing shortage; *‘We are all familiar with the housing shortage and the associated increased importance of costs.’* This indicates a mismatch between a landscape development and the new-to-arise socio-technical structure, as described by the multi-level perspective. Secondly, the participants mentioned that circular construction necessitates innovation, which requires the allocation of time and resources. However, as mentioned by one of the participants: *‘As a*

*company you are mainly concerned with your primary process and then you notice that there are a lot of ideas to innovate but they disappear in the delusions of the day.*’. The same counts for the building projects, where time for harvesting of materials and innovation in general is limited and perceived as a barrier. The mentioned barriers concerning market development relate to the high prices and low availability of secondary materials which therefore creates a mismatch between supply and demand. *‘It is very difficult for us to sell our materials<sup>4</sup>. There is a mismatch between supply and demand.’*

The post-its concerning barriers on knowledge development and knowledge diffusion mentioned low level of knowledge on circular construction in general and the lack of knowledge sharing e.g., *‘There is a fragmentation of initiatives.... Everyone is busy on their own island’*.

## **4.2 Feedback mechanisms in the causal loop diagram**

The causal loop diagram that was developed during the group model building session is shown in Figure 17. Below each feedback mechanism is explained and, if applicable, the exogenous elements<sup>5</sup> are described. The variables composing the causal loop diagram are each defined in Appendix 5.

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<sup>4</sup> Referring to secondary materials.

<sup>5</sup> Exogenous variables are variables that are not synthesized from within the system.

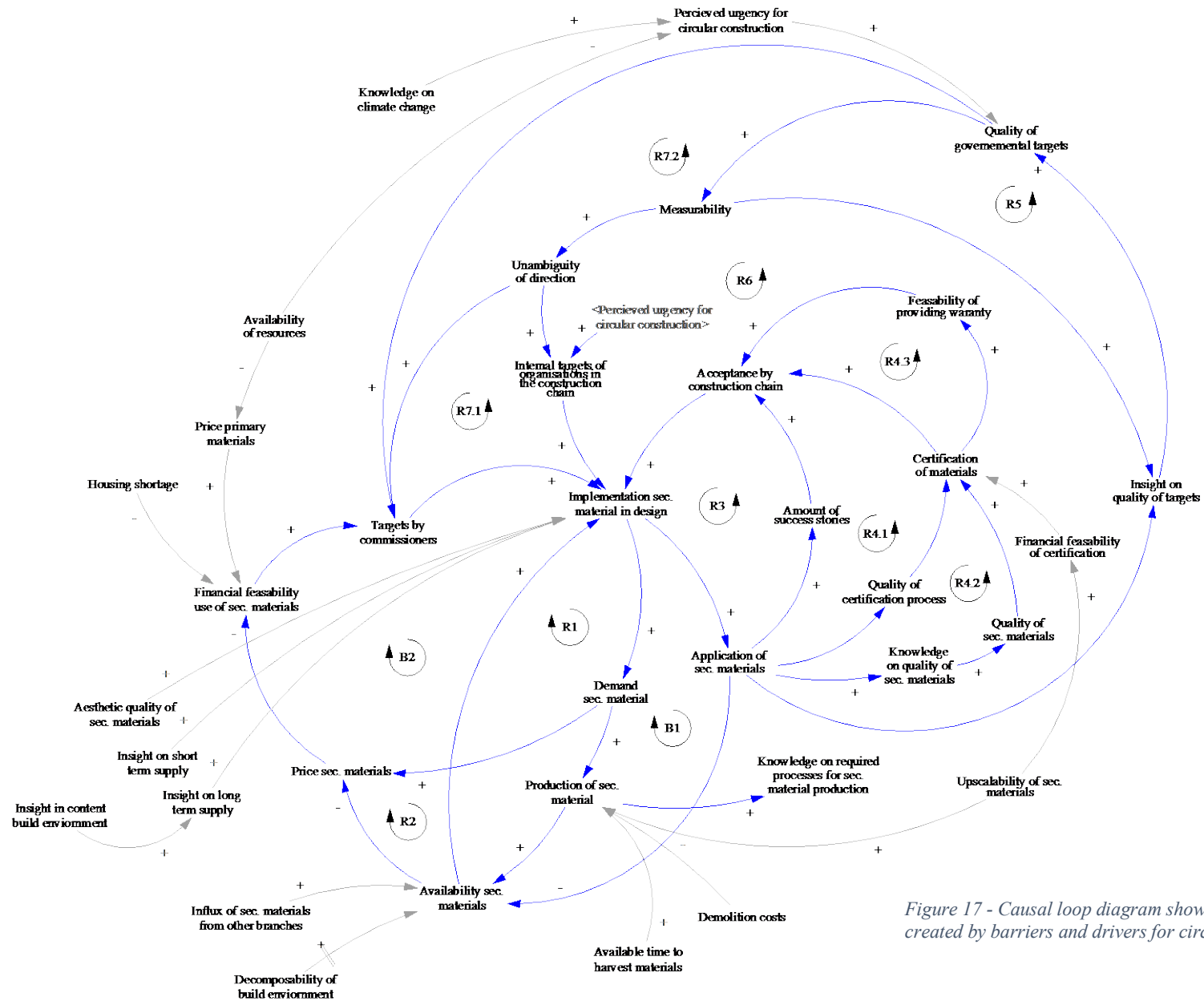


Figure 17 - Causal loop diagram showing feedback mechanisms created by barriers and drivers for circular construction.

R1 – Continuity of supply loop: When the availability of secondary materials increases, their implementation in designs will increase because the constructor will perceive a better continuity of the supply. As noted by one of the participants: *‘it is a condition for us that we don’t apply it just once ... but that we can do it serially.’* This leads to a higher demand which urges the production of secondary materials, hence reinforcing their availability. However, as described in the previous section, the producer of those materials is currently struggling to sell his stock. . Consequently, increasing production is perceived as a high risk. As noted by a producer of secondary materials: *‘If you were to look at it really big, for example thuisbezorgd.nl, they have a huge marketing budget and accepted millions of losses for a decade to eventually reach a market share in such a way that they can now start earning it back. So the question now is, how long do we have to keep pumping money into it until it starts to pay off financially.’* This indicates that producers seek to wait for an increased and stable demand before investing in increased the production. As a result, both supply and demand are waiting for an increased continuity in respectively demand and supply and therefore the reinforcing feedback mechanism is not taking off.

The implementation of secondary materials in designs is also affected by several variables that are exogenous in this model. First, the ecstatic quality of secondary materials is perceived as an important factor. Secondly, the insight into the secondary materials that will be available for construction in the short and long term has an influence. The distinction into short- and long-term was made since insight on long-term supply requires insight in the materials that are stored in the current build environment (material passports) while insight on the short-term supply is created by accessible online marketplaces.

R2 – Affordability loop: When the availability of secondary materials increases, the prices will drop stimulating the financial feasibility of using them. This allows for commissioning companies to increase the demand for secondary material use in their tenders (targets by commissioners) which will increase the implementation and thus their demand by constructors. That increase in demand will spur the production of secondary materials reinforcing their availability. As shown in the model, the financial feasibility of using secondary materials is not only determined by the price of those but also by the price of the primary materials.

B1 & B2 – Availability loop: When the use of secondary materials increases, the availability decreases and therefore the use will decrease because of two reasons. First, a decreased

availability leads to an increased price. Additionally, the lower availability decreases the perceived continuity of the supply and hence makes constructors more hesitant to implement the use of secondary materials into their designs.

Several exogenous elements were identified when it comes to the production of secondary materials. As mentioned in the section about barriers (See 4.1.2), the available time to harvest materials is currently insufficient. In consequence, an increase in time would increase production. The up-scalability of the production and demolition costs were also mentioned.

R3 – Success story loop: The reinforcing effect is set in motion when the implementation of secondary materials leads to successes that are being shared. This leads to a higher acceptance by constructors which in turn has a positive effect on the implementation of secondary materials, contributing to a reinforced amount of success stories.

R4.1, 4.2 & 4.3 – Certification & warranty loop: The use of secondary materials increases the knowledge on the quality of the materials, due to the hands-on experience when using them in the design and construction processes. This understanding supports organisations in improving their quality and consequently increases the amount of certified secondary materials (R4.2). Additionally, the use of secondary materials also directs the way secondary materials are certified (R4.1). For example, secondary materials that initially did not pass the certification criteria can turn out to be perfectly suitable for application. This insight can support changing the certification criteria and therefore increase the quality of the certification process, leading to an increased certification of secondary materials. When the amount of certifications increases, suppliers and/or constructors will be more prone to give warranty on their products and/or constructions (R4.3). These three elements improve the acceptance of secondary materials in the construction chain, leading to more implementation in design. Consequently, their use will increase creating three feedback mechanisms (R4). However, the financial feasibility of the certification process is currently limiting this reinforcing feedback mechanism. This can be reduced by increasing the up-scalability of secondary materials since the costs of certification would then be reduced per produced unit.

R5 – Measurability loop: As mentioned in the section on barriers and drivers, the severity of the governmental targets is currently one of the main drivers, but their specificity lags behind. The specificity and severity of the governmental targets are included in the model by the

variable ‘quality of governmental targets’. When increasing the specificity of governmental targets, the measurability of circular construction will improve. Together with the experience gained by applying secondary materials, the increased measurability allows for better reflection on the quality of the governmental targets (e.g., the specificity or severity). Based on that reflection (insight on quality of targets), the targets can be adjusted and better specified to improve the quality of governmental targets. The knowledge on climate change and the availability of resources also has an influence on the quality of governmental targets through the variable ‘perceived urgency for circular construction’.

R6 – Constructor guidance loop: The use of secondary materials leads to the development of knowledge on the quality of governmental targets, as described previously (R5). This allows for the adjustment of governmental targets, creating better measurability, and therefore contributing to a more unambiguous direction in the transition. This supports constructors to make specific internal goals that stimulate the uptake of secondary materials in designs, consequently increasing its application.

R7.1 & R7.2 – Commissioner guidance loop: The effect of increasing unambiguous direction, described in R6, also allows for commissioning organisations to be more specific in the requirements regarding the use of secondary materials. In turn, this increases the implementation of secondary materials in designs (R7.1). As mentioned before, the quality of the governmental targets also entails the severity of the governmental goals. When increasing the severity of these targets, the commissioning organisations are forced to increase their targets as well, which will lead to more implementation of secondary materials in design (R7.2).

### 4.3 Action development

The full list of generated actions is shown in Appendix 4. Unfortunately, due to a lack of time during the fourth session, not all the listed actions were addressed and positioned in the matrix (Figure 18).

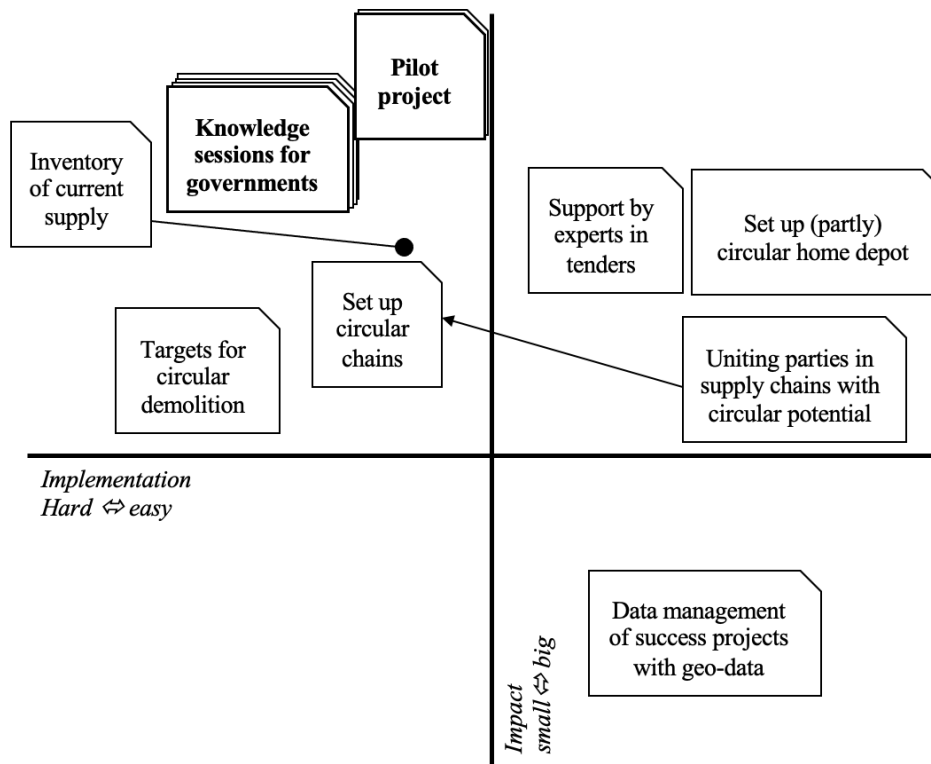


Figure 18 - Plotted actions developed during session 4 (The arrow shows linked actions and the dot shows the original position of the attached post-it).

The action with the most perceived impact being mentioned multiple times, is setting up a pilot project. As shown by the model, the application of secondary materials (entrepreneurial activity) sets in motion several feedback mechanisms that increase knowledge development and guidance of the search, leading to more entrepreneurial activity (R4, R5, R6, R7). The impact of such a project is high while the difficulty of implementation is not hard nor easy. As stated by one of the participants ‘It (setting up a pilot project) falls or stands with the will of a commissioning company.’. Another action that was mentioned multiple times is ‘knowledge sessions for governments’, with the intent to develop the knowledge base of governmental professionals involved in construction projects. The post-it ‘support by experts in tenders’ was mentioned as an easier to implement action with the same purpose, helping governments to better understand what is possible and what are the costs. These actions contribute to improving the quality of the governmental targets.

A combination of actions was made for setting up circular chains to improve the availability and financial feasibility of using secondary materials. *'If you start from the intrinsic motivation, you don't have a lot of people with you ... the moment you can make a financially viable case ... or circular materials that you can then deliver more easily or faster, then you really turn the buttons that people are already used to deciding on.'* A way to do this, according to this participant, is by developing circular chains of specific products. However, he did see the difficulty of implementation. It was then mentioned by another participant that the action 'uniting parties in supply chains with circular potential' could be a good first step.

Furthermore, creating an overview of currently available secondary materials was suggested via the action: 'Inventory of current supply' to improve the variable 'insight in short-term supply'. A more practical approach was the establishment of a home depot with circular products and was taken up with enthusiasm by several participants. This would introduce circular construction materials to consumers and therefore could increase the sales of producers of circular products, as well as create insight into the short-term supply.

To increase the up-scalability of secondary materials, the development of targets for circular demolition was suggested. This has an impact on both productions as well on the financial feasibility of certification. The last addressed action was the development of a geo data interface that allows for knowledge diffusion of success stories (R3), as well as data on availability of secondary materials.

## 5 Conclusion & Discussions

In this chapter, the main conclusions of the current study are addressed and discussed per research question, followed by the theoretical and practical relevance of those results. The section thereafter reflects on the limitations of the research. Lastly, a short consideration on the whole master thesis process is given.

### 5.1 The findings

This section answers the following main research question, by addressing the sub questions below: *What actions should be taken to enhance the implementation of secondary materials in de Dutch construction industry, when looking at the feedback mechanism that are created by barriers and drivers for circular construction?*

*5.1.1 Sub question 1A: What drivers do companies in the Dutch construction industry experience when implementing circular principles into their business activities?*

Guidance of the search was the most prominent function that currently drives the transition. More specifically, it is the increase of governmental targets that is forcing commissioning organisations to request the use of secondary materials into their tenders. The internal motivation to contribute to a more sustainable way of building is another core motivator at this stage of the transition.

It is striking that the retention of value is currently not perceived as a driver for circular construction. As one of the participants noted when addressing the motivators for circular construction: *"You mean it retains value? Well, we're not that far in practice yet."* Contradictory, value retention is frequently mentioned in the literature as one of the main drivers, and consequently incorporated in the conceptual model of this study. However, the sector does not perceive any financial pay off when it comes to circular construction. Future research could focus on the reasons why value retention is not perceived as a motivator and if and how this can be established.

### 5.1.2 What barriers do companies in the Dutch construction industry experience when implementing circular principles into their business activities?

Guidance of the search is also the system's function in which the most barriers are experienced. In this case, it is mostly the unambiguous direction of the transition that is holding back the use of secondary materials. The measurability of circularity is still perceived as low and governmental targets are not specific enough to create any guidance in what is expected. Next to guidance of the search, the market development and resource allocation is a core barrier. The use of secondary materials cannot economically compete with virgin alternatives and, due to the housing shortage, it is especially this economic factor that plays a central role during the design process. Therefore, the housing shortage is a landscape development that is counteracting the use of secondary materials. In addition, the implementation of circularity in projects requires extra time but such time to innovate is not available.

### 5.1.3 What feedback mechanism do the drivers and barriers create in the Dutch construction industry?

The feedback mechanisms found in this study can be categorised into guidance of the search loops (green), acceptance loops (blue) and market development loops (yellow). These three categories are marked in Figure 19 and described below

The prominent role of guidance of the search in the barriers and drivers is also found in the feedback mechanisms. Feedback

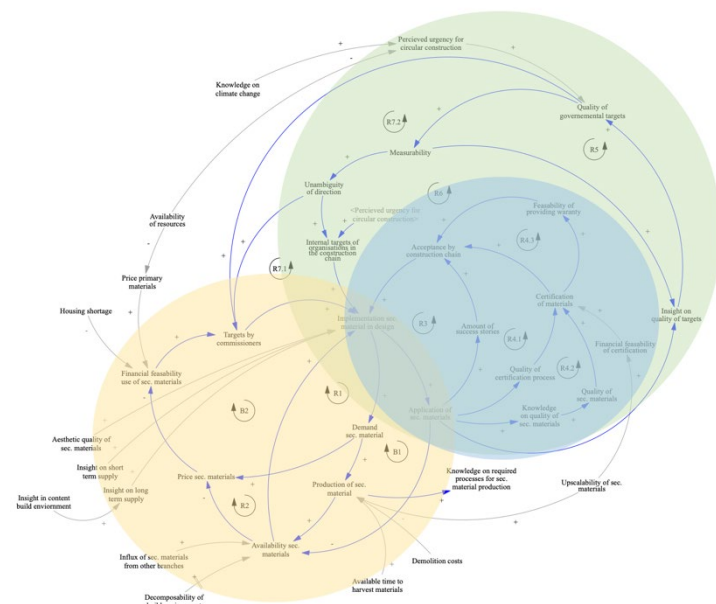


Figure 19 - Categories of loops present in the model.

loops 5, 6, 7.1 & 7.2 reinforce the development of direction into the transition. They do so because entrepreneurial activity creates knowledge on the quality of the governmental target that allows for adjustment to support unambiguous direction. That reinforces actors to increase entrepreneurial activity.

The feedback loops 3, 4.1, 4.2 & 4.3 are related to the development of acceptance within the construction chain. Certification plays a central role in reinforcing the acceptance of secondary materials since certification leads to more trust in secondary materials and increases the willingness to give warranties. Additionally, the acceptance is reinforced by the growing amounts of success stories (knowledge diffusion) that are a result of increased entrepreneurial activity, which resulted from an increased acceptance.

Four feedback mechanisms surrounding market development were discovered during the sessions. The reinforcing continuity of supply (R1) and affordability (R2) loops reinforce the market development by respectively increasing the possibility of implementing secondary materials in a serial manner and increasing their financial feasibility. These effects are limited by two balancing market mechanisms (B1 & B2) that increase the price by respectively increased demand and decreased availability. The most remarkable conclusion when it comes to market development is that the demolition contractor is waiting for a structural demand while the constructor is waiting for a structural supply (R1). As stated in the literature chapter and visualized in the conceptual model, the number of secondary material providers increases the availability and diversity of secondary materials and additionally increases competition. These are all perceived as drivers for the transition. However, as explained in this paragraph and shown by the model, it is mostly the continuity of the supply that is currently perceived as crucial.

#### *5.1.4 Which actions should be implemented according to actors to enhance the use of secondary materials in the Dutch construction industry?*

The development of knowledge on circular construction within the government is crucial in order for them to improve the quality of governmental targets. For this purpose, knowledge sessions should be held in which the governmental professionals are educated on circular construction. The allocation of an expert on circular construction to support governmental professionals in construction projects is also advised. Furthermore, most of the feedback mechanisms include entrepreneurial activity. Therefore, a pilot project needs to be initiated to actively use secondary materials and create movement in the relating feedback loops. Another advised action to improve the entrepreneurial activity is to unite actors in supply chain with circular potential. This supports the development of closed loop supply chains which improve the availability of secondary materials.

## **5.2 Theoretical- and practical relevance**

The research has contributed to the identification of dynamics that currently limit and stimulate the reuse of materials in the construction sector. The goal of this research was not to provide an absolute overview of dynamics that prevent or stimulate the construction sector in applying secondary materials into their projects, but to give an overview of dynamics created by the barriers and drivers that are currently experienced by actors. By doing so it sheds light on the cohesion between some of the concepts described in literature. Furthermore, by taking the experiences of actors as a starting point, it can support the prioritization of future research. Lastly, a multitude of these inductive case studies could be used eventually to deductively test the described dynamics in TIS typology.

There are several elements that made this research relevant for practice. First, a participatory research method was used to create the model, which supported the development of a shared speaking frame between the participating actors. Furthermore, appointments were made to further look into the actions developed in the last GMB session. Lastly, this study also gives direction for future project by the KCCB. The research also confirms that the knowledge sessions that the KCCB is currently developing are perceived as useful. Yet, the practical relevance could have been improved by having more decision-makers in the GMB sessions.

## **5.3 Limitations and future research**

As described in chapter four, most of the participants mentioned some form of internal motivation to contribute to a more sustainable economy. However, as stated by one of the participants: *'What bothers you are the people who don't participate in these kinds of sessions.'* This showcases the risk that the group of respondents is plausibly biased due to their internal motivation to build circular. Furthermore, due to the Covid-19 regulations the GMB sessions had to take place online. The implication of online GMB are relatively unknown (Wilkerson et al., 2020) but it was noticed that interaction and discussions were hard to stimulate at some times. This also might be related to the experience with GMB of the executing researcher. As a master student in business analysis and modelling, basic knowledge, and experience in GMB is present. Nonetheless, these skills are limited and consequently form a risk for the internal validity and reliability of the research. However, to improve the quality of the GMB and thus the internal validity of the research, a professor specialized in Group Model Building was consulted before the data collection to ensure an appropriate design. Risks surrounding

reliability are mitigated by using validated scripts and providing detailed descriptions of the session designs, results and data-modifications done in between sessions.

The external validity of the research is relatively low due to two reasons. First of all, a case study is only generalizable to theoretical propositions but not to populations especially when only one case is studied (Yin, 2008, p. 83). Secondly, the generalizability of a qualitative model is limited and, in order to improve this, validation in future studies is required (de Gooyert, 2018). This means that the dynamics in other regions in the Netherlands can be significantly different compared to the ones found in this study.

Because of the above, a future research suggestion is to conduct this research in multiple regions in the Netherlands to validate the barriers, drivers and feedback mechanisms found in this research. Another suggestion for future research is studying the strength of the different causalities and loops. This study treats the causalities and loops as equal but providing insight into the different strengths would allow for a better understanding of the dynamics within the system and consequently support prioritization of actions. Lastly, As mentioned earlier in this research, circular construction also requires a different approach to designing e.g., design for decomposability. It is suggested to execute a similar research while taking the decomposability of constructions as central problem variable, since this element of circular construction was not addressed during this study.

#### **5.4 Personal reflection**

In this short section I would like to reflect on some of the key difficulties and learning points of the process. I experienced a tremendous learning curve during the facilitation of the sessions, which mostly comes down to being much more comfortable with the role of facilitator. This allowed me to ask more critical questions and taught me how important it is to keep asking clarifying questions. Besides that, I experienced difficulty listening to what participants were saying while, at the same time, translating that into causal structures. Consequently, the attention of the facilitators and the participants was sometimes focused on the actual modelling instead of focusing on retrieving the right information. Getting more experienced with facilitation will reduce the time spent on modelling and therefore make the sessions more productive, consequently producing more detailed results.

Lastly, throughout the process I struggled with finding an appropriate scope for the current thesis. During the research it was mentioned, by an academic specialized in CLCS, that the scope of the research might be too large. However, by that time, agreements had already been made with the KCCB and the participants were informed about the goals of the project. It was therefore not possible to change the scope of the sessions. Eventually during the sessions, the discussion guided the scope towards the application of secondary materials. Even though scoping a big complex problem by means of GMB is common, next time I would temper my ambitions and narrow down the research to create more in-depth results.

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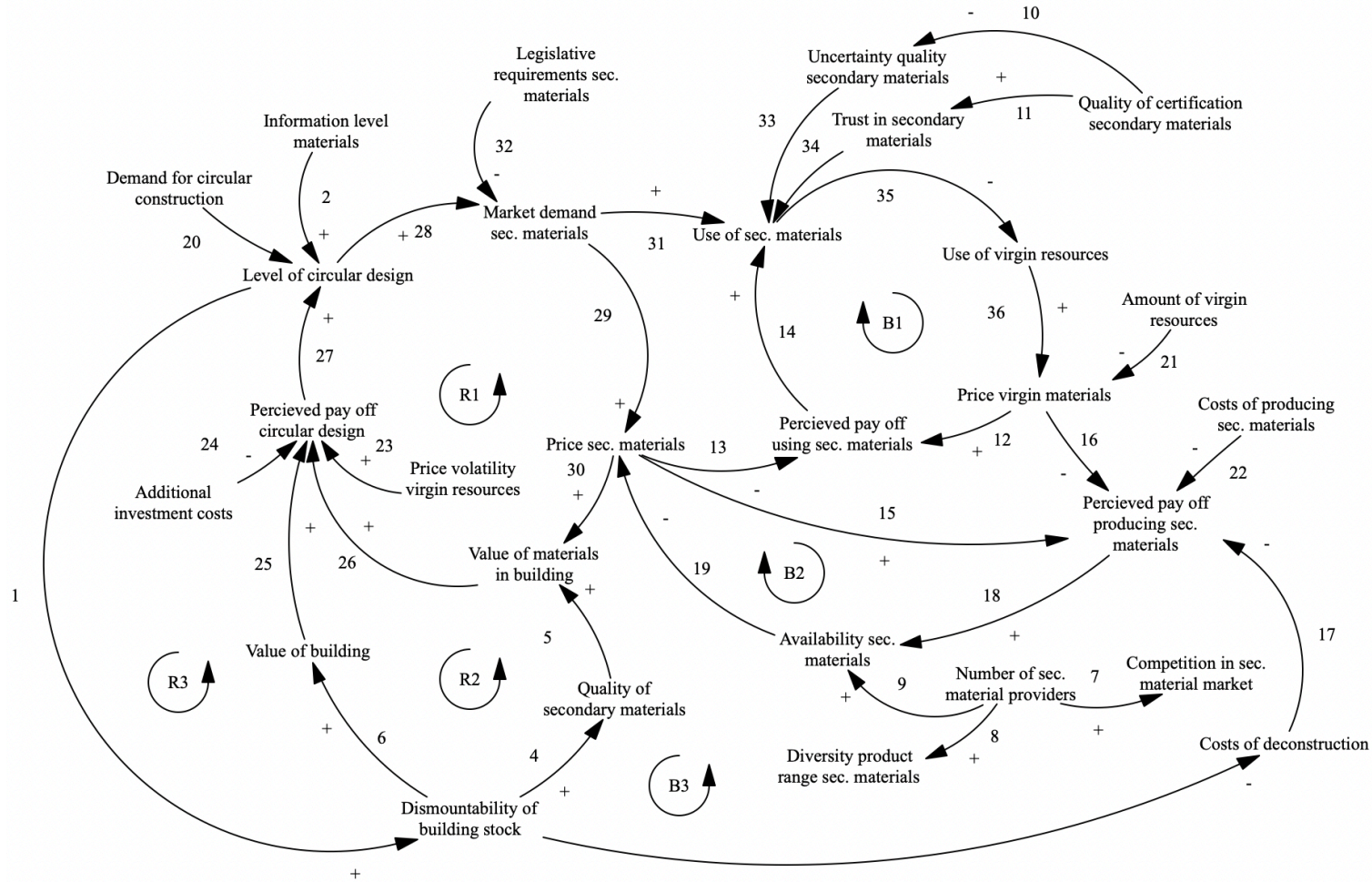
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# Appendices

## Appendix 1 – Explanation causal loop diagram

The causalities in the causal loop diagram are marked with numbers that correspond to the rows in the table below.



	<b>Dependent variable</b>	<b>Independent variable</b>	<b>Polarity</b>	<b>Description/citation on which the causality is based.</b>	<b>Source</b>
1	Level of circular design	Decomposability of building stock	+	In order to apply these circular strategies in the construction sector, it is important that the building and its EMPs are decomposable. Only then, layers or EMPs with a short life span can be replaced without destroying value in the layers or EMPs higher in the 'hierarchy' shown in Figure 1.	Chapter 2.1
2	Information level materials	Level of circular design	+	Namely, only when the specifications, age, amounts, timing of release and quality of the materials in the build environment are known, one can plan and design a new building with circular materials. However, nowadays this knowledge is still insufficient (Honic et al., 2019a).	Chapter 2.3.4
3	Decomposability of building stock	Costs of deconstruction	-	<i>'Building design for modularity, deconstruction and reuse/recycling to reduce costs for deconstruction/demolition operations and increasing quality of materials'</i>	(Nußholz et al., 2019, p. 312)
4	Decomposability of building stock	Quality of sec. materials	+	<i>'Building design for modularity, deconstruction and reuse/recycling to reduce costs for deconstruction/demolition operations and increasing quality of materials'</i>	(Nußholz et al., 2019, p. 312)
5	Quality of sec. materials	Value of materials in building	+	<i>'Where possible, suppliers retain ownership of their materials, urging them to come up with solutions that can be disassembled easily to regain material value at the building's end-of-life'.</i>	(Leising et al., 2018, p. 980)

6	Decomposability of building stock	Value of the building	+	Additionally, the adjustability of a building is also improved by dismountability and this is proven to positively influence the value of a building (Greden, 2005).	Chapter 2.3.2
7	Number of sec. material providers	Competition in sec. material market	+	<i>'Increasing the number of companies engaged in recovery and sale of resources in order to enhance competition and increase supply and diversity in offers'</i>	(Nußholz et al., 2019, p. 312)
8	Number of sec. material providers	Diversity product range sec. materials	+	<i>'Increasing the number of companies engaged in recovery and sale of resources in order to enhance competition and increase supply and diversity in offers'</i>	(Nußholz et al., 2019, p. 312)
9	Number of sec. material providers	Availability of sec. materials	+	<i>'Increasing the number of companies engaged in recovery and sale of resources in order to enhance competition and increase supply and diversity in offers'</i>	(Nußholz et al., 2019, p. 312)
10	Quality of certification secondary materials	Uncertainty quality secondary materials	-	<i>'Improving certification of recovered materials to reduce uncertainty and lack of trust from the construction contractors and engineers'</i>	(Nußholz et al., 2019, p. 312)
11	Quality of certification secondary materials	Trust in secondary materials	+	<i>'Improving certification of recovered materials to reduce uncertainty and lack of trust from the construction contractors and engineers'</i>	(Nußholz et al., 2019, p. 312)

12	Price virgin materials	Perceived payoff using sec. materials	+	<i>'If virgin material prices were higher, there would be more affordable circular products that could spur consumer interest and awareness since consumers are frequently very cost-conscious when making a purchasing decision (Pheifer, 2017); this would, in turn, spur more company interest in circular products, which then may ultimately diminish the barrier 'Operating in a linear system'.</i>	(Kirchherr et al., 2018)
13	Price sec. materials	Perceived payoff using sec. materials	-	<i>'If virgin material prices were higher, there would be more affordable circular products that could spur consumer interest and awareness since consumers are frequently very cost-conscious when making a purchasing decision (Pheifer, 2017); this would, in turn, spur more company interest in circular products, which then may ultimately diminish the barrier 'Operating in a linear system'.</i>	(Kirchherr et al., 2018)
14	Perceived payoff using sec. materials	Use of sec. materials	+	<i>'If virgin material prices were higher, there would be more affordable circular products that could spur consumer interest and awareness since consumers are frequently very cost-conscious when making a purchasing decision (Pheifer, BHGq2017); this would, in turn, spur more company interest in circular products, which then may ultimately diminish the barrier 'Operating in a linear system'.</i>	(Kirchherr et al., 2018, p. 268)
15	Price sec. materials	Perceived pay off producing sec. materials	+	<i>'For instance, Mont et al., (2017, p. 28) suggests that the "low prices of many virgin materials" would prevent CE products to outcompete their linear equivalents. Similarly, Preston (2012, p.10) argues that "the recycling of many materials does not</i>	(Kirchherr et al., 2018, p. 268)

				<i>occur because it is uneconomical relative to the production of virgin material’.</i>	
16	Price virgin materials	Perceived pay off producing sec. materials	-	<i>‘For instance, Mont et al., (2017, p. 28) suggests that the “low prices of many virgin materials” would prevent CE products to outcompete their linear equivalents. Similarly, Preston (2012, p.10) argues that “the recycling of many materials does not occur because it is uneconomical relative to the production of virgin material’.</i>	(Kirchherr et al., 2018) (Kirchherr et al., 2018, p. 268)
17	Costs of deconstruction	Perceived pay off producing sec. materials	-	<i>‘For instance, Mont et al., (2017, p. 28) suggests that the “low prices of many virgin materials” would prevent CE products to outcompete their linear equivalents. Similarly, Preston (2012, p.10) argues that “the recycling of many materials does not occur because it is uneconomical relative to the production of virgin material’.</i>	(Kirchherr et al., 2018, p. 268)
18	Perceived pay off producing sec. materials	Availability of sec. materials	+	<i>‘For instance, Mont et al., (2017, p. 28) suggests that the “low prices of many virgin materials” would prevent CE products to outcompete their linear equivalents. Similarly, Preston (2012, p.10) argues that “the recycling of many materials does not occur because it is uneconomical relative to the production of virgin material’.</i>	(Kirchherr et al., 2018, p. 268)
19	Availability of sec. materials	Price sec. materials	-	Demand-Pull Inflation <a href="https://www.investopedia.com/terms/d/demandpullinflation.asp">https://www.investopedia.com/terms/d/demandpullinflation.asp</a>	

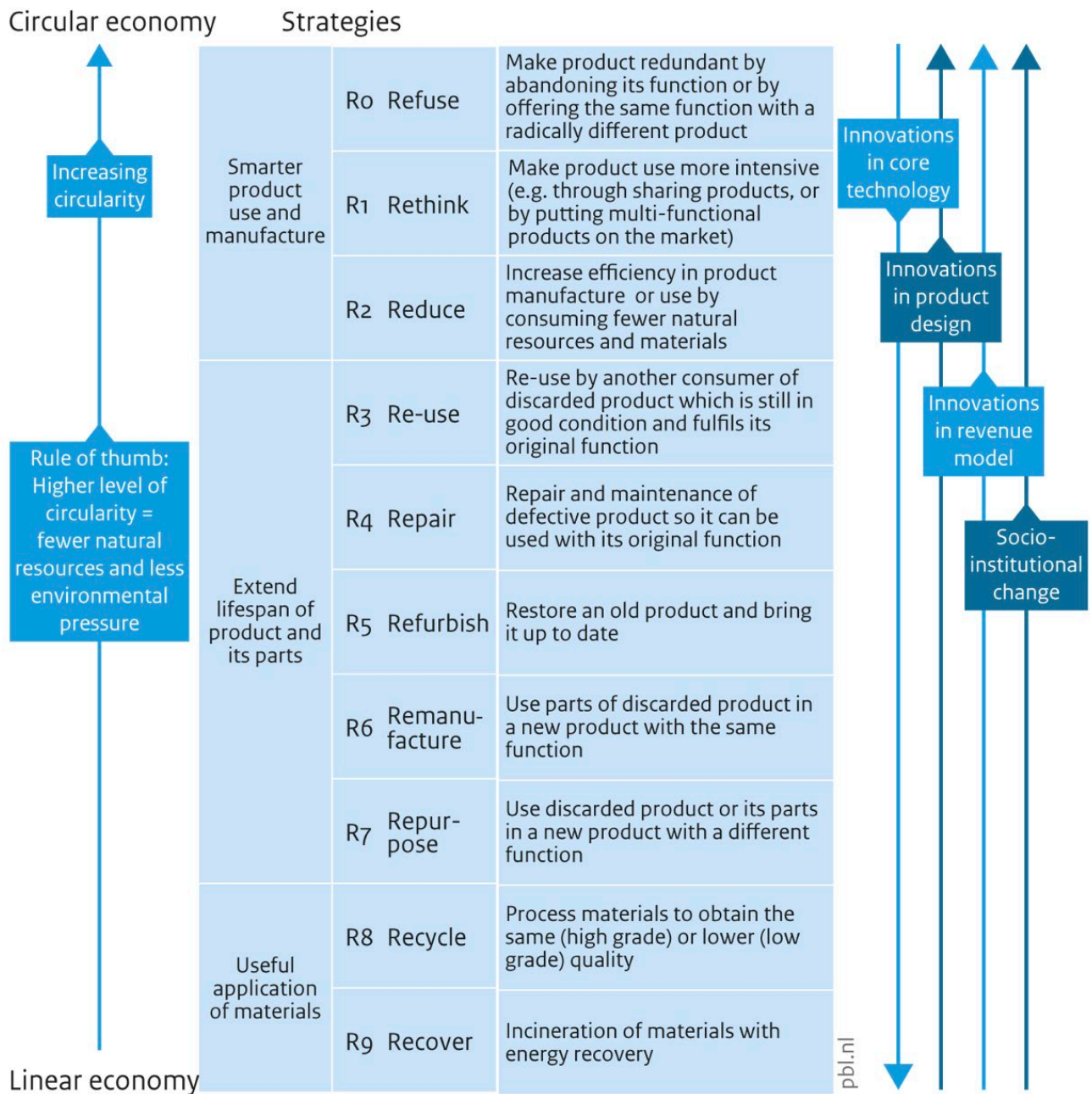
20	Demand for circular construction	Level of circular design	+	<i>‘Moreover, we note that the barrier ‘Lacking consumer interest and awareness’ may result in the barrier ‘Hesitant company culture’, as also implied by some of our interviewees, since companies are conditioned to respond to the consumer (Christensen, 1997; Friedman, 1970)’.</i>	(Kirchherr et al., 2018)
21	Amount of virgin resources	Price virgin materials	-	‘The key risks for competitiveness and future resource prices are political instability, export restrictions, scarcity, oligopolistic markets, low recycling and substitutability rates, and climate change’.	(de Groot et al., 2012)
22	Costs of producing materials	Perceived pay off producing sec. materials	-	‘For instance, Mont et al., (2017, p. 28) suggests that the “low prices of many virgin materials” would prevent CE products to outcompete their linear equivalents. Similarly, Preston (2012, p.10) argues that “the recycling of many materials does not occur because it is uneconomical relative to the production of virgin material’.	(Kirchherr et al., 2018, p. 268)
23	Price volatility	Perceived pay off circular construction	+	By having ‘increased producer ownership’ as one of its core indicators, the circular economy drives companies to maintain ownership over its materials which results in lower vulnerability to price volatility and -shocks (Junnila et al., 2018).	Chapter 2.3.1

24	Investment costs	Perceived payoff circular construction	-	The investment costs of sustainable innovation have been proven to be one of the main barriers for CE implementation (Rizos et al., 2015).	Chapter 2.3.2
25	Value of building	Perceived payoff circular construction	+	It is assumed that when the value of buildings increase (due to increased dismountability and thus flexibility), the perceived benefits of circular construction also increase.	
26	Value of materials in building	Perceived payoff circular construction	+	It is assumed that when the value of materials in buildings increase (due to dismountability) the perceived benefits of circular construction also increase.	
27	Perceived payoff circular construction	Level of circular design	+	It is assumed that the application of circular design is (partly) due to a perceived payoff of using circular construction.	
28	Level of circular design	Market demand sec. materials	+	It is assumed that when more circular building is implemented, the market demand for secondary materials also increase.	
29	Market demand sec. materials	Price sec. materials	+	Based on the assumption that a higher demand leads to a higher price.	
30	Price of materials	Value of materials in building	+	It is assumed that the price of materials in buildings is based on the price of secondary materials.	

31	Market demand sec. materials	Use sec. materials	+	It is assumed that a higher demand has a positive influence on the use of secondary materials.	
32	Legislative requirements sec. materials	Market demand sec. materials	-	A practical example in the construction industry is described by Berghuis (2019). He shows that the requirements for construction materials are sometimes so precise and strict that they do not allow for the reuse in construction. An old doorpost can be in good shape but 1 centimeter shorter than what is required, or an insulation material cannot be reused because it has lost its CE-mark.	Chapter 2.3.3
33	Uncertainty quality secondary materials	Use of sec. materials	-	In chapter 2.3.1 it is stated that ‘Improving the certification of secondary materials is also mentioned by Nußholz et al. (2019) as an important development to reduce uncertainty around the quality of the secondary materials and increase trust in these materials’, it is therefore assumed that this will increase the use of secondary materials.	Chapter 2.3.1
34	Trust secondary materials in	Use of sec. materials	+	In chapter 2.3.1 it is stated that ‘Improving the certification of secondary materials is also mentioned by Nußholz et al. (2019) as an important development to reduce uncertainty around the quality of the secondary materials and increase trust in these materials’, it is therefore assumed that this will increase the use of secondary materials.	Chapter 2.3.1

35	Use of sec. materials	Use of virgin resources	-	This relationship is based on the fact that when an organisation chooses to use secondary materials, it replaces to use of a virgin alternative.	
36	Use of virgin resources	Price virgin materials	+	This relationship is based on the over-simplified fact that an increase in demand leads to a higher price and vice versa.	

## Appendix 2 – Elucidation on the R-ladder



### Appendix 3 – List of collected drivers and barriers including labelling

Driver on post-it	Variabel	Categorie	TIS functions
Woondeal, citydeal, buyersgroup	Government objective of CE building	Targets & ambitions	Advocacy coalitions
More knowledge and experience at your own organization and partners (good examples)	Number of successful projects	Knowledge development	Entrepreneurial activities
People who are internally (and intrinsically) committed to it	Intrinsic motivation for CE building	Awareness	Guidance of the search
Circularity is increasingly in the news or more is being talked about	Media attention circularity	Knowledge development	Guidance of the search
One is going to see the connection between circularity and continuity	Perceived added value circular building	Business case	Guidance of the search
regulations	Government objective of CE building	Targets & ambitions	Guidance of the search
Assessment by the client in EMVI (Most economically advantageous tender)	Weighting CE in EMVI	Targets & ambitions	Guidance of the search
Nijmegen wants to be at the forefront of circularity	Degree of regional ambition	Targets & ambitions	Guidance of the search
Government objectives	Government objective of CE building	Targets & ambitions	Guidance of the search
If circularity becomes part of the CO2 reduction agreements (is not yet)	Degree of CE building in sustainability targets	Targets & ambitions	Guidance of the search
CE is spearhead in sustainability plan	Circularity in internal objectives	Targets & ambitions	Guidance of the search
Stricter demands from financiers	Financiers demand	Targets & ambitions	Guidance of the search
Intrinsic motivation to do things differently	Intrinsic motivation for CE building	Awareness	Guidance of the search
Awareness that the current way of working is not sustainable	Urgency awareness circular building	Sustainability	Guidance of the search

Bringing environmental impact down	Environmental impact of homes	Sustainability	Guidance of the search
Knowledge about climate change	Knowledge about climate change	Awareness	Knowledge development
Cooperation between companies, governments, knowledge institutions (and citizens)	Degree of cooperation between initiatives	Knowledge development	Knowledge diffusion
Knowledge initiatives: living lab, KCCB, Tempo table and acceleration table	Number of knowledge initiatives	Knowledge development	Knowledge diffusion
Increasing interest in sustainability	Importance of sustainability in construction projects	Sustainability	Landscape development
Younger generation more conscious about the environment		Sustainability	Landscape development
Scarcity of raw materials	Availability of raw materials	Business case	Landscape development
End consumer becoming more critical	Market demand circular construction	Targets & ambitions	Market development
Demand from clients	Market demand circular construction	Targets & ambitions	Market development
Economic dependence	Dependence on raw material suppliers	Business case	
External valuation for your business	Company image	Business case	
Future-proofing	Continuity of enterprise	Business case	
Acquiring the right to exist in circular economy / long-term policy	Continuity of enterprise	Business case	
Reducing CO2	Amount of CO2 reduction	Sustainability	

<b>Barriers</b>	<b>Variabel</b>	<b>Categorie</b>	<b>TIS functions</b>
Political interests	Political advocacy from linear economics	Innovation capacity	Advocacy coalitions
Importance in the old business model	political advocacy from a linear economy	Business case	Guidance of the search
Circularity is not so easily expressed in yield ("how does it contribute to the affordability of tenants?")	Measurability value added	Business case	Guidance of the search
Added value for resident	Measurability value added	Business case	Guidance of the search
Individual versus collective	collectivism	Innovation capacity	Guidance of the search
Willingness to change in the branches (prisoners dilemma)	Willingness to change	Innovation capacity	Guidance of the search
Lack of real cooperation (selflessness)	collectivism	Innovation capacity	Guidance of the search
Insufficient sense of urgency in the chain	Sense of urgency	Awareness	Guidance of the search
Regulations based on traditional construction	Degree of outdated regulation	Targets & ambitions	Guidance of the search
regulations	Degree of outdated regulation	Targets & ambitions	Guidance of the search
Lagging laws and regulations	Degree of outdated regulation	Targets & ambitions	Guidance of the search
Ambiguity in measurable/regulations	Policy uncertainty	Targets & ambitions	Guidance of the search
A lot of discussion about what is circular and when it is circular enough	Degree of unambiguous direction	Targets & ambitions	Guidance of the search
From ambition to operationalisation (measurability)	Measurability CE	Targets & ambitions	Guidance of the search

Lack of unambiguous vision	Degree of unambiguous direction	Targets & ambitions	Guidance of the search
Procurement requirements are not really aimed at circular	CE construction requirements in tender	Targets & ambitions	Guidance of the search
Determining circular ambition of project at the front of the project		Targets & ambitions	Guidance of the search
Circularity is seen as a separate element in a project. Circularity should not be drawn over the entire project			Guidance of the search
Lack of knowledge	Knowledge level circular building	Knowledge development	Knowledge development
Lack of basic knowledge: what is circular building and what options are there?	Knowledge level circular building	Knowledge development	Knowledge development
Training often still arranged in the traditional way of building	CE building in training	Knowledge development	Knowledge development
Circularity is more difficult and new (after all, you work differently than usual)	Knowledge level circular building	Knowledge development	Knowledge development
Fragmentation of the landscape: many initiatives that could work well together but do not yet do so	Degree of cooperation between initiatives	Knowledge development	Knowledge diffusion
Little cooperation on knowledge sharing	Degree of knowledge sharing	Knowledge development	Knowledge diffusion
Fragmentation of initiatives	Degree of cooperation between initiatives	Knowledge development	Knowledge diffusion
Availability vs. scalability	Availability of secondary materials	Business case	Market development
Circular working is more expensive	Costs circular construction	Business case	Market development
Mismatch supply and demand		Business case	Market development
sales of materials	Market demand secondary materials	Business case	Market development
Circularity is more expensive than the usual	Price secondary materials	Business case	Market development

Circularity is more expensive than the usual	Price circular design	Business case	Market development
Price is leading	Financial motivation	Business case	Resource allocation
Striving for profit maximisation	Financial motivation	Business case	Resource allocation
Time to harvest	Time to harvest	Innovation capacity	Resource allocation
costs	Costs circular construction	Business case	Resource allocation
Demolition costs (in part labour)	Demolition costs	Business case	Resource allocation
Time to innovate	Time to innovate during project	Innovation capacity	Resource allocation
Circularity is another thing that comes with it	Time to innovate during project	Innovation capacity	Resource allocation
You are more dependent on the entire chain than in the old way	Chain dependence	Innovation capacity	
Unknown makes unloved			
Linear economy			

#### Appendix 4 – List of collected actions

Action	TIS-function
Bouwmarkt met (deels) circulaire materialen	Enterpreneurial activity
partijen uit potentiële circulaire ketens bij elkaar brengen	Enterpreneurial activity
Opzetten circulaire ketens	Enterpreneurial activity
Bouwketen bijelkaar brengen en pilot project opzetten	Enterpreneurial activity
Opdrachtgever zoeken die circulair wil bouwen.	Enterpreneurial activity
Pilot projecten	Enterpreneurial activity
Gebouwen niet meer afschrijven.	Enterpreneurial activity
Doestellingen circulair slopen	Guidance of the search
Maken van prestatie afspraken tussen corporaties onderling [Samenwerken]	Guidance of the search
Maken van prestatie afspraken tussen gemeente en cooperatie	Guidance of the search
Maken van prestatie afspraken tussen corporatie met ketens	Guidance of the search
Instellen minister van circulariteit	Guidance of the search
Model om circulair Meetbaar te maken : breed in de markt zetten.	Guidance of the search
Marktconsultatie	Guidance of the search
Inventarisatie van de aanwezigheid van circulaire materialen	Knowledge development
Kennis over meerkosten	Knowledge development
Centrale plaats inrichten waar knelpunten en vraagstukken neergelegd kunnen worden.	Knowledge development
Invloed van circulair op CO2, Stikstof, pfas inzichtelijk maken	Knowledge development
Kennissessies voor overheidsprofessionals	Knowledge diffusion
Kennissessies voor gemeenteraadsleden	Knowledge diffusion
Bewustwording: programma voor ambtenaren -> wat is circulair bouwen (toepassen sec materialen). (samenwerking met KCCB)	Knowledge diffusion
Kennisdeling / cursus	Knowledge diffusion
Ondersteuning van experts bij aanbestedingen	Knowledge diffusion
Voorlichting/inspiratie VNG	Knowledge diffusion
Voorlichting/inspiratie AEDES	Knowledge diffusion
slimme manier van bijhouden projecten en succesverhalen aan de hand van geodata	Knowledge diffusion

bewustwording: initiatieven voor burgers die makkelijk toepasbaar zijn in of om huis	Knowledge diffusion
Voorlichting en kennisoverdracht organiseren voor opdrachtgevers en opdrachtnemers	Knowledge diffusion
Koplopers in de regio de mogelijkheid bieden om voorbeelden te laten zien wat wel kan.	Knowledge diffusion
Verzamelen van oplossingen in NL op gebied van garantie en toepasbaarheid sec materialen.	Knowledge diffusion
Tastbaarder maken van het verhaal door concrete voorbeelden.	Knowledge diffusion
Delen succes verhalen.	Knowledge diffusion
Subsidie voor circulaire bouwprojecten	Resource allocation

**Appendix 5 – Description of variables in causal loop diagram**

Variable name	Description of variable
<b>Endogenous</b>	
Quality of governmental targets	The quality of governmental targets entails the severity of the targets as well as the extent to which they are specific enough.
Insight on quality of targets	The extent to which knowledge exist on whether the targets are specific and severe enough.
Measurability	The extent to which circular construction is a measurable concept.
Unambiguity of direction	The extent to which actors in the supply chain are aware of what is expected from them, now and in the future.
Internal targets of organisation in the construction chain	The extent to which organisations other than governments and commissioning parties are incorporating targets for the use of secondary materials into their strategy.
Client targets	The extent to which commissioning parties are demanding the use of secondary materials in their tenders.

Financial feasibility of use sec. materials	The extent to which the price of secondary materials is acceptable compared to the price of primary materials.
Implementation sec. materials in design	The extent to which secondary materials are used in a construction design.
Application of sec. materials	The amount of secondary materials actually used in construction.
Demand sec. materials	The extent to which parties desire to purchase secondary materials.
Production of sec. materials	The amount of secondary materials that are produced.
Knowledge on required processes for sec. materials	The extent to which parties understand what processes are required of the production of different secondary materials.
Availability of sec. materials	The amount of secondary materials available to buy.
Price sec. materials	The price that retailers demand for secondary materials.
Amount of success stories	The amount of example that can be communicated in which secondary materials were successfully applied.

Knowledge on quality of sec. materials	The extent to which knowledge is present on the properties of secondary materials. (e.g., aesthetic quality, carrying capacity, ease of application, etc.)
Quality of sec. materials	The extent to which the properties fit with the required properties of construction materials.
Certification of materials	The number of secondary materials that are certified.
Feasibility of providing warranty	The extent to which parties are willing to give warranty on the sold/applied secondary materials.
Acceptance by construction chain	The extent to which the construction chain trusts the use of secondary material and therefore accepts its use in construction.
<b>Exogenous</b>	
Knowledge on climate change	The extent to which parties are aware of climate change and its impact.
Urgency for circular construction	The extent to which parties feel the necessity to build circular
Availability of recourses	The extent to which primary recourses are available.
Aesthetic quality of sec. materials	The extent to which secondary materials have the aesthetic properties that are required for the construction

Insight on short term supply	The extent to which it is know what secondary materials are for sale.
Insight on long term supply	The extent to which it is know what secondary materials will become for sale in the future.
Insight in content of build environment	The extent to which it is know what materials are currently present in the build environment.
Influx of sec. materials from other branches	The amount of secondary materials that are available for construction, coming from other sector than construction.
Decomposability of build environment	The extent to which building can be dismounted without damaging the EMP's inside.
Available time to harvest materials	The amount of time that is available for a urban miner to dismount a building and harvest the potential resources to produce secondary materials.
Demolition costs	The amount of euros that are required to decompose a building.
Up-scalability of sec. materials	The extent to which a production process for secondary materials can be increased in order to reduce the costs per unit.
Financial feasibility of certification	The extent to which a secondary material can be certified based on the costs of the certification process and the potential size of the production.

