From Demolition to Deconstruction: Engaging with Demolition Contractors in a Circular Real Estate Construction Sector

A thesis submitted to the Delft University of Technology in partial fulfilment of the requirements for the degree of

Master of Science in Construction Management and Engineering

by

Ysbrandt Christiaan Kaaks

March 10, 2023

Ysbrandt Kaaks: *From Demolition to Deconstruction: Engaging with Demolition Contractors in a Circular Real Estate Construction Sector*

The work in this thesis was made in the:

MSc. Construction Management and Engineering (track: Projects and People)
Faculty of Civil Engineering and Geosciences
Delft University of Technology

Thesis Committee: Prof.Dr. P.W. Chan

Dr. D.F.J. Schraven

A. Batallé Garcia

Preface

It is with great pleasure that I present this master's degree thesis, which is a significant part of my journey as a student of the MSc. program in Construction Management and Engineering at the Faculty of Civil Engineering and Geosciences, TU Delft.

I owe a debt of gratitude to my thesis supervisors who have supported me throughout this academic journey. First and foremost, I would like to express my sincerest thanks to my main supervisor Anna Batallé Garcia, for her continuous enthusiastic involvement during this project. I would also like to extend my gratitude to Prof. Dr. Paul Chan, the chair of the supervising committee, and Dr. Daan Schraven for their valuable feedback and constructive criticism.

I am also deeply grateful to Dave Grund from Oxand and all my colleagues at Oxand for their assistance and mentorship throughout this research project and for the possibility to have an insight in the infrastructure consulting sector. Lastly, I would like to acknowledge the unwavering support of my parents, family, and Lara, who all have been a constant source of motivation.

To my friends who have made my time at TU Delft unforgettable, I extend my heartfelt thanks. Especially my friend Wilco has been a source of great joy and comradery.

Ysbrandt Kaaks
March 10, 2023
Delft

Summary

Issue
The issue addressed in this research is that due to the transition from a linear to a circular real estate construction sector, the position of demolition contractors in the stakeholder network will change. This will change the relations of demolition contractors with other stakeholders. Research is required on how stakeholders in the circular real estate construction sector can engage with demolition contractors.

Current knowledge
Academic literature reveals a longstanding interest in stakeholder networks in a circular real estate construction sector, recommending increased stakeholder collaboration as key driver for the success of circular strategies. The stakeholder engagement matrix (Savage et al., 1991) has been applied to identify relations between asset owners, designers, building contractors and demolition contractors. Recent studies show that demolition contractors will play an important role in a circular real estate construction sector, although academic research does not propose what function demolitionists will take on in a circular real estate construction sector. Potential roles are those of ‘industrial facilitator’ (Rincón-Moreno et al., 2020) or supplier (Senaratne et al., 2021), as opposed to fulfilling an isolated role in the linear value chain.

Knowledge gap
Research is lacking on how the role of demolition contractors will be different in a circular real estate construction sector and how other stakeholders in the sector should engage with demolition contractors. What seems as two knowledge gap is in fact one: understanding the new role of demolition contractors in the circular stakeholder network will pave the way for understanding how to engage with them.

Research goal
The goal of this research is to understand how stakeholders in the circular real estate construction sector can engage with demolition contractors. Asset owners, construction contractors, and designers can benefit from this knowledge by understanding how to apply their current business processes to reuse strategies developed by demolition contractors. This way circularity is achieved by collaboration throughout the sector.

Research methodology
The research through design methodology (van Stijn et al., 2011) approach is applied to a practical context, to gather academic findings. The practical context was provided through an internship at an asset management consultancy bureau and interviews with four demolition contractors, verified by representatives from a large asset owner and research institute. The findings gathered from this empirical research contribute to overcoming the knowledge gap and are academically relevant.

Results
The design output is a visual representation of the difference between the stakeholder networks in a circular real estate construction sector compared to a linear sector, as well as a strategy framework used by demolition contractors to harvest reusable building elements. The key academic findings extracted from this design process are the identification of stakeholder relations according to Savage’s typology (1991). Demolition Contractors change roles within the context of the real estate life cycle. To asset owners and construction contractors they are characterized as ‘Mixed Blessing’ stakeholders, implying both potential for threat, but also cooperation. The potential threat to asset owners is the competition with demolition contractors over the sharing of financial risks of a reuse

strategy and over the gained profit from supplying harvested building elements. The potential for cooperation for asset owners is achieving sustainable asset management through applying a circular deconstruction strategy. The potential threat to construction contractors is based on empirical findings that demolition contractors are experimenting with engaging in construction projects with harvested building elements. The potential for collaboration between construction and demolition contractors is the opportunity for constructors to answer to the expected increase in demand for sustainable construction practices. Collaborating with demolition contractors on harvesting methods has shown to improve the quality of harvested building elements for construction purposes.

Keywords
Circular asset management; circular construction; circular demolition; circular economy; circular real estate; deconstruction; deconstruction strategies; harvesting building components; harvesting building elements; reuse of building components; reuse of building elements; reuse strategies; research through design; stakeholder engagement; stakeholder engagement strategies; stakeholder networks.

Table of Contents

1. Introduction

Modular houses built like Lego® structures will dominate future real estate according to Circular Economy principles: designing real estate for easy construction and, equally important, *deconstruction,* different to demolition, will enable closing the loop in the real estate sector (Guerra, 2021; Rahla, 2021). Innovations in this field are evolving rapidly, but to achieve the circularity goals established by the Dutch government, reuse of all building elements coming available in the real estate sector should be strived for: The Netherlands should reduce use of raw materials by 50% in 2030 and become a fully circular economy in 2050 (MIW, 2016). Nearly all existing real estate is built according to traditional (linear) construction methods: in the design and construction phase, the need for easy deconstruction has not been considered (Pomponi, 2016). This research shows that striving for maximum reuse of harvested building elements from linear built real estate requires a different approach to demolition and stakeholder relations.

A different approach to demolition can stimulate circular innovation in the real estate sector (Guerra, 2021; Rahla, 2021). One of the most promising reuse approaches is reusing building elements from otherwise demolished buildings (EMF, 2015).

Trends in academic research on the Circular Economy

Many literature studies show that the circular economy has become one of the most trending research directions for dealing with material shortage and pollution in the construction sector (Hossain et al., 2020).

There are multiple definitions for 'Circular Economy' found in academic literature and there is an ongoing discussion on how to define circular economy. Independent from such academic discussion is the common goal of the circular economy: minimizing the footprint of production by targeting zero waste production and pollution through reuse of (parts of) products (Nobre et al., 2021). The term 'waste' describes a product, or parts of, that is relieved of its function and meet their end-of-life with no fulfilment of another function.

Lahti (2018) indicated that the academic discussion on the circular economy topic is shifting from an existential discussion whether the circular economy should be adopted or not, to a discussion of the financial prospects of the circular economy. For stakeholders and intermediaries in the construction sector it is important to understand what the financial prospects of circular business processes are to prepare for the transition to the circular economy. Lahti's research identified an absence of empirical studies on economic perspectives, strategy, and organisation of the circular economy (Lahti et al., 2018). As the linear-to-circular transition may change the traditional roles in an industry, research on economic perspectives, strategy, and organisation is needed to understand how stakeholders can develop their business processes accordingly. Therefore, the transition to a circular economy in the infrastructure and built environment sector is a recent trend in academic research.

Circularity in the infrastructure and built environment sector

In line with academic literature, there are many aspects relating to the circular transition of an industry, such as economic perspectives, reuse strategies and organisational decisions. These aspects provide both challenges and opportunities for the involved stakeholders. For the real estate construction sector, the complexity of the buildings is a challenge.

Buildings are unique and complex systems of different materials with individually defining life cycles: "although buildings are made up of elements which are manufactured products, when assembled together those products create an entity" (Pomponi et al., 2016). According to Pomponi, this makes achieving circularity in the infrastructure and built environment sector more complex than more homogeneous manufacturing sectors, such as glass bottles. Pomponi identified the development of new economic models for supporting circular business processes as a major challenge in the transition to a circular built environment sector (Pomponi et al., 2016). Regarding circularity from a more technical context will inevitably bring along financial complexities.

Financial considerations for reuse or recycling

Financial complexities arise from attempting to recover useful elements from amortised buildings. Reusing building elements embedded in pieces of infrastructure or buildings that would otherwise be considered waste, whilst retaining a high functional value, is how the circular economy can be applied on assets in the infrastructure and built environment sector. 'Retaining a high functional value' describes a minimum or no loss of function when reusing embedded building elements in new assets (Van den Berg, 2020). For instance, structural elements from an end-of-life infrastructure can be reused in the construction of a new piece of infrastructure whereby the elements fulfil the same function, or these elements can be reduced to debris and used as filling material for the foundation of the same piece of infrastructure. In both cases the building elements are fully reused. However, using the building element as filling material will result in a loss of functional value: investments in the production of the building element from raw materials are lost, and investments needed to pulverize the building element need to be added. Lesser so applies to recycling: additional investments in terms of labour, energy, logistics, and materials need to be done to upkeep the recycling process. Reuse is considered a more sustainable alternative than recycling as most of the functional value is retained (Blengini et al., 2010, Vefago et al., 2013).

Demolition or deconstruction?

A distinguishing change in a circular real estate construction sector from a linear sector is the treatment of end-of-life assets. In a linear economy, an end-of-life asset is demolished, and the demolition waste is recycled or disposed. In a circular economic sector, end-of-life assets are to be dismantled to 'harvest' the embedded building elements, while striving for the highest possible value retention. This process is hitherto referred to as 'deconstruction' (Guerra et al., 2021).

Deconstructing an end-of-life asset to meet circularity goals is expected to influence technological, organisational, and external aspects of business processes of each stakeholder. Challenges arise, such as appointment of responsibility for the extra costs, selecting building elements for reuse, finding a new function for harvested building elements, and getting access to the needed building information (van den Berg, 2020). This research investigates how designers, construction contractors, and asset owners can engage with demolition contractors through strategic collaboration is expected to contribute to overcoming challenges and pave the way to a circular real estate construction sector.

1.1. Review of previous studies

In this section, key findings from academic literature are presented, whereby literature on stakeholder networks and the role of demolition contractors is analysed for understanding the relevancy of demolition contractors in a circular real estate construction sector.

1.1.1. Stakeholder networks in a circular real estate construction sector

Traditional literature on stakeholder management in the construction sector does not include demolition contractors among clients, project managers, designers, subcontractors, suppliers, investors, users, owners, employees, and local communities, which are all stakeholders included in construction project life cycles (Newcombe, 2003). Logically, traditional stakeholder analyses of the construction sector do not include the role of the demolition contractor, as it plays no role in design or construction. In a circular construction sector however, the demolition contractor harvests potentially reusable building components, therefor it should be included in a stakeholder analysis.

In traditional stakeholder management in the construction sector, stakeholders are categorised in direct and indirect (Project Management Institute, 2016) or internal and external (Atkin and Skitmore, 2008). Both direct and indirect stakeholders can exert influence on the project, direct stakeholders by influencing the execution of the project, and external stakeholders by influencing the project conditions. Investors, the project team, and suppliers are regarded as direct, whereas the public, governmental and non-governmental agencies, media, and other actors involved are regarded as indirect stakeholders (Senaratne et al., 2021). In a circular real estate construction sector, building elements harvested from deconstruction projects are the supply for new construction projects. Based on this categorisation, a demolition contractor in a circular construction sector can be regarded as suppliers, making the demolition contractor a direct stakeholder.
Savage (1991) developed a matrix for determining stakeholder engagement based on potential for cooperation with, and potential for threat to, the organisation, see figure 1.

		Potential for Threat to organization/goals	
		High	Low
Potential for cooperation with organization/goals	High	Stakeholder Type: MIXED BLESSING Strategy: COLLABORATE	Stakeholder Type: SUPPORTIVE Strategy: INCLUDE
	Low	Stakeholder Type: NONSUPPORTIVE Strategy: DEFEND	Stakeholder Type: MARGINAL Strategy: MONITOR

Figure 1: Stakeholder engagement matrix (Savage, 1991)

This matrix can be applied to identify stakeholder types in new stakeholder networks resulting from a disruption in the industry. The transition to a circular real estate construction sector is such a disruption, and the expectation is that demolition contractors will find another role in the stakeholder network. Being able to identify the stakeholder type of demolition contractors will contribute to understanding how to engage with demolition contractors.
Salvioni (2020) developed a stakeholder engagement strategy for any industry sector in the circular economy and elaborated on how engagement between industry partners in a circular economy can provide costs and risk sharing, logistic advantages, and balance competitive positioning. Sharing of strategic objectives between companies should be part of the described engagement, and “two-way communication is essential for a proactive approach”. Salvioni continues that the transition to a circular economy is not only an organisational and technical transition, but also a cultural, and an inclusive approach to stakeholder management will facilitate the cultural aspect of the transition. The expected cultural transition originates from the required development of stakeholder relations from a linear to a circular economic sector. In a linear economic sector, value creation happened in a chain with links of each two stakeholders. In a circular economic sector, value creation occurs through engagement of multiple stakeholders (Tolkamp et al., 2018). For a company to remain relevant in a circular economic system, it must be able to recognize the relevant stakeholders for the implementation of its circular strategy, and engage with these stakeholders. (Salvioni et al., 2020). Salvioni’s research illustrates a required change in stakeholder engagement in a circular economy

industry in relation to a linear economy industry. This is confirmed by the recent research 'Promoting circular economy transition: A study about perceptions and awareness by different stakeholder groups in a linear economic industry' by van Langen (2021). This research describes that a circular economic system requires more and closer strategic collaboration between stakeholders compared to a linear economic system (van Langen et al., 2021), which is juxtaposed to the competitive nature in linear economic industries (Alonso-Almeida et al., 2020).
To conclude, the transition to a circular economic system is expected to disrupt the current stakeholder paradigm, in which market competitiveness limits close stakeholder collaboration. In a circular economic real estate construction industry, sharing of strategic objectives is expected to contribute to overcoming challenges related to the highly complex nature of circular construction and demolition. This level of collaboration is especially new to demolition contractors, which are traditionally limited to being involved only in the end of the value chain in the real estate sector. Their position as supplier in a circular real estate sector shifts the position of demolition contractors in the value chain.

1.1.2. Role of demolition contractors in a circular real estate construction sector

The construction sector is known for its traditional character, and many academic sources predict an uneasy adoption to circularity for this sector (Smol, 2015; Eberhardt, 2019; Jiménez-Rivero, 2017; Geissdoerfer, 2018). There is little academic research on the role of demolition contractors in a circular real estate construction sector. Jayasinghe, 2019 identified the lack of research on decision-making in stakeholder collaborations in the post end-of-life phase of buildings, stating that "existing literature reviews have overlooked the interrelationships between the post end-of-life phase of buildings related concepts and operations" (Jayasinghe et al., 2019). Jayasinghe continues with promoting the involvement of demolition contractors in the initial design stage of buildings. However, this does not contribute to effective stakeholder engagement in circular deconstruction of currently, linear designed buildings, which logically from the majority of current building stock.
Recent academic literature on circular economic systems in general, not construction-segment specific, identifies consumers as the suppliers of reusable materials (Kozlowski, 2018; Tolkamp, 2018; Salvioni, 2020). For the construction sector however, as a business-to-business sector, it is less obvious to appoint a supplier for reused building elements.
Rincón-Moreno (2020) and Deutz (2022) describe how the concept 'industrial symbiosis' will contribute to a network of waste reuse. This concept describes how stakeholder relations in an industry resemble a natural ecosystem. In such stakeholder network, 'industrial facilitators' are put forward as the core of the network, connecting supply and demand and incentivising "managers and other stakeholders" to partake in the value chain (Blomsma, 2018; Homrich, 2018). Which specific actors should take the role of industrial facilitator is left unanswered in recent studies, while Salma (2017) explains that an increase in supply of reusable building components is an expected key driver for successful adoption of reuse strategies by stakeholders in the sector (Salma et al., 2017). Logically, the leading actor in the deconstruction of real estate is the demolition contractor. This provides the demolition contractor with the opportunity to become the supplier of harvested building elements. Potentially, demolition contractors can fulfil the role of industrial facilitator as described by Rincón-Moreno (2020) and Deutz (2022). This way, local circular economic networks are developed whereby demolition contractors are included at the heart of the circular value chain. Rincón-Moreno concluded that collaboration between alle stakeholders involved in the value chain will increase operational efficiency in the circular economic system, and Saavedra (2018) proposed the inclusion of companies, (research) institutes and policy makers in circular networks (Rincón-Moreno et al., 2020; Saavedra et al., 2018). Therefore, it is relevant to understand how included stakeholders should engage with demolition contractors as industrial facilitators in the circular real estate construction sector.

In recent academic literature, the role of the demolition contractor in stakeholder networks is being researched. In the European Journal of Sustainable Development, Forghani wrote that the large majority (90.0%) of demolition contractors agree or strongly agree that cooperation between demolition contractors and other construction professionals contributes to the reusability of building components. 10% of respondents were neutral in this statement, and none agreed or strongly disagreed. The base for these statements is 40 surveys conducted with actors in the circular construction sector in Australia, of which 15 licensed demolition practitioners. (Forghani et al., 2018). According to Leising, every actor involved during the life cycle of a building needs to fulfil a responsibility towards circularity to close the loop of materials flow. Leising continues that collaboration between all stakeholders will increase the success of circular strategies in construction, naming demolition contractors specifically among the list of other involved actors, being designers, manufacturers, contractors, recycling companies (Leising et al., 2018), but does not elaborate on the relevancy of demolition contractors' role among the other stakeholders. More recently, Senaratne (2021) stresses the importance of "suppliers of surplus material in another construction or demolition project" among clients, end users, circular economy experts, designers, and manufacturers as key stakeholders in the circular construction sector (Senaratne et al., 2021), but does not explicate which actor should take on the role of supplier or how stakeholders should engage with the supplier.

Guerra (2021) found that direct sharing of harvested building elements between stakeholders is becoming a common practice, as opposed to procurement of reclaimed materials from a secondary market. This does not advocate for a reusable building components market as it shows that direct collaboration between the supply and demand side of harvested building elements is more successful than linking supply and demand through an intermediary actor. As the current paradigm at asset end-of-life is passing on the ownership to a demolition contractor, Guerra's research reads as a recommendation for demolition contractors to collaborate with designers and construction contractors to link supply and demand of reusable building elements. This is substantiated by Guerra's conclusions from extensive stakeholder interviews that actors with a construction background proposed 'selective demolition' as the most relevant, and 'deconstruction' as the second-most relevant, strategy for a successful circular construction sector (Guerra et al., 2021). This exemplifies the recent recognition of demolition contractors as important stakeholders in the circular real estate construction sector.

A change in stakeholder roles is expected to introduce barriers for innovation to the sector, on which recent academic literature reports. Through interviews with different stakeholders in the construction sector, Guerra (2021) found five groups of barriers for the implementation of circular strategies, being: (1) budget and upfront costs; (2) schedule and project timeline; (3) lack of awareness and change resistance; (4) current construction business model; (5) lack of regulations and implementation guidelines (Guerra, 2021). In these studies, conclusions on the effect of these complexities to demolition contractors specifically is lacking. A study by Ghaffar (2020) did include the role of demolition contractors in barriers relating to achieving a circular construction sector. Ghaffar's interview with the environmental manager of a demolition contractor pointed out that demolition contractors can increase sustainability in their practices, but choose not to due to loss of competitive position. The conclusion of the interview with the demolition contractor is that demolition contractors only apply expensive circular strategies upon client request (Ghaffar et al., 2020). Hence, client willingness for reuse can be regarded as the main bottleneck to demolition contractors specifically, thereby influencing the opportunity for Demolition contractors for fulfilling the role of supplier.

To conclude, recent studies recognize demolition contractors as important stakeholders in the circular real estate construction sector. More specifically, studies implicate that demolition contractors can fulfil the role of supplier of reusable building elements. This shift in stakeholder position is expected to introduce sector-wide barriers regarding budget, time management and regulations. Focusing on demolition contractors, an expected barrier is the willingness of clients to cover the costs of reuse strategies such as deconstruction.

1.1.3. Engaging with demolition contractors in the circular real estate construction sector

The consulted academic literature clearly describes the importance of the demolition contractor in the circular real estate construction sector. However, academic literature is lacking on how other stakeholders should engage with demolition contractors in this new role.

Across academic literature, more stakeholder collaboration is advocated as key driver for circular development in the construction sector. However, the role of the demolition contractor is under-addressed. An extensive literature research covering a hundred recent studies on the circular construction sector does not describe an expected or required development for demolition contractors, but proposes to train demolition contractors in the circularity principles (Hossain et al., 2020).

Forghani (2018) confirms the recently developed awareness in the academic world that the demolition contractor has a role in the stakeholder network of a circular construction sector but does not elaborate on how stakeholders should engage with the demolition contractors exactly. Forghani conducted surveys with demolition contractors in Australia and thereby revealed that 37.5% of demolition contractors do not have a “strategy, guideline or goal for the practice of reusing building components”. This shows that the demolition sector has not yet fully adapted to the circular economy. On the other hand, this also shows that 62.5% of demolition contractors *do* have a strategy for reuse practices. The study does not illustrate what these strategies are, neither how other stakeholders can engage with these strategies or vice versa. Forghani recommended for further research to develop an “appropriate communicative and interactive system” for stakeholders in the building industry to engage with demolition contractors. (Forghani et al., 2018)

Salvioni (2020) stresses that for a company to remain relevant in a circular economic system, it must be able to recognize the relevant stakeholders for the implementation of its circular strategy, and engage with these stakeholders (Salvioni et al., 2020). Recent studies (see section 5.2.) recognise the importance of demolition contractors in the circular real estate construction sector, however, developing a communicative and interactive system, (Forghani, 2018), or understanding how to engage with demolition contractors (Salvioni, 2020), is less researched.

1.1.4. Review of previous studies - Conclusion

Drawing from the key findings in academic literature on stakeholder networks in circular industries and the role of demolition contractors in the built environment sector, it can be concluded that the stakeholder network in the construction sector will change in the transition to a circular economy. Recent studies have shown that demolition contractors will play an important role in this new stakeholder environment. However, academic literature is lacking understanding on how other stakeholders should engage with demolition contractors in this new stakeholder environment.

1.2. Problem statement and knowledge gap

Literature study shows an academic interest in stakeholder networks in the circular real estate sector, and applying academic insights to the expected disruption in the stakeholder network identified in the empirical study reveals the problem statement addressed in this research.

The problem statement is as follows: demolition contractors are expected to obtain the role of supplier of reusable building components in a circular real estate construction sector. As demolition contractors are traditionally positioned at the end of the linear value chain, stakeholders traditionally positioned at the beginning of the linear value chain have no history of collaboration with demolition contractors. Academic literature points out the increasing importance of interdisciplinary stakeholder collaboration throughout the transition to a circular real estate construction sector. Although recent studies have shown that demolition contractors will play an important role in a circular real estate sector, there is lacking academic research on how other stakeholders should engage with demolition contractors.

Above problem statement has led to the formulation of the three sentences defining the knowledge gap addressed in this research:

1. There has been longstanding interest in stakeholder networks in a circular real estate construction sector.
2. Recent studies show that demolition contractors will play an important role in a circular real estate construction sector.
3. However, research is lacking on how stakeholders in the sector should engage with demolition contractors.

In addition to this problem statement, empirical study and literature analysis prognose many barriers and challenges for the transition to a circular real estate construction sector. The high competitiveness in the demolition market, and the heavy dependency on the willingness of asset owners to engage in circular projects are the main barriers found in this research phase.

A potential solution to the problem statement is a strategy framework for how construction companies and asset owners can engage with demolition contractors. Being able to place the demolition contractor in a stakeholder type according to Savage's (1991) matrix (see section 5.1.) will support the process of developing a suitable strategy. Next, understanding demolition contractors' strategies for achieving reuse of building components will contribute to finding business opportunities for strategic collaboration with other stakeholders.

1.3. Research questions

This research will ultimately answer the main research question. In order to answer this overarching problem, an exploratory, methodological, results-oriented, and existential sub-question have been formulated. Answering the exploratory research question will gather all factors of influence relating to the solution space. The methodological research question serves for asking how to draw results from these factors of influence. The results-oriented question serves for formulating the results. Lastly, the existential research question is answered to put the results from this research in an academic context.

Main research question
How should stakeholders in the circular real estate construction sector engage with demolition contractors?

Exploratory research question
How will the position of demolition contractors in the stakeholder network change in the transition to a circular real estate construction sector?

Methodological research question
What research method supports the development of a strategy for stakeholders in the real estate construction sector to engage with demolition contractors?

Results-oriented research question
How can the stakeholders in the real estate construction sector apply their business models to the reuse strategies of demolition contractors?

Existential research question
How does understanding of engagement with demolition contractors contribute to the transition to a circular real estate construction sector?

1.4. Research strategy

The combined answers to the research sub-questions will comprise the answer to the main research question (see Section 6. *Conclusion*). The below mentioned sections in this thesis report contribute to answering different research questions. Answers to the exploratory (Section 2. *TOE Analysis*) and methodological (Section 3. *Methodology*) research questions are expected to be found through academic literature research. Whether the found methodology does indeed support the methodological question is validated through execution of the methodology in Section 4. *Results*. Answers to the results-oriented research question is expected to be found by analysing qualitative interview data from practitioners, as incongruency between academic and empirical knowledge is expected. Below is described which research question is answered in each section, along with the research strategy per section.

Section 2. *TOE Analysis*	Exploratory research question	The TOE framework (Technical, Organisational, Environmental) is applied to analyse the development of the demolition segment in the transition to a circular real estate construction sector. Qualitative data from Sub-section 1.1. *Review of Previous Studies* and from the internship period at the asset management consulting company Oxand are the input to the TOE framework. The TOE analysis will conclude with answering the exploratory research question.
Section 3. *Methodology*	Methodological research question	Section 3. *Methodology* will expand on applying the Research through Design (RtD) methodology as interpreted by van Stijn et al. (n.d.) on the problem statement of this research, substantiating the relevance of this particular methodology to answering the research questions. Furthermore, the interview protocol is described in this section. Section 3. concludes with answering the methodological research question.
Section 4. *Results*	Results-oriented research question	The three RtD stages (analysis, synthesis, evaluation) are carried out in Section 4. *Results*, whereby the results-oriented research question is answered in the sub-section 4.4. *Knowledge Extraction*.
Section 5. *Discussion*	Existential research question	Section 5. *Discussion* will relate the results of this research to the theoretical, and will reflect on the empirical relevance of this research, thereby answering the existential research question.
Section 6. *Conclusion*	Main research question	The conclusion will answer the main research question and reflect on the research, identifying limitations and proposing recommendations for further academic research.

1.5. Scope

This research is conducted during an internship period at Oxand, a consulting company for asset management in the real estate and infrastructure sector. Academic literature research is complemented by a case study at Oxand to identify Technological, Organisational and Environment aspects of harvesting building elements from end-of-life assets for reuse. 'Environment aspects' describe external influences on the system, not to be confused with the physical 'atmospheric' environment. Expected is that this will break down the complexity of the system and identify opportunities for Oxand to develop circular strategies for its clients.

To fulfil its clients' needs, Oxand has developed its proprietary software tool, Oxand Simeo, which is used to monitor the state of building elements embedded in real estate and infrastructure assets and to provide predictive maintenance advice to clients. A detailed description of Oxand's predictive maintenance protocol can be found in Appendix 12.2. This protocol has been designed to develop the most effective and efficient maintenance strategy for a built asset during its lifetime. However, as the scope of Oxand's services currently ends at the technical end-of-life of assets, the company anticipates a required shift in its business model as the construction sector will move towards a more circular model. To remain relevant in a circular construction sector, it is proposed that Oxand expand its scope of value proposition beyond the end-of-life phase of built assets by including reuse strategies of building components in its consulting services. This development is expected to trigger innovations across several disciplines within Oxand's business model. This research will focus on the business processes of demolition contractors for two reasons. First, the issue addressed in this research evolves around the end-of-life moment of a real estate asset. Demolition contractors are inherently involved in managing or operating whatever happens with the real estate asset at this moment. Secondly, this research uses the empirical background provided by the asset management consulting company Oxand. This company mainly has construction companies and asset owners within its customer base. Expected is that the solution space to the research problem may not be found within Oxand's own business model.

The scope will be set on reuse of building elements from real estate only. A building element is a part of a real estate asset (housing, office buildings, factory halls) that consist of multiple building components. Throughout this research will be referred to building elements when discussing operations of reuse strategies, however this may also include building components. The specific nomenclature is less relevant than the notion that parts of buildings, components, or elements, can be harvested as potential construction stock for new buildings. In the technical aspect the focus will lie on the materials brick (masonry), concrete, timber and steel as these elements have the highest share in weight in real estate assets.

2. TOE Analysis

Based on a case study at Oxand and confirmed by academic literature, it is expected that the relevance of demolition contractors to the construction sector will change throughout the transition to a circular construction economy. For Oxand it is relevant to understand how demolition contractors will develop throughout the transition to a circular construction sector as Oxand is anticipating on demolition contractors becoming more relevant to its clients.

TOE analysis explained

In this section, a TOE (Technological-Organisational-Environmental) framework is used to analyse the relevancy of demolition contractors to a construction sector applying circularity. Within the TOE framework the technological, organisational, and environmental aspects of operating in a circular construction sector are explained from the perspective of the demolition contractor. The TOE framework has been designed by Tornatzky and Fleischer in 1990 to prognose or evaluate how a business or organisation’s situation influences the adoption of a new technology or (economic) paradigm (Baker, 2011). In this research, the TOE framework is used to prognose how the adoption of a circular economy by the construction sector will change the technological, organisational, and environmental aspects of demolition contractors’ practices.

Relevance of TOE analysis

The TOE framework is specifically applicable for assessing the adoption of innovation in any sector. The aspects and sub-aspects of the framework as described in section *2.1. TOE analysis* allow the allocation of insights gained from academic literature or empirical studies in a wide range of categories. The complex nature of this research’s problem statement asks for such an approach. Furthermore, the problem statement is of a practical nature: demolition contractors are practitioners in their sector. The TOE analysis is suitable for assessing insights gained from both academic literature, as from the internship period at Oxand. This assessment will contribute to conducting an effective interview protocol with demolition contractors, translating academic knowledge to the practical and back.

2.1. TOE framework

The TOE (Technological-Organisational-Environmental) framework described by Tornatzky and Fleischer is applied to the innovation of *demolition* to *deconstruction.* For the real estate sector to develop to a circular economic system, end-of-life buildings should no longer be demolished, but deconstructed, to retain value of the used building elements becoming available for reuse. This innovation is expected to change the business processes of demolition contractors, introducing technological, organisational, and environmental complications.

Technological factors play a crucial role in the adoption of the circular economy by the construction sector. The availability of new and innovative technologies that are more sustainable, more efficient, and more circular, such as modular and low-maintenance building components, but also disassembly techniques, can facilitate the implementation of the circular economy. Moreover, technical characteristics of building elements such as material, type of connections between elements, and adaptability of the element are expected to influence the development of circular strategies.
Organisational factors are also essential in the adoption of the circular economy. Given the traditional nature of the industry, effective communication and collaboration are crucial for the successful implementation of circular economy practices. Furthermore, a strategic and systemic approach to innovation is necessary to fully embrace the entire value chain of the construction sector and to effectively navigate the complexity of various value propositions and stakeholder needs. One key

aspect of embracing the full value chain is recognising the importance of stakeholders involved after the end-of-life of building elements. Organisational factors after end-of-life of assets are not included in the linear viewpoint. Hence, it is expected that a new approach to engaging with stakeholders in the circular construction sector will be required. The industry will need to develop new ways of communicating and collaborating, which is crucial for the successful adoption of circular economy practices. These efforts will likely involve the cultivation of new partnerships and collaborations across the value chain.
Environmental factors can also have a significant impact on the adoption of the circular economy. The availability of policy frameworks and regulations, such as building codes and environmental standards, can create incentives and support for circular economy practices, and create barriers for those who do not meet them. Moreover, societal and consumer awareness and demand for sustainable products can also create pressure on the construction industry to adapt to circular economy practices.

In conclusion, the TOE framework provides a useful perspective to understand the adoption of the circular economy by the construction sector. It highlights the importance of technological, organisational, and environmental factors that need to be addressed to successfully implement circular economy practices. By considering these factors, organisations in the construction sector can develop strategies that align incentives and foster collaboration across the value chain, as well as ensure compliance with regulatory frameworks and consumer demand.

2.1.1. Technical

In this subsection, the technical aspects of the transition to a circular economy be analysed from the perspective of a demolition contractor. The technical aspects are comprised of 'availability of needed techniques' and 'technical characteristics'.

Technical - Availability of needed techniques

Deconstruction
Deconstruction, or disassembly, is found across academic literature as a key element in successful reuse strategies (Bertino et al., 2021; Coenen, 2022 Iacovidou & Purnell, 2016; Rios et al., 2015). Deconstruction implies reverse construction: taking apart the elements that comprise a building while preserving the state of these elements to keep them applicable for reuse, as opposed to demolition, in which elements no longer retain function.
In order to deconstruct buildings effectively, new techniques are required for harvesting elements. which is a means to a quick end to the building's lifecycle, discarding the debris for landfill or recycling. It is expected that the cost of adopting these new techniques will be substantial, due to high labour costs and the requirement of specialized equipment. This requires a serious commitment of the demolition contractors, forming a technical barrier.
Demolition contractors would need to adopt new techniques for treating end-of-life buildings in order to preserve the functional value of harvested elements. Expected is that these techniques bring along higher costs due to special labour and equipment requirements, and due to more time spent on demolition operations.
Iacovidou and Purnell present interventions in the construction and demolition sector, based on literature analysis, which can guide actors in the sector to engage in successful reuse strategies. Three of the five interventions propose strategies for designing newly built assets (see Appendix 1: Reuse potential of a range of construction components (Iacovidou & Purnell, 2016). The "adaptive reuse" and "deconstruction" interventions describe, respectively, reusing structural elements in good condition of a building with outdated skin; services; and/or space plan, and disassembling a building instead of demolishing it. Adaptive reuse is characterised by the development of different reuse

strategies for different building elements based on the elements' characteristics. Challenges for adaptive reuse are "lack of information on the performance of reclaimed elements, legislative and safety issues, accessibility, and heritage constraints".
Deconstruction is characterised by the needed investment of a labour-intensive process for the benefits of reduction of construction and demolition waste and harvesting of building elements for reuse. Challenges for deconstruction are achieving financial feasibility despite high labour and machinery costs, the need for experienced personnel, uncertainty in the reclaimed building elements market, as well as complex time management due to the traditionally short time span for demolition and dependency on construction planning of new projects (see Appendix 3).

Building information
Academic literature on building information management (BIM) for improving construction and maintenance processes is abundant. However, there is little research on using building information for efficient deconstruction of a building. A recent empirical study in the Netherlands by van den Berg (2020) stresses the importance of reliable building information at the end-of-life phase, and continues that this is often absent, leading to the treatment of reusable building elements as (recyclable) waste. This substantiates the need for cataloguing building element properties for assessing reuse value before deconstructing the building (Van den Berg et al., 2020). 'BIM' is a recent innovation that has potential to provide demolition contractors with useful knowledge for efficient deconstruction, but as Van den Berg states, reliable building information is often absent at the END-OF-LIFE phase of buildings. Therefore, demolition contractors may benefit from receiving any reliable building information from the client, whereby ultimately BIM may play a role.

Technical – Characteristics
According to academic literature, the following technical characteristics are relevant when assessing harvested building elements for reuse: material type (Antonini et al., 2020; Bertino et al., 2021; Cai et al., 2019; Finch et al, 2021; Heisel et al., 2020; Rahla et al., 2021). When assessing structure and skin layers (Brand, 1996), the most relevant material types in the structure and skin layer are brick, concrete, steel, and timber.

According to Rahla (2021), for efficient reuse of structural steel elements mechanical connections are preferred to chemical ones, and the connections need to be accessible and easily detachable. Apart from the type of connection, a low number of connections between building elements is important as well (Rahla et al., 2021). Antonini (2020), Heisel (2020), Cai (2019), Finch (2021). Bertino (2021) presented reversibility as one of the indicators for reuse potential of a building. High reversibility means easy dismantling with none to low damage to the harvested elements. Easy detachable connections, as well as a low number of connections, increase reversibility.

Reuse potential of the most relevant building elements
Based on a literature review of 16 sources on building materials properties between 2002 and 2014, Iacovidou and Purnell formulated four reuse potential rates of reuse potential: no potential, low potential, medium potential and high potential. Different building materials have been included in this categorization, which can be found in Appendix 1: Reuse potential of a range of construction components (Iacovidou & Purnell, 2016). From this categorization, the most significant findings for the scope of this research are brick, concrete, steel or wooden building materials for real estate. As non-reusable has been categorised: masonry with cement-based mortar, steel rebar, steel connections, structural concrete, non-ferrous metal elements (aluminium window frames). Structural steel can be found in both the low and high reusable categories. Apart from structural steel, structural timber is also listed in the high-reuse potential category. Other materials to be found in this category,

relevant to the scope of this research, are clay masonry with lime-based mortar (as opposed to cement-based mortar), concrete building blocks, and non-glued and non-casted forms of paving and roof covering. Different forms of concrete-based building elements have different reuse potentials. Detachability is the determining factor for these elements, hence in-situ-cast concrete has less reuse potential than pre-cast concrete (Iacovidou and Purnell, 2016).

Connection types may be related to the type of material used. Brick has been identified as highly reusable due to the high durability of the material (Bertino et al., 2021; Smith, 2022). Disassembly of a brick wall however is time consuming, and disassembly success is dependent on the type of mortar used. Use of non-detachable "sticky" mortar will inevitably lead to a downcycling process of bricks such as shredding and used for roadbeds. Prefabricated, mechanically connected concrete elements are easier to detach than in-situ cast concrete elements, or prefabricated concrete elements with cast concrete connections (Bertino et al., 2021; Dermisevic et al., 2010). A steel construction with bolted connections is easily detachable, while a construction with welded connections needs to be cut apart for deconstruction. Bertino (2021) identifies nailing and bolting as the most common connection in use timber as building element, implying timber is often easily detachable.

2.1.2. Organisational

In this subsection, the organisational aspects of the transition to a circular economy be analysed from the perspective of a demolition contractor. The organisational aspects are comprised of 'formal and informal linking structures', 'communication processes', 'size', and 'resources'.

Formal and informal linking structures

Demolition contractors are traditionally not involved in partnerships or consortiums. The formal linking structure in a demolition contract is between the client and the demolition contractor. Logically, the client is the owner of the to-be demolished asset. The demolition contract entails that the client pays the demolition contractor to receive ownership over the asset, thereby taking on full responsibility for the demolition. In a circular real estate sector, this would result in the demolition contractor obtaining ownership of all harvested building elements.

Van den Berg (2020) generalised from his case study that demolition contractors, gaining ownership over harvested building elements, prefer to sell these elements directly from the building site. Potential customers identified are individuals and local traders or contractors (Van den Berg, 2020).

Rios (2015) and van den Berg (2020) also proposed direct sales on-site as best practice for trading harvested building elements as it reduces storage and transportation costs. Furthermore, Rios identified the availability of salvage markets (4) and strength of market demand (5) as two of five main variables of deconstruction cost-effectiveness (Rios et al., 2015).

Communication processes

A demolition contract is most often won through a tender procedure whereby demolition contractors bid on a demolition project, taking into consideration the client's requirements set out in the tender.

Coenen (2022) identified barriers related to communication processes in circular economic projects in the Dutch infrastructure sector. Coenen observed that involved actors perceive the problems and solutions in circular infrastructure projects: clients and contractors often have different perceptions on which alternatives are the "most circular". This complication leads to less or slow implementation of circular practices in the infrastructure sector, leading to less experience in circular practices, leading to less understanding. This vicious cycle is what Coenen calls the 'contestation cycle'.

Size
In the Netherlands, demolition contractors operate regionally. Every region has several local demolition contractors for demolition project of municipal buildings. A few larger demolition contractors operate nationally for large projects. As the largest part of demolition contractors are small-to-medium-sized companies, innovation is not expected to follow from internal research and development due to budget limitations and the traditional price competition in the sector.

Resources
Due to price competitiveness in the demolition sector, the profit margins are low, leaving marginal space for costly reuse strategies. Harvesting building elements for reuse is a costly process compared to traditional demolition. These high costs are comprised by the need for more labour time, as well as more specialised labour. The needed extra time for deconstruction is also a scarce resource: in both demolition and construction projects, the client values a time-efficient approach. Furthermore, storage space is a resource employed for reuse strategies. Van den Berg (2020) found that a selection criterium for reuse is the possibility to store harvested building elements on-site safely, meaning resistance to influence from weather or environment. Harvested elements susceptible to corrosion, rot, discolouration, short-circuiting (in case of electronics), or other forms of quality deterioration, should be stored in controlled circumstances, potentially adding to the total reuse costs (Van den Berg, 2020).

2.1.3. Environmental
In this subsection, the environmental aspects of the transition to a circular economy be analysed from the perspective of a demolition contractor. The environmental aspects are comprised of ‘industry characteristics and market structure’, ‘technology support infrastructure’ and ‘government regulation’.

Industry characteristics and market structure
The demolition industry in the Netherlands is highly competitive due to low profit margins and a lot of competition: the market is dispersed over 2435 small-medium sized companies (CBS, 2023), meaning the Netherlands has more than seven companies per municipality (MBZK, 2022). The low profit margins and high level of market dispersion result in a strong competitive climate. Regarding the market of harvested building elements: Icibaci (2019) pointed out the DIY sector as the largest consumer group for harvested building elements from demolition projects in the Netherlands. Achieving an embedded circular real estate construction sector requires a more developed offset market for pre-used building elements.

Technology support infrastructure
Commonly, deconstruction requires more specialised equipment than demolition (Iacovidou et al., 2016). Assumed is that the needed equipment for deconstruction is available. Furthermore, van den Berg (2020) stresses the importance of sharing building information with the demolition contractor, but found through empirical study that demolition contractors most commonly do not have access to the needed information. Ghinoi (2020) assigns lagging information streams between stakeholders as a reason for the slow transition to a CE: organising stakeholders in a collaborative form still takes too much time in relation to the time available. Therefore, across academic literature, close stakeholder cooperation is identified as crucial for achieving a circular construction sector (Xiang, 2019; Kalmykova, 2018; Rincón-Moreno, 2020; Salvioni, 2020). The case study at Oxand confirms that actors in the construction and real estate sector do not maintain and communicate their data well. In recent years, Business Information Modelling has been developing rapidly. Hence, the supporting

infrastructure for information sharing and management is available, however, it has not yet been adopted by the demolition sector.

Government regulation
In academic literature there is a call for government-imposed financial incentives for engaging in circular strategies (Adams et al., 2017; Aranda-Usón, 2019; Hossain et al., 2020). Yet, in the Netherlands, there are little subsidies or other financial incentives to stimulate adoption of circular strategies, even though the Dutch government is aiming on reducing virgin resource use by 50% with regards to 2016 in 2030 and on becoming a fully circular economy in 2050 (MIW, 2016).

2.2. TOE Analysis - Conclusion

Demolition contractors are relevant to a circular real estate sector for harvesting reusable building elements: harvested building elements are the stock of a circular real estate construction sector, used in design and construction of new buildings. Hence, demolition contractors can take the position of supplier in the sector's stakeholder network. This is different to the position demolition contractors have in a linear real estate construction sector, where demolition contractors only business opportunity is at the end of the value chain.

From the TOE analysis several challenges arise when placing demolition contractors in a circular system. First, the technical context shows that demolition contractors do not receive enough technical data to develop an effective circular strategy and that there are many building element properties that influence the reuse potential. Secondly, the organisational context shows that demolition contractors are isolated from the construction sector and only have a formal linking structure with the client, obtained amidst heavy competition, leaving little slack resources for circular strategies. Lastly, the competitive market and lack of government support is expected not to deliver the most ideal climate for risky innovation. The TOE analysis has outlined the challenges faced for demolition contractors wanting to engage in circular reuse practices. On the other hand, the TOE analysis also highlights the potential for demolition contractors to become suppliers of harvested building elements in a circular real estate construction sector. This implies actively taking part of the value chain, instead of closing it. This leads up to answering the Exploratory research question:

How will the stakeholder position of demolition contractors change in the transition to a circular real estate construction sector?

The role of demolition contractors in relation to other stakeholders in a circular real estate construction sector will change through two inter-related developments.

Firstly, demolition contractors will develop new services, being the harvesting of reusable building elements through deconstruction. Retaining high functional value of building elements is a key driver for a circular real estate construction sector, requiring careful deconstruction of an asset. Generally, deconstruction is more expensive than demolition. Therefore, demolition contractors need to align strategic objectives with the asset owner and communicate who takes financial responsibility. Selling the reusable building elements to new users (designers, constructors) before starting deconstruction will improve this decision-making process.
This development follows through into a second development. The success of a circular strategy can be promoted through reassignment of reusable building elements to a new function in a construction project before start of deconstruction, making the demolition contractor the designated supplier of

harvested building elements. Fulfilling this role will demand collaboration with designers and construction contractors in order to bring the supply and demand sides for building elements together, while communicating with the client, the asset owner, about the costs and benefits.
In the transition to a circular real estate construction sector, the demolition contractors will develop in its position in the value chain from an isolated position at the end of the linear value chain, to a supplying role in the heart of the circular value chain, managing relations with the asset owner, designers, and construction contractors.

3. Methodology

This section describes the methodology for creating understanding of how construction contractors and asset owners can engage with demolition contractors in a circular real estate sector. Academic literature analysis and a case study at Oxand illustrate the development of demolition contractors towards a supplier role embedded in the value chain of a circular real estate construction sector, as opposed to a more isolated role in a linear economic demolition sector. Other stakeholders in the construction sector have no experience with collaborating with demolition contractors in this role.

To create understanding how construction contractors and asset owners can engage with demolition contractors in a circular real estate construction sector, this research will conduct a design process of a strategic framework by which demolition contractors harvest reusable building elements. Bringing into context the strategies that demolition contractors can apply to harvest high-quality reusable building components is expected to pave way for other stakeholders to apply their own business strategy to those of demolition contractors. The research methodology will deliver academic learnings from an empirical context. The results strived for are practically implementable reuse strategies for achieving the highest possible level of reuse. In the process of designing these strategies, academic knowledge on the development of demolition contractors' stakeholder position is gathered. Oxand can use this knowledge to find business opportunities as a consulting company by actively engaging with demolition contractors or advising other stakeholders how to establish successful reuse strategies in collaboration with demolition contractors.

The Research through Design (RtD) principle has been differently interpreted by researchers throughout the years. Section 3.1. describes the RtD methodology applied in this research. This methodology is an interpretation of RtD by two researchers from the faculty of Architecture and the Built Environment at the Technical University of Delft, the Netherlands. Section 3.2. describes the execution of the RtD methodology in the context of the problem statement. Lastly, section 3.3. describes the application of this methodology to delivering academic results, thereby answering the methodological research question.

3.1. The Research through Design methodology

The Research through Design methodology as established by van Stijn (n.d.) is applied to find answers on how stakeholders in the circular real estate sector should engage with demolition contractors. This methodology has been selected for two reasons. Firstly, this research's problem statement (see Section 4. *Problem statement and knowledge gap*) can be categorised as a 'wicked problem' (Rittel, 1973) due to the many related aspects that comprise the problem, and potentially conflicting values of stakeholders. Secondly, a solution space for the knowledge gap is expected to be found in the circular practices of demolition contractors. Designing a product that can be applied in practice is expected to contribute to finding academic solutions to overcoming the knowledge gap.

According to van Stijn, Research through Design is the process of gaining knowledge through designing. The design process focusses on designing a solution to a defined problem, whereby the process of achieving this result is a means to draw academical findings from the process. The solution can take on many different forms such as a set of formula's, an operational or conceptual model, a roadmap, a process diagram, and others (van Stijn et al., n.d.). In this design research, the problem is that there is a lack of academic knowledge on the reuse strategies applied by demolition contractors. The design process will focus on delivering a reuse strategies framework that demolition contractors apply to engage in circular demolition projects. Relating this design process to findings from academic literature will provide insights in how stakeholders in the real estate construction sector can engage with demolition contractors. This answers the methodological research sub-question.

3.2. Design framework

In this section, the design framework is described using figure 2: *Research through Design set-up*. The RtD framework according to van Stijn is built up of three phases in one iteration: analysis, synthesis, evaluation. The output of the evaluation phase of an iteration is the input for the analysis of a next iteration. This research has conducted one iteration of the design process as described in this section.

The RtD methodology is performed in section 4. *Results* and is divided in Analysis, Synthesis, Evaluation, and Knowledge extraction. In the analysis phase, the results from the TOE analysis and literature review are compared to the results from semi-structured interviews with demolition contractors to deliver a stakeholder analysis. In the synthesis phase, a strategy framework for reusing harvested building elements is designed using the results from the analysis phase as well as the validation process of the first set of semi-structured interviews (demolition contractors) by the second set of semi-structured interviews with (semi-)public actors. The evaluation phase will be used to reflect on the delivered results from the empirical context using input from experts at Oxand. In section *4.4. Knowledge extraction* the strategy framework resulting from the synthesis phase is worked out in three scenarios: one for each strategy. In the knowledge extraction, the product developed in the design process, the reuse strategies framework, is brought into the academic

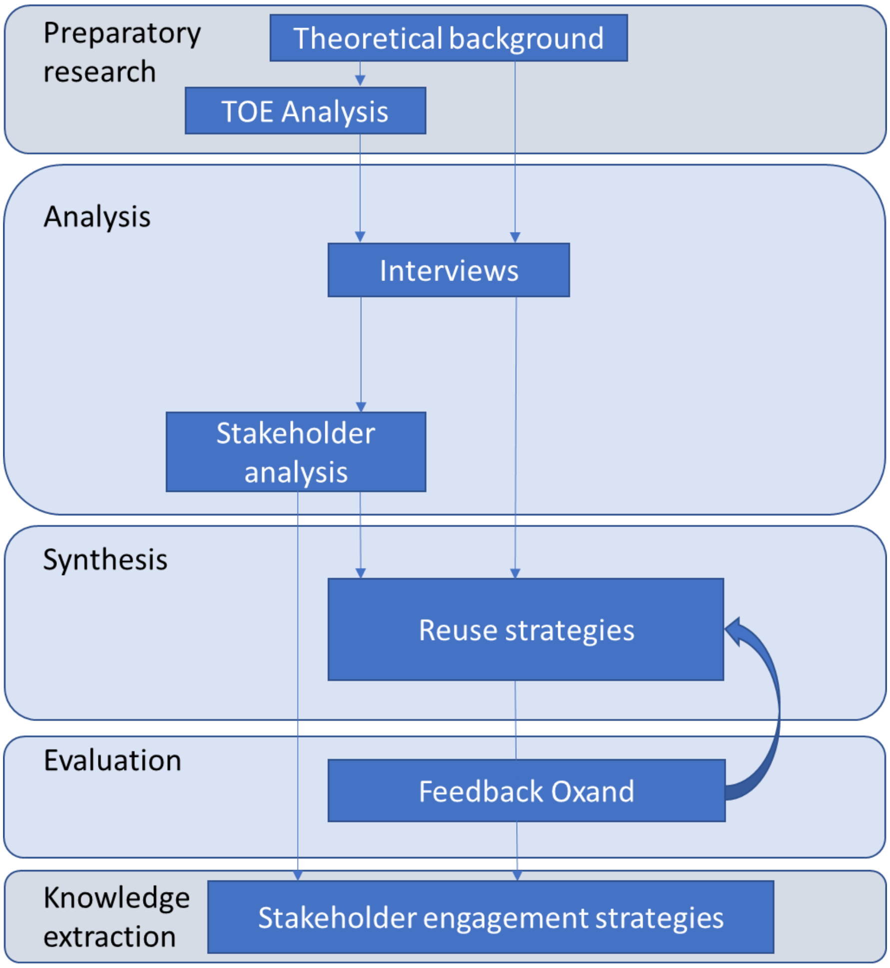

Figure 2: Research through design set-up

context, thereby drawing learnings from the design process and answering the results-oriented research question.

3.2.1. Preparatory research

The preparatory research phase, as well as the knowledge extraction phase, are not part of the design process, but connect the design process to the academic research process. The design process is a result of the knowledge gap identified in the theoretical background:

1. There has been longstanding interest in stakeholder networks in a circular real estate construction sector.
2. Recent studies show that demolition contractors will play an important role in a circular real estate construction sector.
3. However, research is lacking on how stakeholders in the sector should engage with demolition contractors.

Theoretical background

Academic literature on the role of demolition contractors in a circular real estate sector show the importance of collaboration, but remains superficial on the operational practices demolition contractors apply to achieve circularity. From academic literature, as much knowledge on challenges and opportunities in the technical, organisational, and environmental aspects is gathered to be included in the TOE analysis in the first design phase. Furthermore, interview questions concerning the knowledge gap are included in the interview protocol (see appendix 11.3 *Interview protocol*).

TOE Analysis

The Technological, Organisational, and Environmental (TOE) analysis is a framework for categorising all aspects of influence relevant to the development of an innovation. In this design process, it is used to identify and categorise the practically applicable findings from academic literature, as well as the knowledge gained through an internship period at Oxand. Categorising these findings in a TOE framework contributes to understanding the challenges and opportunities that demolition contractor's encounter in their transition to a circular real estate construction sector. Understanding these challenges and opportunities contributes to formulating a solution-driven interview protocol.

3.2.2. Analysis

In the analysis phase the empirical research is conducted. The findings from this research are compared to academic literature to identify complementing or contrasting knowledge.

Interviews

The interview questions (see 8.3 Appendix - *Interview protocol*) are derived from the knowledge gap found in academic literature. Questions regarding specifics from the operational context are derived from the TOE analysis.

This research will use semi-structured interviews to gather data for the design process. The main group of interview respondents are demolition contractors promoting 'circular demolition' as one of their key selling points. The identity of the respondents and their companies have been anonymised. Four employees responsible for achieving high reuse values within the companies' projects have been interviewed. Furthermore, two experts from another side of the stakeholder field were interviewed to validate the data. Both experts were responsible for the circular department of their organisation, one working at a large semi-public research institute, the other working for a large public real estate owner in the Netherlands. Qualitative data gained from the interviews can be found in 8.4 Appendix - *Interview data*. The automated transcript of the interviews (in Dutch) can be found in the Clausula attached to this research.

The interview protocol for the demolition contractors was categorized in three subjects: (1) Preparation phase of deconstruction, (2) Execution phase of deconstruction, (3) Finalising phase of deconstruction. The first phase is to understand how demolition contractors get to engage in a circular strategy in the first place, and how agreements, competition, and internal decision-making plays a role in this phase. Next, the technical aspects of deconstruction are subject of the interview questions: what techniques are applied for harvesting building elements, how does cost play a role here, how element characteristics influence the reuse potential. Lastly, demolition contractors are questioned on what they do with the harvested building elements, and how the agreements made pre-deconstruction are followed up on.

Stakeholder analysis

The results from the literature and TOE analysis are compared to, and complemented with, the interview results. Empirical knowledge gained at Oxand contributes to understanding the stakeholder network in a linear construction sector and academic knowledge from the literature analysis contributes to understanding that the linear stakeholder network will change. Categorizing this knowledge in the TOE analysis sheds light on the challenges and opportunities for reuse by demolition contractors, and semi-structured interviews fill in the blanks. This provides in-depth understanding of demolition contractors to position them in a circular operating stakeholder network for the real estate construction sector. The stakeholder analysis will be visualised in two stakeholder diagrams, one adhering to a linear real estate construction sector, the other to a circular real estate construction sector.

3.2.3. Synthesis

Following the analysis phase, the stakeholder map in a circular real estate sector is clear, however, this alone is insufficient for understanding how stakeholders can engage with demolition contractors within this network. Understanding what demolition contractors have to offer is expected to pave the way to opportunities for circular business processes for other stakeholders. Therefore, a reuse strategies framework for demolition contractors is developed.

Reuse strategies

The reuse strategies follow from the stakeholder analysis and the interview results. Academic literature does not provide insight into operational practices for harvesting reusable building elements. Therefore, demolition contractors are interviewed on their experiences from the operational context. The aim of these interviews is to discern different strategies for harvesting building elements, and understanding what influences the decision-making for conducting a particular strategy.

3.2.4. Evaluation

In the evaluation phase, the strategic framework is presented to Oxand in order to receive input from experts in the real estate construction sector. This feedback is used to evaluate the strategy framework delivered in the synthesis phase and to establish recommendations for a second iteration of the design process.

Feedback Oxand

The feedback is gathered after presenting the design phase to experts at Oxand. These experts have been informed on the subject and research process in an earlier stage. The feedback is delivered verbally.

3.2.5. Knowledge extraction

The knowledge extraction phase is not part of the design process. This research has conducted one iteration of the design process. After this iteration, knowledge extraction takes place by gathering all learnings resulting from the design process.

Stakeholder engagement strategy

Understanding demolition contractors' reuse strategies combined with the stakeholder network in a circular real estate construction sector, supported by academic literature on stakeholder engagement strategies, will result in developing a stakeholder engagement strategy. The stakeholder engagement strategies are visualised in a complemented version of the stakeholder analysis diagram. Three scenarios are worked out, one per strategy, investigating the implications of the reuse strategies for the engagement strategies.

3.3. Applying the Research through Design methodology to this research

The role development of demolition contractors in the stakeholder network is expected to relate to the reuse strategies offered by the demolition contractors. For other actors to engage with demolition contractors, understanding of the possible strategies will contribute to success of collaboration. However, findings from empirical and academic research occasionally contradict, such as the proposed best practice of selling harvested building elements straight of the demolition site to small traders as opposed to retaining functional value. The combination of different technological, organisational, and environmental aspects leads to infinite unique scenarios to which a suitable reuse strategy should be designed. This complexity, or 'wickedness' of the problem leads to the choice of 'Research through Design' as best supporting research method. Through designing a strategy framework by which demolition contractors harvest building elements, academic findings can be extracted on how designers, construction contractors, and asset owners can engage with demolition contractors. This answers the methodological research question:

> *What research method supports the development of a strategy for stakeholders in the real estate construction sector to engage with demolition contractors?*

A positive side effect is the creation of the strategy framework, which can guide demolition companies in their decision-making process, as well as provide Oxand with a tool for providing advice to clients.

3.4. Methodology - Conclusion

The method of this research is designing a framework that describes the different deconstruction strategies demolition contractors can apply to harvest reusable building elements. From this method, academic learnings are to be gained in order to answer the main research question regarding engagement with demolition contractors. Understanding of the possible strategic scenarios forms the core of understanding how stakeholders in the real estate construction sector should engage with circular operating demolition contractors. Developing an engagement strategy without understanding the strategic possibilities for engagement with demolition contractors is assumed a less viable alternative.

4. Results

This section describes one iteration of the RtD process as explained in 3. *Methodology* and illustrated in figure 2. *Research through design set-up*. Executing the design framework as described in sub-section 3.2. *Design framework* results in the design process as described in the sub-sections 4.1. *Analysis*, 4.2. *Synthesis*, and 4.3. *Evaluation*. In the analysis phase, four circularity experts from demolition contractors have been interviewed, as well as circularity experts from a large public asset owner and from a research institute. In the synthesis phase, reuse strategies have been developed based on the qualitative interview data. The evaluation phase elaborates on the feedback received from experts at Oxand. Succeeding the RtD process is the *Knowledge extraction* in sub-section 4.4., where the results-oriented research question is answered.

4.1. Analysis

In the preparatory phase, prior to the analysis phase, a literature analysis has been conducted in sub-section 1.1., stressing the importance of collaboration between stakeholders in a circular real estate sector, and the importance of the role demolition contractors are expected to play in this sector. These insights have been complemented with experience gained during the internship period at Oxand, and categorised in a TOE framework, see section 2. Identifying challenges and opportunities in Technical, Organisational and Environmental categories contribute to achieving a practical understanding of the academic problem statement, which is useful for addressing the relevant topics in interviews with demolition contractors.

To gain insights in the practical solution space, semi-structured with demolition contractors and circularity experts from a large public asset owner and a research institute have been conducted. The interview questions can be found in Appendix 8.3 *Interview protocol*. The interviews have been held in Dutch; the automatic transcriptions can be found in the Clausula attached to this thesis. The goal of the interviews is to verify the findings from academic literature and the TOE analysis, and to gain insight in whether practitioners experience the problem statement addressed in this research, and whether there are practical solutions available. The interviews with the circularity experts from the public asset owner and research institute validate the interviews with respondents from demolition contractors. The qualitative interview data is compared to the data from academic literature and described in section 4.1.1. Section 4.1.2. builds forth on this comparison with an analysis of the new role of demolition contractors in a circular real estate construction sector.

4.1.1. Difference between literature and interview results

This section compares findings from academic literature to findings from the empirical context. Each paragraph covers one topic.

Selling building elements from the site

In academic literature, selling harvested building elements straight of the construction site, to local dealers, small contractors, or individuals, is proposed as best practice (Van den Berg (2020), Rios (2015). Practitioners are more nuanced on this topic.

From a purely organisational perspective, selling building elements straight from the deconstruction site makes sense, but in practice the technical, organisational and environment perspectives are more interwoven, exposing the inability of this practice to safeguard function retention. The interview results present function retention of harvested building elements as one of the key drivers of high-level reuse strategies. In achieving function retention, demolition contractors aim to find a new function for harvested elements before starting deconstruction, which reduces the need for selling harvested building elements after deconstruction. Furthermore, other practices for stimulating function-retention are opposed by selling building elements in an ad-hoc manner.

Function retention

Academic literature describes function retention as key driver for achieving high quality reuse (Atonini, 2020; Akinade, 2016), but there is little academic consensus on how to achieve function retention with a certain strategy. The interview results illustrate examples from the field for achieving function retention.

The respondents propose safeguarding design as best practice for function retention. Grouping multiple building elements within the same design as they were originally built. Striving to realise this and finding as-good-as-possible alternatives for building elements that do not fit in this strategy, will result in the highest possible function retention. There are examples of the complete rebuilding of assets, such as industrial halls with mechanically connected steel structures. Another example is the complete reuse of two overpasses made from prefabricated concrete elements. Applying this strategy on real estate can result in high-quality reuse, such as the reuse of foundations (Interviews 1 and 3) and structures (Interviews 1,3,4) for real estate of equal weight and dimension: the harvested foundation or structure fulfils the exact same function in the new asset. For the harvested building elements to be included in the construction of a new asset according to the original design requires alignment between the demolition contractor and the designer. For the designer to incorporate harvested building elements in its design, information sharing between asset owner, demolition contractor and designer should happen in an early phase. Respondents acknowledge that this is not yet customary.

Dealing with challenges

Academic research presents characteristics of building elements suitable for reuse and best practices for designing for deconstruction. However, literature does not explicate how to deal with challenging circumstances for deconstruction. (Antonini et al., 2020; Akinade et al., 2016; Bertino et al., 2021; Cai et al., 2019; Finch et al., 2021; Icibaci et al., 2019; Rahla et al., 2021). Challenging circumstances can be non-mechanically connected building elements, lack of time or budget, lack of building information data.

What misses from this research is how to deal with non-ideal design of real estate assets when applying a reuse strategy for deconstruction, whether stakeholders would still execute a reuse strategy of an asset that is badly designed for reuse strategies, and how these stakeholders assign costs and benefits in different situations. Interviews describe how innovative demolition contractors invest in reuse practices for non-ideal buildings in order to profit from long-term benefits: monolithic and welded connections can be cut or sawn open.

Interview respondents explain that there are long-term, non-financial benefits from engaging in a reuse strategy: increased interdisciplinary partnerships, more exposure, new business opportunities and gained experience. Hence it pays to engage in non-ideal circular strategies as this is where demolition contractors can distinguish themselves. Asset owners often take a large financial responsibility: 10% to 25% increase in demolition costs. The majority of the tender requests for circular strategies come from public asset owners.

Ownership

Concerning ownership, academic research is focused on a centralised role of 'industrial facilitators' in stakeholder networks of reuse strategies (Blomsma, 2018; Homrich, 2018). Traders of harvested building elements can fulfil the role of such industrial facilitator (Alonso-Almeida, 2020; Rincón-Moreno, 2020). These traders will operate as hubs for the dispersion of harvested building elements. Empirical research opposed this theory, illustrated by two scenarios. The first scenario is the current best practice for ownership of harvested elements, the second scenario is the expected best practice for the future.

For demolition contractors, successfully selling harvested building elements is a challenge. The respondents explained that they always sell harvested elements straight to a constructor of a new asset, not to traders. The respondents illustrate that increased collaboration with constructors lead to increased transactions of harvested building elements. Constructors can deliver requirements for the needed building elements for the demolition contractors to take into account when deconstructing, as opposed to traders. Furthermore, directly selling to constructors removes the transaction fee imposed by traders, and improves information symmetry and trust: demolition contractors acknowledge the long-term benefits gained by collaborating with constructors.

The interview results describe the current ownership paradigm in the demolition sector as a transactional business model: an asset owner pays the demolition contractor to obtain full responsibility of the discarded asset. With this responsibility comes ownership of all building elements, whereby the demolition contractor is responsible for selling these reusable elements. Agreements on costs and benefits can be determined in the tender contract. Interview respondents expect that in the future, asset owners will retain ownership of discarded assets in order to retain ownership of the reusable building elements. This results in asset owners hiring demolition contractors according to an as-a-service model in order to reuse harvested building elements within their own asset portfolio. The largest public asset owner in the Netherlands has already begun applying this strategy, using its own internal marketplace. This decentralised ownership prospect will diminish the need for traders.

Deconstruction strategies

Bertino et al. (2021) identified two types of deconstruction strategies: structural and non-structural deconstruction. Deconstruction is different to demolition and defined by keeping building elements intact. In structural deconstruction, the structural building elements are kept intact, such as the foundation and supporting beams. Often, these elements are made from reinforced concrete. Any further typology of deconstruction strategies is lacking in academic literature.

The data collected from interviews with demolition contractors show that demolition contractors apply different reuse strategies in different situations. The selection of a strategy can be based on design characteristics of the end-of-life asset (Technical), financial and ownership agreements (Organisational) or external influences on the project (Environment).

The 'lowest' level of reuse can be the selling of doors, windowpanes, and other easy disassembled building elements. The 'middle' level of reuse requires cooperation with the asset owners and potential buyers of harvested building elements to increase the number of reused elements. The 'highest' level of reuse entails striving for 100% reuse of an asset.

4.1.2. Role development of demolition contractors in the circular transition

Understanding how demolition contractors apply certain deconstruction techniques and organisational innovations to achieve reuse of harvested building elements illustrates the circular business processes of these companies. Analysing this leads to identifying the new role of demolition contractors in the sector. This section describes this analysis.

Figure 3 describes the simplified economic stakeholder network in a linear real estate construction sector. Figure 4 shows the simplified economic stakeholder network in a circular real estate construction sector. In figure 3, the asset owner hires a designer to design an asset (1) and hires a construction contractor to build the asset (2). The designer and the contractor often work together to ensure the success of the project (4). After many years (5) the asset reaches end-of-life, which is when the asset owner hires a demolition contractor (3) to take responsibility for the asset and end the value chain.

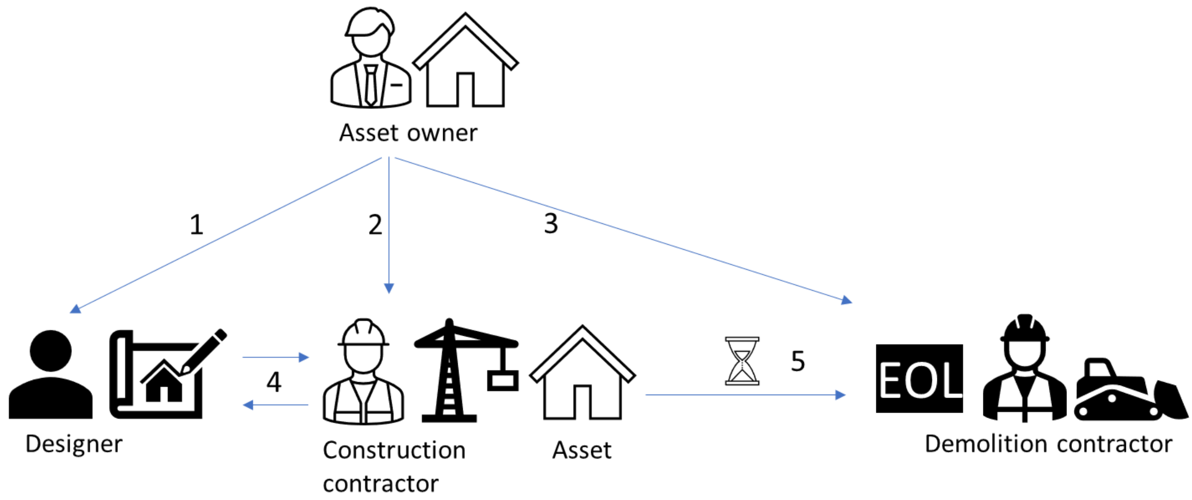

Figure 3: Stakeholder network in a linear real estate construction sector

In a circular real estate construction sector, an asset owner hires a designer to design an asset using as much pre-used building elements (1). The designer already has ties with construction contractors and demolition contractors for suitable building elements (6) and building techniques (2). The end-of-life assets constructed by construction contractors (3) deliver potentially reusable building elements (4). The challenge not only lies in harvesting these elements, but also in selling (6). The interview results contradict academic literature, showing that selling harvested building elements straight of the construction site is counteracts value retention. The interview results and academic literature conclude that minimising dispersion of building elements originating from the same asset and finding a new function in an early stage increases value retention. As the demolition contractor is the first actor to identify the reusable building elements and assumes responsibility over the asset from the asset owner, it is the dedicated actor to find a new user for the harvested elements (5 + 6). This confirms the demolition contractor’s role as supplier in the circular value chain. Furthermore, as opposed to academic literature, demolition contractors may occasionally invest in a highly challenging deconstruction project to gain long-term benefits such as improved relations with asset owners, designers, and constructors: by deconstructing a linear designed building and delivering high quality reusable building elements, at a high cost, the demolition contractor earns less money, but shows to asset owners and other stakeholders in the field what is possible. Such projects get attention from regional media and trade journals, stimulating other stakeholders in the sector to participate in such an innovative project, for instance by including the harvested building elements in the design of a new building (6). Such flagship projects are useful for demolition contractors to establish credibility for winning future tenders requiring a circular strategy. The vast majority of circular requests in tenders come from public asset owners willing to cover the financial responsibility of the reuse strategy (7). Technically speaking, every built asset can be reuse for up to 100%, according to the interview respondents, depending on the willingness to pay from the asset owner. Demolition contractors compete to propose the best circular strategy for winning the tender (7) based on circular requirements, which are said to weigh heavy in public tenders. Depending on the building information the demolition contractor receives of the asset in question (4), it proposes a reuse strategy. The reuse strategy is where other stakeholders can engage with the demolition contractors: designers can use building elements embedded in to-be deconstructed assets (6), the demolition contractor can collaborate with the construction contractor how to retain functional value of the building elements in the harvesting process (5), and by knowing this, the demolition contractor can use the sales revenues of harvested building elements to partake in the financial responsibility of the asset owner for the expensive reuse strategy (7). However, the interview results prognose an even further evolution of the role of demolition contractors in a further developed circular economic system, whereby they offer deconstruction 'as a service', and the asset owner remains proprietor of the harvested building elements.

The development of the demolition contractor's role in the stakeholder network in the transition to a circular real estate construction sector as described in this section can be related to the theory that industrial facilitators should be at the heart of stakeholder networks in a circular sector. (Blomsma, 2018; Homrich, 2018). Clearly, there is not one circular deconstruction strategy, but that a demolition contractor can apply a different strategy based on a combination of circumstances. The next section, 7.3. Methodology – *Synthesis*, dives deeper in the insights gained from the analysis to formulate the reuse strategies demolition companies can apply to realise reuse of harvested building elements.

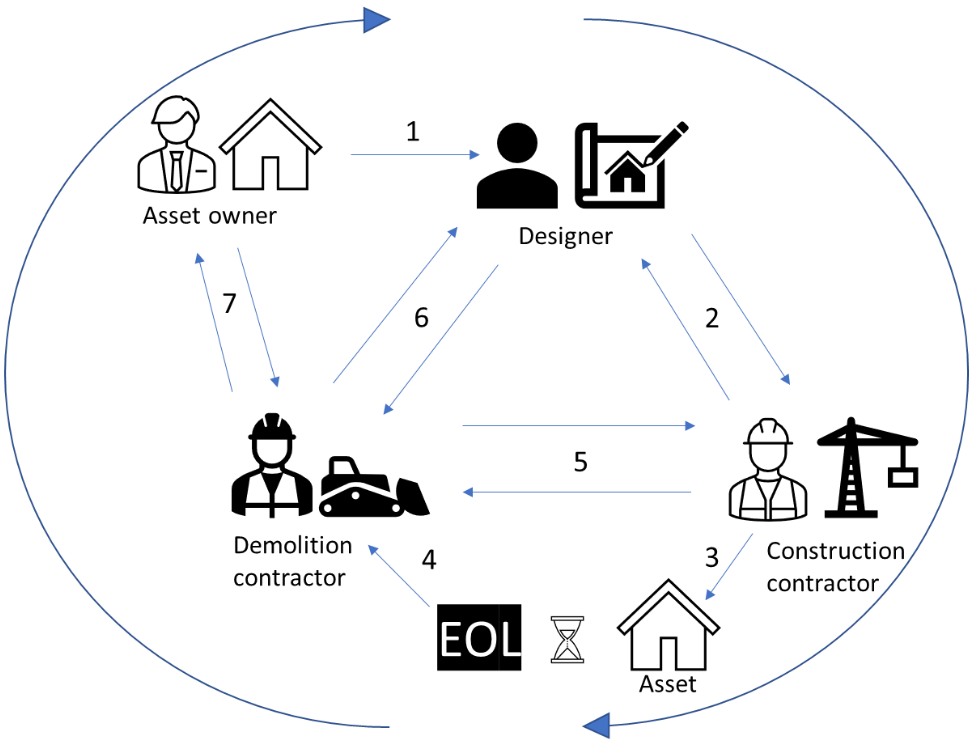

Figure 4: Stakeholder network in a circular real estate construction sector

4.2. Synthesis

Verifying the assumptions following from the academic literature analysis showed some asymmetry between academic research and the field.

The main insight is the identification of multiple reuse strategies from the interview responses juxtaposed to one reuse 'best-practices' strategy strived for in academic literature. These best-practices strategies in academic literature all have in common a strong focus on design and material properties. The analysis from the interviews verifies the relevance of technical properties of building elements to the financial viability of reusing such elements. However, whether a circular deconstruction strategy is applied or not is determined by the stakeholder profile, not by the technical properties of the building elements: according to three respondents, "any building can technically be reused for 100%, the only challenge is money". Currently, public actors are by far the largest and most significant client group requesting circular strategies in tenders, even for projects that are far from financially attractive. There are examples of public clients requesting a 100% reuse strategy for deconstruction projects of real estate or infrastructure assets. These public actors have a leading role as clients in the circular deconstruction sector, and the respondents from interviews signalled an increasing demand for circular deconstruction strategies from private actors also. The extra costs for a circular strategy, ranging from a 10% increase to 25% compared to traditional demolition, are shared between the deconstruction contractor (new term for demolition contractor) and the asset owner in varying ratios.

Deconstruction contractors are willing to achieve a smaller profit margin for applying a circular deconstruction strategy compared to a traditional strategy to gain indirect financial benefits. The identified indirect financial benefits are: (1) winning tenders; (2) establishing interdisciplinary relations; (3) investing in making the company future-proof; (4) gain positive publicity within the field. (1) Clients of demolition/deconstruction projects increasingly request circular strategies in tenders, whereby propositions with the most effective circular strategy are rewarded. For the demolition contractor performing a more expensive deconstruction method will decrease the profit margin compared to traditional demolition but will strengthen its position in the tender process. (2) Engaging in deconstruction instead of demolition influences the position of a demolition contractor in the stakeholder field, according to the respondents. Circular deconstruction asks for collaboration between the demolition contractor and asset owner over the deconstruction strategy, and between the demolition contractor and buyers of harvested building elements: contractors and architects. These new interdisciplinary relations provide business opportunities, but also ask for a business process more integrated in the overall infrastructure and built environment sector. As a respondent in the interviews put himself: "we are becoming more than wreckers, we are becoming builders and advisors". (3) The Dutch government is writing policies to increase circularity to reach the target of becoming a complete Circular Economy in 2050. The respondents experience the need to adapt to this transition in the current stage, to stay relevant in the future. (4) Successful implementation of circular strategies can count on positive publicity from local media, but also through communication channels of public authorities, word of mouth, and trade journals. Successful implementation of a circular strategy leads to follow-up of new projects requiring a certain level of reuse.

Interpreting the interviews

From analysis of the qualitative data derived from the interviews, three different reuse strategies have been formulated. These strategies are based on experiences, challenges and opportunities, and reuse practices from four different demolition contractors from varying sizes and with varying expertise in the reuse of building elements. These results have been validated through an interview with a circularity expert from a research institute and with a 'circularity broker' from the largest public asset owner in the Netherlands. In the explanation of each strategy, challenges and opportunities are identified with a (T) for Technical, (O) for Organisational, and (E) for Environmental, according to the TOE framework presented in Section 2. *TOE Analysis*.

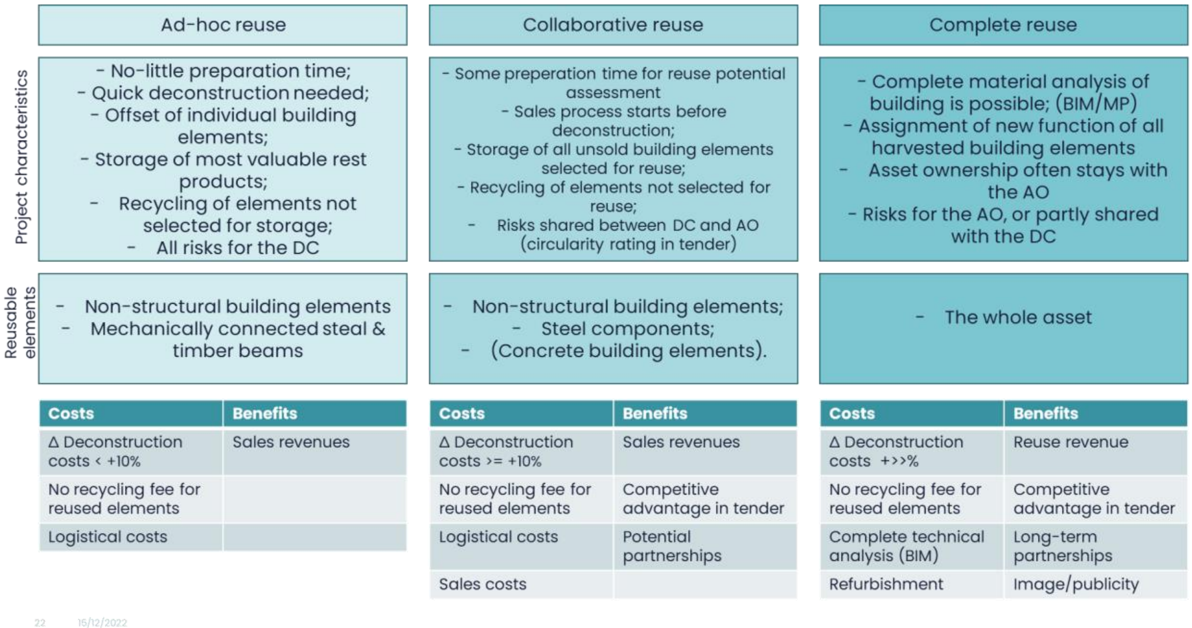

Figure 5: Reuse strategies

4.2.1. Ad-hoc reuse

This reuse strategy is the simplest form of reuse and has been conducted by demolition contractors before the concept 'Circular Economy' existed. This strategy entails selling harvested elements for reuse if profitable (O), and if possible, within a short period (O): the demolition contractor takes none to a little time (O) to analyse reuse potential up front and must demolish the asset quickly (O). The focus lies on recycling, but any building elements of value (E), mostly wooden or steel beams and technical installations (T), are kept aside for resell. No effort is taken to take apart glued or welded connections (T). Concrete is not selected for reuse; brick walls may be sold in pieces to a brick trader (E) who dismantle the walls and cleans the bricks individually for resale.

4.2.2. Collaborative reuse

'Collaborative reuse' is the most common strategy found in business processes of demolition contractors having the ambition to achieve high-quality reuse. This strategy differentiates itself from 'ad-hoc reuse' by assessing the reuse potential of building elements (T;O) and bringing the identified building elements on the market (O) before demolition and storing building elements for resale if not sold immediately (O). This strategy generates a higher level of reuse than an ad-hoc strategy, as more effort is put into salvaging building elements (T). This also brings, apart from some exceptions, more costs than ad-hoc reuse (O;E). Interviewed demolition contractors note that this most often leads to a lower profit margin compared to traditional demolition projects O), but that this is seen as an investment leading to indirect benefits. Interviews have put forward extra average costs of 10%

compared to traditional demolition (DC1) (O). The extra costs are shared by the contractor and asset owner in a ratio agreed upon in the tendering process (O). The indirect benefits are (1) increased collaboration with (mainly) architects and (increasingly) building contractors (O); (2) a competitive tender position (O;E): circularity is weighed increasingly heavy in, mainly public, tenders; (3) positive public publicity: stories of successful reuse strategies are still new and can count on attention from local media (E), or stakeholders in the sector (E).

The building elements selected for reuse can be all non-concrete building elements (T). Concrete building elements have proven to be cost ineffective to reuse due to low concrete prices (E) and high deconstruction prices compared to demolition (T;O). The building elements selected for reuse can vary from steel beams, bricks and roof tiles to windowpanes, doors, and technical installations (T). Building elements with fixed connections, such as welded beams, can be sawed or grinded apart (T). Investing labour in such action is a balance between the extra costs (O), tender agreement (O) and market demand (E).

From the interview results can be concluded that this strategy is very often found in demolition tenders from public asset owners, but increasingly in tenders from private asset owners as well (E). The success of this strategy rises and falls with the possibility of matching the supply side of reusable building elements with the demand side from individuals, architects and building contractors (E). Demolition contractors benefit from the new stakeholder playing field whereby they participate in inter-disciplinary partnerships (O;E) with other actors for stimulating functional reuse of the harvested building elements, although individuals remain a large client group (E). Selling harvested building elements to individuals will not guarantee preservation of function (T;O). For instance, someone buying a load-bearing steel beam off a construction site may use it to make a bicycle stand with it. This way, energy spent on creating a load-bearing beam, which is more than the energy needed for creating a bicycle stand, will not be used (T). Preservation of function can be safeguarded by reuse of building elements by architects and building contractors (O), where a harvested steel beam may be used to as a structural element in a new asset (T).

4.2.3. Complete reuse

The complete reuse strategy is the ultimate goal of deconstruction strategies in the Circular Economy. This strategy entails salvaging of all building elements whereby it is technically possible to reuse them, leading up to 100% reuse of all sorts of buildings and infrastructure assets.

Respondents in the interview protocol have provided several examples of complete reuse of buildings and infrastructure assets. One of these has been used as case study in interviewing respondent DC4: a circularity expert of a frontrunner medium-sized company in circular demolition. The example revolves around a multi-story office building built in the mid 1980's and is described below.

Complete reuse example

The building was not built with disassembly in mind (T) but has been reused completely, with a few exceptions of building elements getting damaged during transport (T). The outer load-bearing structure was built using prefab reinforced concrete elements, connected with in-situ cast concrete (T). The floor consisted of hollow-core concrete slab floors (T). All technical installations and wiring have been disassembled, refurbished and resold, as well as the carpeting, doors, inner walls and more (T). The supply of harvested building elements has been linked to demand from different projects (E). Elements from the complete structure of the building are re-assigned to function as main construction elements for a construction project conducted by the construction branch of the same company (O). Assigning all harvested building elements to new building projects safeguards function retention (T;O).

In preparation of the tender offering, the demolition contractor used building plans and on-site measurements to create a Business Information Modelling (BIM) model to map all the available building elements and asset build-up (T). This digital model helped in selecting building elements for reuse and developing a disassembly strategy (T;O). Having the supply side covered, the demolition contractor could now fill in the demand side by finding potential clients for the harvested building elements (O;E), as well as having an architect design a new building using harvested building elements (T;E).

The tender did not request any specifics on the circular strategy for deconstructing the asset, but merely asked for a circular approach to demolishing the building (E). The demolition contractor offered the asset owner a bid on the tender with a 100% reuse strategy, including a guarantee for selling all harvested building elements (O;E), apart from those discredited due to technical malfunctions (for example due to transport/disassembly accidents) (T).

Due to the successful vending process of harvested products (O), and due to the possibility to apply many harvested structural building elements in the construction of a new project within the contractor's portfolio (T;O), the extra costs were less than expected from such an ambitious reuse strategy: 25% (O). This is below the price the asset owner was willing to pay (E), so the asset owner took full responsibility for these costs and the contractor made equal profit compared to a traditional demolition situation (O).

Although the structural concrete building elements were prefabricated (T), the connections between the elements were made with cast concrete (T). Hence, disassembly was not a straight-forward procedure: the casted concrete used in each connection had to be cut loose for disassembly (T). Once disassembled, the connections of each structural element had to be restored (T). The demolition contractor applied mechanical connections to the harvested structural elements. This way, the elements have become modular: suitable for easy disassembly in the future without the need for adaptation (T). Now, the elements could be reused repeatedly in different assets (O).

The respondent is part of multiple inter-disciplinary circular project groups (O;E. According to the respondent, this is the only way to achieve high level of circularity. The respondent uses these groups to bring supply and demand side of reusable building elements together (E). The disciplines represented in these project groups, next to the demolition contractor, are in all cases architects and constructors, and in some cases also constructional engineers and researchers (O).

The respondent's company became owner of all building elements (O). Traditionally, the demolition contractor gains ownership over the to-be demolished asset (O), thereby also obtaining responsibility for demolition, handling toxic substances (such as asbestos), disposal of waste, and recycling of materials (O;E). In circular projects nowadays, traditional ownership mechanisms are still in place, but the respondent is experiencing an increasing change in mindset of asset owners. In several reuse projects, both public and private, asset owners kept ownership of the harvested building elements after disassembly (E), however lacked the experience as well as the technical know-how to successfully match the supply and demand side of used building elements (O;E). Although recent examples have not proven successful, the respondent expects asset owners to retain ownership over harvested building elements (E), whereby the demolition contractor provides disassembly as a service (O), and fulfils an advising role in matching supply and demand for the harvested building elements (O;E).

Regarding the connections, the most complex technical challenges in achieving complete reuse are the use of reinforced in-situ cast concrete and inseparable connections (T).

Disassembling reinforced in-situ cast concrete requires cutting through the steel rebars, exposing these to oxygen, leading inevitably to corrosion, even in stainless steel (T). Therefore, structures made with in-situ cast reinforced concrete cannot be reused nowadays and should be recycled.

Inseparable connections, whereby separation would result in damaging the element, are another challenge for complete reuse. An example often mentioned in the interviews is glued floor covering, whereby removing the covering, a labour-intensive process, would not deliver reusable floor covering (T). Respondent DC4 explained that the best practice from his experience is to leave any inseparable connections intact, if possible (T). In the case of glued floor covering, the respondent has often let the covering attached to the structural component, and reused the element as a whole, covering the old floor with a new, detachable, covering (T). As the old floor covering could not be salvaged by applying an alternative disassembly procedure, no more function has gone to waste through leaving the covering connected to the structure (T).

4.3. Evaluation

The results from the analysis and synthesis phase have been presented to Oxand. The experts at Oxand validated the relevancy of the stakeholder analysis and reuse strategies to current knowledge in the sector. Furthermore, the experts acknowledged the business opportunities arising from engaging with demolition contractors' reuse strategies and encouraged extracting knowledge from the reuse strategies and stakeholder network to gain insight into stakeholder engagement with demolition contractors.

For a second iteration of the design process, Oxand recommended to conduct research on complementing the reuse strategy framework with two more strategies: a 'complete demolition strategy' and a 'refuse deconstruction' strategy, demarcating the boundaries of reuse possibilities in the demolition sector. A 'complete demolition strategy' implies complete demolition of an asset, without reuse of recycling of any sort. The 'refuse deconstruction' strategy implies extending the end-of-life moment of an asset as long as technically possible through maintenance, renovations, or rebuilding where necessary. According to the 10R principle (Cramer, 2015) this is the highest achievable level of circularity, whereby circularity must be strived for when additional building elements are required for renovation or rebuilding. As the analysis phase conducted in this design research did not deliver results relating to these strategies, a second iteration of the design process is required. Interviews can be conducted with demolition contractors with a long history of traditional demolition to gain insight into the 'complete demolition strategy'. For the 'refuse deconstruction' strategy, interviews with construction and renovation contractors can provide insight into extending the lifespan of existing assets. A simplified example of the expected strategy framework after the second iteration is shown in figure 6: *Reuse strategy evaluation* to show the position of the 'Complete demolition' and the 'Refuse demolition' strategies.

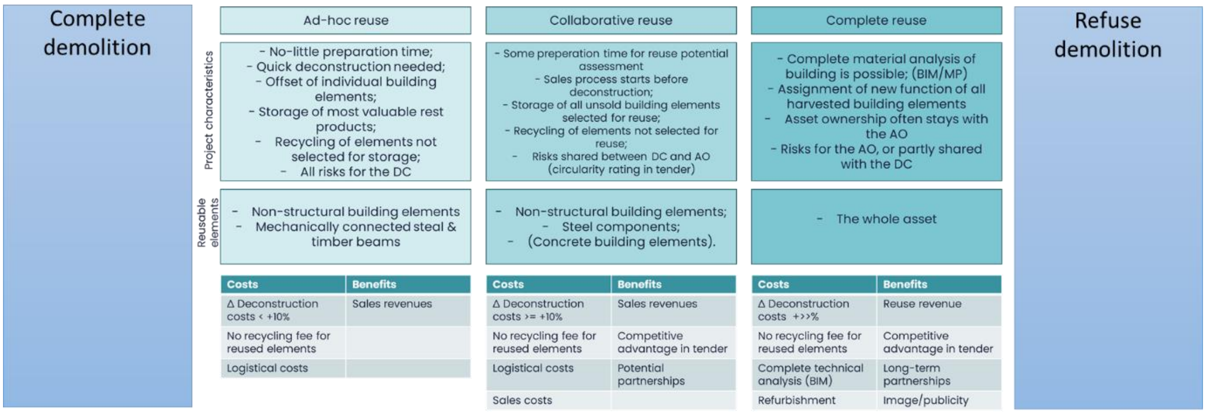

Figure 6: Reuse strategy evaluation

4.4. Knowledge extraction

The three reuse strategies developed in the design process (figure 5) result in new possibilities for stakeholder engagement. These possibilities for stakeholder engagement are discussed in this section.

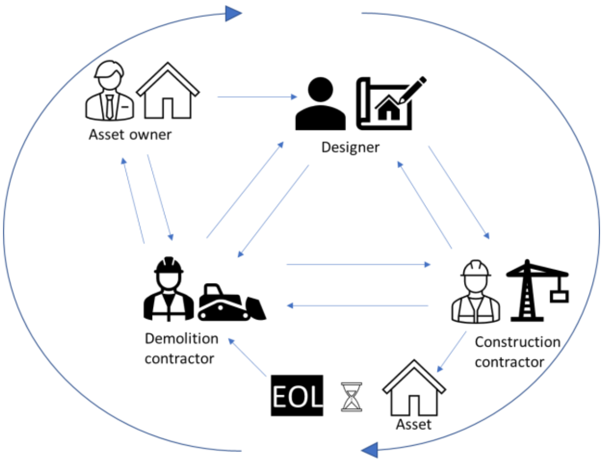

Figure 4: Stakeholder relations in a circular real estate construction sector

The stakeholder network developed in sub-section *8.1.* Analysis, displayed in Figure 4: *Stakeholder relations in a circular real estate construction sector* can be combined with the reuse strategies developed in the sub-section *8.2. Synthesis*, displayed in Figure 5: *Reuse strategies.* From analysing the reuse strategies can be understood how the stakeholders engage with each other. The following sub-sections 4.4.1. and 4.4.2. describes how the design process of the reuse strategies for demolition contractors leads to academic findings on stakeholder engagement with demolition contractors. Sub-section 4.4.1. describes the academic findings drawn from the design process of the reuse strategies, sub-section 4.4.2. applies Savage's stakeholder engagement theory on these findings. Sub-section 4.4.3. concludes with answering the results-oriented research question.

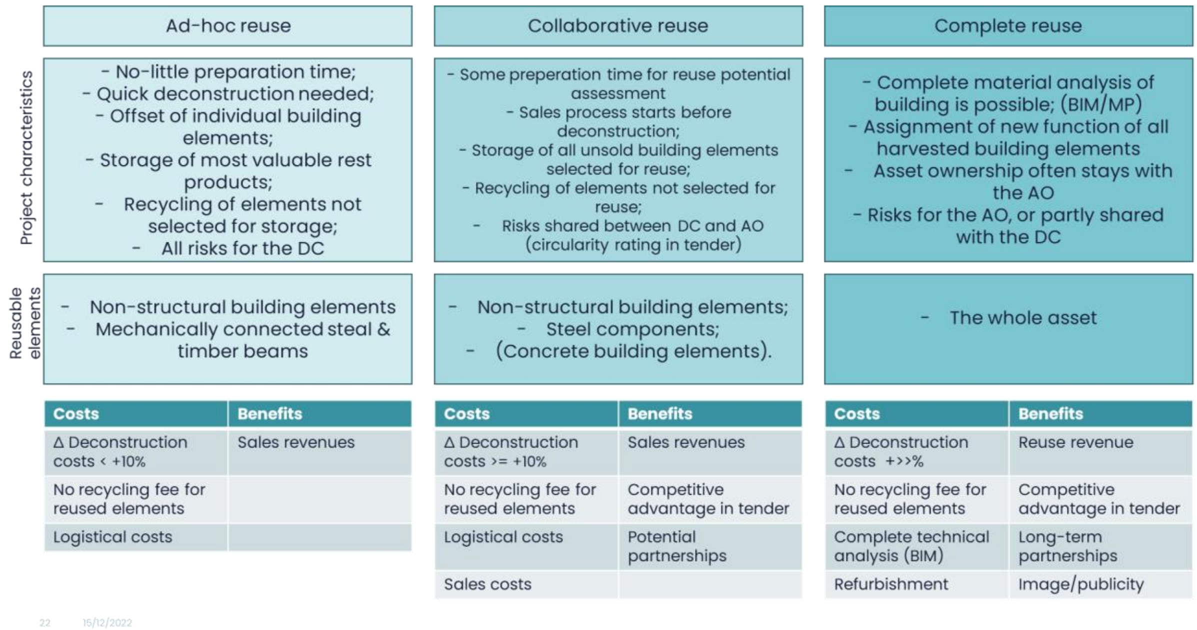

Figure 5: Reuse strategies

4.4.1. Knowledge extraction - Findings from the design process

In a linear economic construction sector, demolition contractors are isolated from building contractors. This research predicts a change in this paradigm and expects construction contractors to need the supply of harvested reusable building elements to adhere to circularity standards requested by clients, the demolition contractor being the supplier.

In the client-supplier relationship between constructors and demolitionists, the demolition contractor is a ‘Supportive’ stakeholder type and can be engaged by the include strategy. However, the interview with respondent DC4 (see Appendix 8.3 *Interview protocol*), a successfully circular operating demolition and construction contractor, explains that this company re-uses harvested building elements within the company, as the construction sector ‘is not on the same level yet’. This company manages to win big public tenders due to their image of expertise in circular deconstruction and construction. Demolition contractors developing in this way are of a ‘Mixed Blessing’ type, and should be engaged with in a collaborative manner by construction contractors. Through collaboration, knowledge-sharing will be made possible, adhering to the industrial facilitator role that demolition contractors are expected to obtain.

For designers, demolition contractors can fulfil the supplier role of harvested building elements. Building strong relations with innovative deconstructionists will get them access to high-potential reusable building elements. As designers and demolitionists have no competition in the services they offer, the reciprocal threat is low. The demand-supply role between designers and demolitionists identified demolition contractors as of the ‘Supportive’ type to designers. Designers should engage with demolition contractors through the ‘include’ strategy, establishing long-term relations for early access to harvested building elements.

Asset owners, especially public, appoint increasingly more importance to sustainability in their demolition tenders, whereby circular strategies score high. Public asset owners are leading the way because circular strategies are expensive. Private asset owners requesting circular construction or demolition are often institutes with a sustainable representation to uphold, such as a sustainable investment bank. Either private or public, asset owners requesting circularity take the largest responsibility for the financial risk between the demolition contractor and asset owner. Therefore, asset owners must work together with demolition contractors, setting standards for expected profits made from selling harvested building elements and agreeing on sharing the risk of a reuse strategy in order to incentivise demolition contractors to cut costs. Although asset owners and demolition contractors are no direct competitors, they have a mutual interest in decreasing the financial risk of a circular strategy. The success of the circular strategy is dependent on an interplay between the willingness to pay from the client, and the expertise of the demolition contractor in deconstruction and offsetting the harvested elements. This places the demolition contractor in the 'Mixed Blessing' category for asset owners. Asset owners should engage with demolition contractors through a 'Collaborate' strategy.

		Potential for Threat to organization/goals	
		High	Low
Potential for cooperation with organization/goals	High	Stakeholder Type: MIXED BLESSING Strategy: COLLABORATE	Stakeholder Type: SUPPORTIVE Strategy: INCLUDE
	Low	Stakeholder Type: NONSUPPORTIVE Strategy: DEFEND	Stakeholder Type: MARGINAL Strategy: MONITOR

Figure 3: Stakeholder engagement matrix (Savage, 1991)

4.4.2. Knowledge extraction – Stakeholder engagement

This section connects the engagement strategies according to Savage (1991) to the stakeholder engagement strategies presented in figure 5 *Reuse strategies*. Related Technical, Organisational and Environmental characteristics are identified with (T); (O); (E). This section concludes with answering the results-oriented research question.

Ad-hoc reuse

The ad-hoc reuse strategy is the most implemented strategy in a linear economic demolition sector. This is the strategy for saving money on waste products after demolishing an asset (O). The priority of this strategy is adhering to recycling standards (E) and minimising costs (O). Therefore, it is a low-level reuse strategy, whereby salvaged building elements (T) can be sold ad-hoc to local buyers (O;E), preferably straight from the building site (O). Function retention of the harvested elements is not a priority (T): non-harvested elements can be recycled or disposed of as waste. In this strategy, all risks are for the demolition contractor (O;E). The demolition contractor traditionally obtains all responsibility and ownership of the asset (O). Therefore, it will not take high risks in achieving circularity. Hence, an expensive deconstruction strategy does not fit in this strategy. The ad-hoc reuse strategy does not fit in a circular real estate construction sector. A scenario whereby this strategy may still be implemented in a circular economy is in the demolition of (parts of an) asset contaminated with illegal or dangerous substances, such as asbestos (T). Overall, the ad-hoc reuse strategy will not be effective in a circular economy. Designers and construction contractors are not the suitable clients for ad-hoc selling of harvested building elements (E): these actors require information on potential reusable building elements long before the design or construction phase of a new asset (E). Ad-hoc selling of reusable building elements is only relevant to local traders, small contractors, or individuals (E). The ad-hoc reuse strategy is applicable in a linear economic construction sector, depicted in figure 3: *Stakeholder network in a linear real estate construction sector* in section 4.1.1.

In an ad-hoc reuse strategy, a demolition contractor will face challenges in finding buyers for salvaged building elements (O;E), therefore only easy detachable or valuable elements are salvaged (T). In order to overcome this challenge, a demolition contractor needs to improve the offset strategy of harvested building elements (O). The goal would be to find buyers for more types of building elements, and to find buyers quicker (O). Establishing agreements with buyers before demolition starts will benefit the financial prospects of harvesting building elements (O). To do so, the demolition contractor must engage with these potential buyers in an early stage (O). Being included in design projects will provide Demolition contractors with information on the demand of needed building elements. However, in order to supply reusable building elements to designers, the demolition contractor would require information on these building elements long before demolition (T;O). This requires inclusion of the demolition contractor by the asset owner, as the demolition contractor needs building information of the to-be demolished assets long before demolition starts. This brings the asset owner in the situation whereby the demolition contractor is potentially gaining extra profit on top of the tender agreement (O). By only supporting the demolition contractor, according to Savage's matrix (Figure 3.), the asset owner is missing out on reuse benefits (O). Recognising this potential threat will result in engaging with demolition contractors in a collaborative strategy (Savage, 1991).

Taking the ad-hoc reuse strategy and improving the offset strategy for harvested building elements results in the strategy evolving in a new strategy: the 'collaborative reuse' strategy. This strategy aims to find as much potential for reusing harvested building elements (T) through engagement with designers and construction contractors (O;E). This requires information symmetry between the actors involved in deconstruction of the old asset (T;O), and construction of the new asset, therefore inclusion of the demolition contractor by the asset owner is needed (O). To avoid the risk of missing out on potential reuse benefits, the asset owner should collaborate with the demolition contractor, sharing strategic challenges and opportunities related to reuse with each other (O). Now, the 'ad-hoc' strategy has evolved to a 'collaborative reuse' strategy.

Collaborative reuse

The collaborative reuse strategy is the most common circular deconstruction strategy. The interview respondents explain that achieving a higher level of reuse, from the perspective of the ad-hoc strategy as starting point, requires engagement with asset owners, designers, and constructors (O;E). Engagement with other stakeholders is necessary for executing this strategy for multiple reasons. First, the demolition contractors cannot take responsibility for all the risks and associated potential costs and benefits, therefore collaboration with the asset owner is needed (O). The initiative for a circular alternative to demolition 'nearly always' comes from asset owners, mainly public, not demolition contractors (E). Such asset owners heavily weigh circular strategies in the appreciation of tender proposals by demolition contractors (E). The success of the deconstruction strategy proposed by demolition contractors relies on the supply of technical building information by the asset owner (T;E), and on finding demand for the harvested building elements to new construction projects (E). Occasionally, demolition contractors work for large asset owners that can reuse harvested building elements from a deconstruction project within their own asset portfolio, but in regular projects, re-allocating harvested building elements is a challenge (O;E). Therefore, being included in the design process of a circular construction project can contribute to bringing the supply and demand of harvested elements together (E). According to the interview respondents, designers increasingly receive requests for circular alternatives to linear construction (E). Demolition contractors can provide the supply of harvested building elements (O), and building contractors would then have to construct with these harvested elements (E). The interview respondents describe a lack of trust in pre-used building elements from the construction sector, and identify this as one of the main challenges for achieving reuse (E). The interviewed demolition contractors illustrated examples whereby the role of the construction contractor has been bypassed in circular construction. The following sections describes an example of demolition contractors competing with building contractors in the construction of industrial facilities.

The deconstruction of industrial facilities such as agricultural silo's or warehouses often deliver complete steel frames, highly suitable for reuse due to the mechanical connections (T). There is demand from asset owners for such asset, however, constructors are not willing to perform the construction (E). Demolition contractors now offer the construction of pre-used, steel-frame supported industrial facilities (T) to asset owners, taking over the role of construction contractors (E). This example illustrates the potential for threat (see Figure 3.) to construction contractors from demolition contractors. Therefore, collaboration between construction and demolition contractors is proposed, different to inclusion. Collaboration can be achieved through sharing of strategic opportunities (Savage, 1996). This can be applied in practice through partnerships between demolition and construction contractors, fulfilling long-term supply and demand needs (O;E). Construction contractors can provide demolition contractors with technical requirements for harvested elements (T), for demolition contractors to selectively deconstruct assets, with the guarantee of reallocation of the harvested elements (O;E).

The key driver behind a successful 'collaborative reuse' strategy is quick allocation of harvested building elements in new construction projects (O;E): inclusion in design processes and collaboration with constructors can potentially allocate building elements during the tender phase of a deconstruction project (O). This provides all stakeholders with clarity on the involved costs and benefits, allowing for fair risk sharing (E).

Complete reuse

In theory, all built assets can be reused in full (T), according to each interview respondent questioned for this research. Apart from willingness to pay, the success of a complete reuse strategy is dependent on allocating harvested building elements successfully in construction projects (E). To illustrate the challenges and opportunities in a 'complete reuse' strategy, thereby proposing engagement strategies between stakeholders, an example of successful execution of this strategy is described, based on the interview with respondent DC4 (see Appendix 8.3 – *Interview protocol*). The name of the project or involved entities are undisclosed.

Respondent DC4 is a project manager of a nearly completed complete reuse deconstruction project. The project concerns the deconstruction of a multiple-story office building, built according to linear economic design principles: building elements were not easily detachable due to glued or casted connections (T). The respondent's company won the tender to demolish the asset 'as sustainable as possible', and proposed complete reuse of the old office building. According to the respondent, there are two main requirements for a complete reuse strategy. First, all technical information of the asset should be available to the demolition contractor (T). Second, each harvested building element should be assigned to a new function as soon as possible (E), preferably before deconstruction starts, and most certainly before the end of the deconstruction process. For both requirements, the demolition contractor is dependent on the asset owner (O;E), for supplying the needed building information (T;O) and contributing to allocating harvested building elements to a new function through its connections with designers and constructors (E). In the project, the asset owner took full responsibility for the extra costs incurred by deconstruction, but shared the risks for selling harvested elements with the demolition contractor (O), typical for the proposed 'collaborative' engagement strategy between asset owner and demolition contractor (Savage, 1991). This way, the asset owner had the incentive to use its network to find designers and constructors willing to work with harvested building elements (E) and the demolition contractor had the incentive to strive for quality preservation of building elements during deconstruction operations (T;O). The asset owner mediated in contact between the demolition contractor and potential buyers of harvested elements, whereby the stakeholders aligned expectations and requirements concerning usability, quality, and safety of harvested elements (T).

In validating the results drawn from this example with the circularity experts of a large public asset owner in the Netherlands and of a research institute (respondents 'AO' and 'RI', see Appendix 8.3 – *Interview protocol*), the experts describe a potential future development in the complete reuse strategy. This development entails the shift from deconstruction as a transactional business model to an as-a-service model (O;E). The current transactional business model in deconstruction includes the transaction of partial or full responsibility over the deconstructed asset from the owner to the demolition contractor. In an as-a-service model, the asset owner would hire a demolition contractor to take apart an asset, and the asset owner will take responsibility for allocation of the harvested building elements in new construction projects, or within its own asset portfolio. The respondents were unanimous in the fact that currently, asset owners rely on the demolition contractors expertise to preserve function of harvested building elements and to allocate these to new projects efficiently.

4.4.3. Knowledge extraction - Conclusion

This section answers the results-oriented research question:

How can the stakeholders in the real estate construction sector apply their business models to the reuse strategies of demolition contractors?

The mutual dependence of the demolition contractor and the asset owner in successful reuse operations illustrate both a high potential threat and a high potential for cooperation in the stakeholder engagement matrix (Savage, 1991), hence a 'collaborative' engagement strategy is proposed for asset owners to engage with demolition contractors. For designers to get access to the supply of harvested building elements, proposed is to 'include' demolition contractors in their business processes, as demolition contractors pose no threat to designers. Demolition contractors do pose a potential threat to construction contractors, as shown by instances of demolition contractors engaging in construction practices using harvested building elements that construction contractors were not willing to use. Therefore, construction contractors should engage with demolition contractors according to a 'collaborative' strategy. Figure 6 *Stakeholder engagement with demolition contractors in a circular real estate construction sector* visualises the engagement strategies within the stakeholder network.

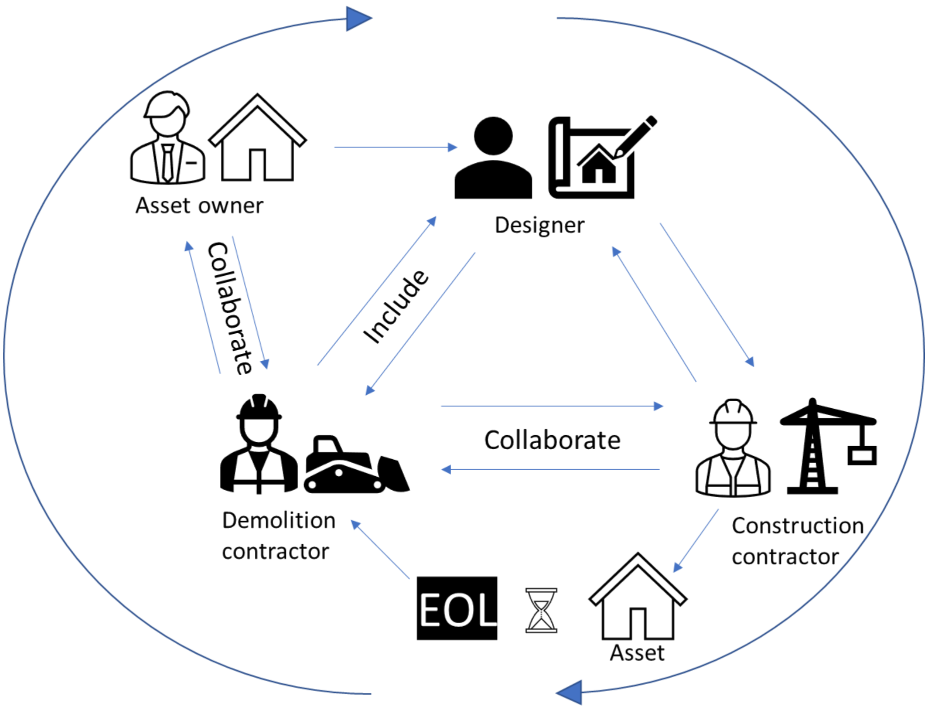

Figure 6: Stakeholder engagement with demolition contractors in a circular real estate construction sector

5. Discussion

Sub-section 5.1. positions the findings from this research against findings from academic literature on stakeholder engagement in the circular economy, answering the existential research question. Sub-section 5.2. discusses the relevance and empirical validity of this academic research to practitioners.

5.1. Relating the research to the theoretical

In academic literature on stakeholder engagement in the circular economy, there is consensus on the need for engagement with multiple stakeholders, whereby value creation includes all relevant stakeholders, as opposed to a single stakeholder, often the customer/client, in a linear economic perspective (Tolkamp et al., 2018; Salvioni et al., 2020). Hence, in circular economic stakeholder networks all relevant stakeholders engage with one another. This is in line with the results of this research, which focusses in the specific on the demolition contractor, a rather isolated stakeholder in a linear economic system, engages with multiple stakeholders in a circular economic system.

All circular business models found in academic literature include waste reduction through efficient use and reuse of materials (Ranta, 2018). The circular stakeholder network proposed in this research allows for efficient allocation of harvested building elements through stakeholder collaboration and inclusion. Furthermore, circular business models require the sharing of strategic objectives between stakeholders more than linear business models as this stimulates identifying stakeholder expectations and promotes their fulfilment (Salvioni et al., 2020). Applying this to the circular real estate construction sector it shows that every stakeholder faces its own challenges in the transition to a circular system; sharing these challenges and related strategies for overcoming them with other stakeholders will promote adoption of a circular strategy. For demolition contractors, selling the harvested building elements is a challenge; being included in designers' business processes will open supply chains for reusable elements.

Many academic sources appoint the lack of knowledge and understanding of the circular economy as reason for slow adoption in the construction sector (Smol, 2015; Eberhardt, 2019; Jiménez-Rivero, 2017; Geissdoerfer, 2018). This research shows something different: the knowledge and understanding of the supply side of harvested building elements lies embedded in the demolition sector. As this sector is isolated in the still dominant linear construction sector, designers and construction contractors are unlikely to engage with demolition contractors, therefore do not get access to this knowledge. Engaging in collaborative, for construction contractors and asset owners, and inclusive, for designers, strategies will foster interdisciplinary knowledge sharing.

Academic literature by Kozlowski, Salvioni and Tolkamp on stakeholder engagement in circular economic systems identifies consumers as suppliers of reusable material and Salvioni calls for the formulation of strategies for transforming consumers into suppliers (Salvioni et al., 2020). In a consumer sector this makes sense, however, the construction industry is business-to-business. The asset owner is the stakeholder being the closest to being the consumer, but is not the supplier as it transfers all responsibility and ownership of the asset to a demolition contractor upon reaching end-of-life. In a circular construction sector, demolition contractors are the suppliers of harvested building elements. In line with academic research, engagement with the supplier of harvested material is expected to drive innovation (Kozlowski, 2018; Tolkamp, 2018; Salvioni, 2020).

Forghani identified a lack of cooperation between demolition contractors and other stakeholders in a case study in Australia and assigned this as the reason for slow innovation of circular building practices. Forghani called out the absence of effective systems or mechanisms for stakeholders to interact as the reason for the lack of cooperation (Forghani et al., 2018). This research has a different perception of the problem, perhaps related to the different sector demographics in the Netherlands compared to Australia. In the Netherlands, the demolition sector is heavily dispersed among many locally or regionally operating contractors with varying experience in circular deconstruction. For asset owners, designers, and construction contractors, it is difficult to have a clear picture of the possibilities of circular deconstruction in a widely dispersed sector. Gathering data from differently sized demolition contractors with varying level of experience provides insight into the different reuse strategies possible. This provides stakeholders in the construction industry, but also demolition contractors, an overview of the possibilities, opening communication possibilities between stakeholders. An example: designers can engage with demolition contractors presenting a 'Collaborative reuse' or 'complete reuse' strategy in a deconstruction tender for getting access to harvested building elements. For demolition contractors with less experience in circular deconstruction, the strategic framework (Figure 5.) can teach them about the technical possibilities and about the possibilities for collaboration with other stakeholders. This research contributes to overcoming the knowledge gap presented by Forghani, being the lack of a stakeholder engagement and communication system (Forghani et al, 2018).

An extensive literature research on stakeholder engagement strategies in a circular construction sector, by Hossain et al, 2020, confirms this research's findings on the need for stakeholder collaboration and sharing of strategic opportunities, but does not identify the pivotal position of demolition contractors in the stakeholder network. In Hossain's research a hundred recent studies on circular economy, stakeholder management, innovations in the construction sector and combinations of the three have been analysed, of which only 10 published before 2010. The extensive analysis of these recent and relevant studies has not pointed to demolition contractors fulfilling a supplying role in the circular construction sector, but still appoint manufacturers of new building elements to role of supplier, and call for sustainable production, modularity, and high rates of recycling. Recent research recommends the training of demolition contractors in circularity principles (Hossain et al., 2020). The results from this research point out that a lot of knowledge on harvesting building elements is embedded in the isolated demolition sector and proposes increased stakeholder engagement with demolition contractors, to extract that knowledge and apply it to the business process of asset owners, designers, and construction contractors. This requires for the other stakeholders to accept the supplier role of demolition contractors in a circular construction sector.

Conclusion

How does understanding of engagement with demolition contractors contribute to the transition to a circular real estate construction sector?

This research has identified demolition contractors as pivotal stakeholders in a circular real estate construction sector. Reusing building elements from linear-constructed assets has proven to be complex. Through stakeholder engagement as described in this research, technical, organisational, and environmental challenges related to this complexity can be overcome. For asset owners, sharing of strategic opportunities with demolition contractors will contribute to selecting the most effective reuse strategy (See Figure 5: *Reuse strategies*). For demolition contractors, being included in designers' business processes, and collaborating with construction contractors will contribute to an efficient execution of the reuse strategy by quick allocation of harvested building elements in construction projects and function retention of the harvested elements.

5.2. Empirical relevance of this research

This research has applied a pragmatic approach to solving an academic knowledge gap due to the expectation of finding a solution space within the empirical context. Operational experience from demolition contractors has formed the main source of qualitative data on which the results have been based. The decision has been made to apply the TOE framework for categorising the gained insights from the internship at Oxand, complemented with academic literature, due to the variety of factors influencing the potential of a reuse strategy. Categorising the factors of influence in the TOE framework reduced the complexity of the problem, creating the needed understanding for developing an academically relevant interview protocol.

Looking back, selecting demolition contractors as target stakeholders for empirical research was a good choice. This group is underrepresented in academic literature on circular building: the focus often lies on builders and designers. The development of demolition contractors' business processes throughout the circular transition is interesting for the academic world. Applying research through design strategy enabled retrieving academic findings from practical experiences. The reuse strategy framework as outcome of the design process is a valuable finding on its own, however, the insights this provides on stakeholder engagement is more relevant to the identified academic problem.

Assessing the research through design process concludes that this methodology is suitable for solving academic problems originating from an operational context. In this research, one iteration has been conducted, meaning the output of the evaluation phase has not been included in another iteration of the design phase. Expected is that performing another, or multiple, iterations of the design phase would have increased the level of detail of the research results. The proposed 'extreme' strategies by Oxand should be included in the strategy framework in a second iteration. Furthermore, in the synthesis phase, change in ownership paradigms between the asset owner and demolition contractors was identified as a potential future development. This change in ownership example was encountered in a 'complete reuse strategy' and can require further research as ownership paradigms is outside the scope of this research.

6. Conclusion

Before moving to modular, Lego®-like houses in a circular real estate construction sector, the current asset stock built according to traditional principles needs to be managed resource-efficiently. Reusing building elements from otherwise demolished buildings is the key driver behind a circular real estate sector. In a linear economic construction sector, demolition contractors are naturally isolated due to their position at the end of the value chain. However, this changes in a circular economic system. Demolition contractors have already developed three different strategies for harvesting building elements from end-of-life assets and are dependent on other stakeholders in the sector to develop their business processes to join demolitionists in the transition to a circular real estate construction sector.

This research investigated the practices of demolition contractors through semi-structured interviews, and developed a reuse strategy framework through a Research through Design process as proposed by van Stijn et al. (n.d.). This resulted in identifying demolition contractors as a supplying actor in a circular economy and proposed asset owners and construction contractors to engage with this supplying actor and designers to include demolition contractors in their business processes.

This research illustrates the dependency between stakeholders in a circular economic sector: demolition contractors need involvement from other stakeholders to put their reuse strategies to use. A complicating factor is that stakeholder engagement between actors that do not engage in the traditional system is not obvious. This research contributes to overcoming this challenge and providing stakeholders in the construction sector with tools to engage with demolitionists.

6.1. Answer to main question

The problem statement addressed in this research is the incongruency between the importance of interdisciplinary stakeholder collaboration for driving circular innovations, as addressed in academic literature, and the lack of knowledge on how to stakeholders in a circular real estate construction sector should engage with demolition contractors. The problem statement is addressed in the main research question:

How should stakeholders in the circular real estate construction sector engage with demolition contractors?

The process of answering this question involved identifying and describing the position stakeholders will take in a circular real estate construction sector and developing a strategic framework from which engagement strategies were derived, contributing to understanding the requirements for transitioning to a circular real estate construction sector.

Asset owners, designers, and construction contractors are the selected stakeholders in the circular real estate construction sector for engaging with demolition contractors. The relation of demolition contractors in to these stakeholders has been identified according to the stakeholder engagement matrix developed by Savage (1991). For all three identified stakeholders, demolition contractors has been identified as a potential organisation for cooperation. For asset owners, cooperating with demolition contractors in a circular real estate sector does introduce risks, related to sharing costs and benefits of a reuse strategy, therefore they are identified as a mixed-blessing stakeholder type, whereby sharing of strategic opportunities is crucial for the 'collaborate' engagement strategy.

Designers are dependent on demolition contractors for the supply of harvested building elements to design with, and demolition contractors vice versa for the demand side, but both stakeholders do not pose a threat to one another, therefor an ‘include’ engagement strategy is proposed. Demolition contractors require construction contractors to use the harvested building elements in construction of new assets. Demolition contractors have shown to engage in construction themselves in cases where no construction contractor was willing to use harvested building elements. Due to the competitive nature of the relation between these stakeholders, demolition contractors are identified as a ‘mixed blessing’ type to construction contractors and require a ‘collaborate’ engagement strategy.

6.2. Limitations and recommendations

This section discusses limitations to this research and related recommendations for future research.

First, the Research through Design process applied in this research performed one iteration. As described by van Stijn (n.d.), an RtD process should consist of multiple iterations, whereby the output of the evaluation phase is the input for the analysis phase of the next iteration. In this research, the output of the evaluation phase was the advice from experts at Oxand to add boundaries to the strategy framework by including a ‘complete demolition’ and a ‘refuse demolition’ strategy. For future research, it is recommended that more iterations of the RtD process are performed to contribute to further development of the results.

Secondly, the selection of stakeholders in the real estate construction sector was limited to asset owners, designers, construction contractors, and demolition contractors. Other stakeholder such as local governments, the national government, citizens, and landowners are kept outside of the scope. A recommendation for future research is to apply the results of to a broader stakeholder network in order to validate the results in a more complete stakeholder context.

Thirdly, in developing the interview protocol, the choice fell on demolition contractors as main respondents, validated by an interview with circularity experts from a large public asset owner and a research institute. For future research it is recommended that results of this research are validated by all stakeholders involved in the results, being asset owners, designers, and construction contractors.

Last, the applied stakeholder engagement theory by Savage has its limitations. This theory has been selected due to its simplicity, a welcome characteristic in this complex problem statement. However, other academic theories put forward more stakeholder types than the four identified by Savage (1991). For future research it is recommended that the analysis of the design process in section 4.4.1. is complemented with one or more stakeholder engagement theories in addition to Savage’s theory.

7. References

Alonso-Almeida, M. del, Rodríguez-Antón, J. M., Bagur-Femenías, L., Perramon, J. (2020). Sustainable development and circular economy: The role of institutional promotion on circular consumption and market competitiveness from a multistakeholder engagement approach. Business Strategy and the Environment, 29(6), 2803–2814. https://doi.org/10.1002/bse.2544

Antonini, E., Boeri, A., Lauria, M., Giglio, F. (2020). Reversibility and durability as potential indicators for Circular Building Technologies. Sustainability, 12(18), 7659. https://doi.org/10.3390/su12187659

Aranda-Usón, A., Portillo-Tarragona, P., Marín-Vinuesa, L., Scarpellini, S. (2019). Financial Resources for the circular economy: A perspective from businesses. Sustainability, 11(3), 888. https://doi.org/10.3390/su11030888

Atkin, B. and Skitmore, M., 2008. Editorial: Stakeholder management in construction. Construction Management and Economics, 26(6), pp. 549-52.

Baker, J. (2011). The technology–Organization–Environment Framework. Information Systems Theory, 231–245. https://doi.org/10.1007/978-1-4419-6108-2_12

Bertino, G., Kisser, J., Zeilinger, J., Langergraber, G., Fischer, T., Österreicher, D. (2021). Fundamentals of building deconstruction as a Circular Economy strategy for the reuse of construction materials. Applied Sciences, 11(3), 939. https://doi.org/10.3390/app11030939

Blengini, G.A., Garbarino, E., Journal of Clean Production, 18 (2010), pp. 1021-1030, https://doi.org/10.1016/j.jclepro.2010.01.027

Blomsma F, Brennan G (2017) The emergence of Circular Economy: a new framing around prolonging resource productivity. J Ind Ecol 21:603–614. https://doi.org/10.1111/jiec.12603

Brand, S. (2012). How buildings learn: What happens after they're built. Penguin Books.

Cai, G., Waldmann, D. (2019). A material and component bank to facilitate material recycling and component reuse for a sustainable construction: Concept and preliminary study. Clean Technologies and Environment Policy, 21(10), 2015–2032. https://doi.org/10.1007/s10098-019-01758-1

CBS. (2023). CBS Statline - bedrijfstak - sloopbedrijven. CBS Statline. Retrieved January 13, 2023, from https://opendata.cbs.nl/#/CBS/nl/dataset/81589NED/table?searchKeywords=bedrijven

Coenen, K. Visscher & L. Volker (2022) A systemic perspective on transition barriers to a circular infrastructure sector, Construction Management and Economics, DOI: 10.1080/01446193.2022.2151024

Cramer, J. Circulaire Economie: Van Visie Naar Realisatie, Utrecht, Utrecht Sustainability Institute. 2015. Available online: https://www.circulairondernemen.nl/uploads/0b8158873a73fcc63fb82105000e2945.pdf (accessed on 10 November 2022).

Deutz, P., Cecchin, A. & Salomone, R. Circular Economy and Sustainability: View from the International Sustainable Development Research Society 2020 Conference. Circ.Econ.Sust. 2, 665–668 (2022). https://doi.org/10.1007/s43615-022-00178-6

Eberhardt, L. C., Birgisdottir, H., Birkved, M. (2019). Potential of circular economy in Sustainable Buildings. IOP Conference Series: Materials Science and Engineering, 471, 092051. https://doi.org/10.1088/1757-899x/471/9/092051

Finch, G., Marriage, G., Pelosi, A., Gjerde, M. (2021). Building Envelope Systems for the Circular Economy; evaluation parameters, current performance and key challenges. Sustainable Cities and Society, 64, 102561. https://doi.org/10.1016/j.scs.2020.102561

Forghani, R., Sher, W., Kanjanabootra, S., Totoev, Y. (2018). The attitudes of demolition contractors to reusing building components: A study in New South Wales, Australia. European Journal of Sustainable Development, 7(3). https://doi.org/10.14207/ejsd.2018.v7n3p364

Geissdoerfer, M., Morioka, S. N., de Carvalho, M. M., Evans, S. (2018). Business models and supply chains for the circular economy. Journal of Cleaner Production, 190, 712–721. https://doi.org/10.1016/j.jclepro.2018.04.159

Guerra, B. C., Leite, F. (2021). Circular economy in the construction industry: An overview of United States stakeholders' awareness, major challenges, and Enablers. Resources, Conservation and Recycling, 170, 105617. https://doi.org/10.1016/j.resconrec.2021.105617

Ghinoi S, Silvestri F, Steiner B (2020) The role of local stakeholders in disseminating knowledge for supporting the Circular Economy: a network analysis approach. Ecol Econ 169:106446. https://doi.org/10.1016/j.ecolecon.2019.106446

Heisel, F., Rau-Oberhuber, S. (2020). Calculation and evaluation of circularity indicators for the built environment using the case studies of Umar and Madaster. Journal of Cleaner Production, 243, 118482. https://doi.org/10.1016/j.jclepro.2019.118482

Homrich AS, Galvão G, Abadia LG, Carvalho MM (2018) The Circular Economy umbrella: trends and gaps on integrating pathways. J Clean Prod 175:525–543. https://doi.org/10.1016/j.jclepro.2017.11.064

Hossain, M. U., Ng, S. T., Antwi-Afari, P., Amor, B. (2020). Circular economy and the construction industry: Existing trends, challenges and prospective framework for Sustainable Construction. Renewable and Sustainable Energy Reviews, 130, 109948. https://doi.org/10.1016/j.rser.2020.109948

Iacovidou, E., Purnell, P. (2016). Mining the physical infrastructure: Opportunities, barriers and interventions in promoting structural elements reuse. Science of The Total Environment, 557-558, 791–807. https://doi.org/10.1016/j.scitotenv.2016.03.098

Icibaci, L. (2019). Re-use of Building Products in the Netherlands - the development of a metabolism based assessment approach. Delft University of technology, pp. 129 – 132. ISBN 978-94-6366-119-5

Jayasinghe, R. S., Rameezdeen, R., Chileshe, N. (2019). Exploring sustainable post-end-of-life of building operations. Engineering, Construction and Architectural Management, 26(4), 689–722. https://doi.org/10.1108/ecam-08-2017-0148

Jiménez-Rivero, A., García-Navarro, J. (2017). Best practices for the management of end-of-life gypsum in a circular economy. Journal of Cleaner Production, 167, 1335–1344. https://doi.org/10.1016/j.jclepro.2017.05.068

Kalmykova Y, Sadagopan M, Rosado L (2018) Circular Economy – from review of theories and practices to development of implementation tools. Resour Conserv Recycl 135:190–201. https://doi.org/10.1016/j.resconrec.2017.10.034

Kozlowski, A., Searcy, C., & Bardecki, M. (2018). The Redesign Canvas: Fashion Design ad a tool for Sustainability. Journal of Cleaner Production, 183(14), 194-207. http://dx.doi.org/10.106/j.clepro.2018.02.010

van Langen, S., Vassillo, C., Ghisellini, P., Restaino, D., Passaro, R., Ulgiati, S. (2021). Promoting circular economy transition: A study about perceptions and awareness by different stakeholder groups. Journal of Cleaner Production, 316, 128166. https://doi.org/10.1016/j.jclepro.2021.128166

Leising, E., Quist, J., & Bocken, N. (2018). Circular Economy in the building sector: Three cases and a collaboration tool. Journal of Cleaner Production, 176, 976-989. https://doi.org/10.1016/j.jclepro.2017.12.010

Liu, J., Wu, P., Jiang, Y., Wang, X. (2021). Explore potential barriers of applying circular economy in construction and Demolition Waste Recycling. Journal of Cleaner Production, 326, 129400. https://doi.org/10.1016/j.jclepro.2021.129400

Ministerie van Binnenlandse Zaken en Koninkrijksrelaties (MBZK). (2022, December 21). Gemeentelijke Herindeling. Gemeenten | Rijksoverheid.nl. Retrieved January 13, 2023, from https://www.rijksoverheid.nl/onderwerpen/gemeenten/gemeentelijke-herindeling#:~:text=Rond%201900%20waren%20in%20Nederland,gemeentelijke%20herindelingen%20afgenomen%20tot%20342.

Ministerie van Infrastructuur en Milieu (MIW), Ministerie van Economische Zaken (MEZ), Ministerie van Buitenlandse Zaken (MBZ), Ministerie van Binnenlandse Zaken en Koningshuisrelaties (MBZK) (2016). Rijksbreed programma Circulaire Economie. Circulaire economie. Rijksoverheid.nl Retrieved September 30, 2022, from https://open.overheid.nl/repository/ronl-a6ce8220-07e8-4b64-9f3d-e69bb4ed2f9c/1/pdf/bijlage-1-nederland-circulair-in-2050.pdf

Munaro, M.R., Tavares, S.F. and Bragança, L., 2020. Towards circular and more sustainable buildings: A systematic literature review on the circular economy in the built environment. Journal of Cleaner Production, 260, pp. 121-134.

Newcombe, R. (2003) From client to project stakeholders: a stakeholder mapping approach. Construction Management and Economics, 21, 841–8

Nobre, G. C., Tavares, E. (2021). The quest for a Circular Economy final definition: A scientific perspective. Journal of Cleaner Production, 314, 127973. https://doi.org/10.1016/j.jclepro.2021.127973

Project Management Institute, 2016. Construction extension to the PMBOK® guide, Newtown Square, Pennsylvania: Project Management Institute, Inc.

Provincie Gelderland. (2022). Prinsenhof. Gelderland.nl/themas/duurzaamheid/circulaire-economie/prinsenhof. Retrieved December 11, 2022, from https://www.gelderland.nl/themas/duurzaamheid/circulaire-economie/prinsenhof

Rahla, K., Mateus, R., Bragança, L. (2021). Implementing Circular Economy strategies in buildings—from theory to practice. Applied System Innovation, 4(2), 26. https://doi.org/10.3390/asi4020026

Rincón-Moreno, J., Ormazábal, M. & Jaca, C. Stakeholder Perspectives in Transitioning to a Local Circular Economy: a Case Study in Spain. Circ.Econ.Sust. 2, 693–711 (2022). https://doi.org/10.1007/s43615-021-00098-x

Rios, F. C., Chong, W. K., Grau, D. (2015). Design for disassembly and deconstruction - challenges and opportunities. Procedia Engineering, 118, 1296–1304. https://doi.org/10.1016/j.proeng.2015.08.485

Rittel, H.W.J., Webber, M.M. (1973). Dilemmas in a general theory of planning. Policy Sci 4, 155–169. https://doi.org/10.1007/BF01405730

Saavedra YMB, Iritani DR, Pavan ALR, Ometto AR (2018) Theoretical contribution of industrial ecology to Circular Economy. J Clean Prod 170:1514–1522. https://doi.org/10.1016/j.jclepro.2017.09.260

Salama, W. (2017). Design of concrete buildings for disassembly: An explorative review. International Journal of Sustainable Built Environment, 6(2), 617–635. https://doi.org/10.1016/j.ijsbe.2017.03.005

Salvioni, D. M., Almici, A. (2020). Transitioning toward a Circular Economy: The impact of stakeholder engagement on Sustainability Culture. Sustainability, 12(20), 8641. https://doi.org/10.3390/su12208641

Savage, G. T., Nix, T. W., Whitehead, C. J., Blair, J. D. (1991). Strategies for assessing and managing organizational stakeholders. Academy of Management Perspectives, 5(2), 61–75. https://doi.org/10.5465/ame.1991.4274682

Senaratne, S., KC, A., Perera, S., Almeida, L. (2021). Promoting stakeholder collaboration in adopting circular economy principles for Sustainable Construction. Proceedings of the 9th World Construction Symposium 2021 on Reshaping Construction: Strategic, Structural and Cultural Transformations towards the 'Next Normal'. https://doi.org/10.31705/wcs.2021.41

Smith, N. (2022). The Circular Economy: Retaining value by transforming our process. Architecture AU. Retrieved November 22, 2022, from https://architectureau.com/articles/the-circular-econogy-retaining-value-by-transforming-our-processes/

Smol, M., Kulczycka, J., Henclik, A., Gorazda, K., Wzorek, Z. (2015). The possible use of sewage sludge ash (SSA) in the construction industry as a way towards a circular economy. Journal of Cleaner Production, 95, 45–54. https://doi.org/10.1016/j.jclepro.2015.02.051

van Stijn, A., Lousberg, L. (n.d.). Approaching Research through Design in the field of Architecture and the Built Environment: Relating to the history, key theories and discourse. Department of Management in the Built Environment, Faculty of Architecture and the Built Environment, Delft University of Technology, Amsterdam Institute for Advanced Metropolitan Solutions.

Tolkamp, J., Huijben, J. C. C. M., Mourik, R. M., Verbong, G. P. J., & Bouwknegt, R. (2018). UserCentred Sustainable Business Model Design: The Case of Energy Efficiency Services in the Netherlands. Journal of Cleaner Production, 182(13), 755-764. http://dx.doi.org/10.1016/j.jclepro.2018.02.032

Vefago, L. H., Avellaneda, J. (2013). Recycling Concepts and the index of recyclability for Building Materials. Resources, Conservation and Recycling, 72, 127–135. https://doi.org/10.1016/j.resconrec.2012.12.015

Xiang P, Yuan T (2019) A collaboration-driven mode for improving sustainable cooperation in smart industrial parks. Resour Conserv Recycl 141:273–283. https://doi.org/10.1016/j.resconrec.2018.10.037

8. Appendix

8.1. Figures

E. Iacovidou, P. Purnell / Science of the Total Environment 557–558 (2016) 791–807 795

Table 1
Reuse potential rates of a range of construction components.

No potential (0%)	Low (<50%)	Medium (~50%)	High (>50%)
Clay bricks (cement-based mortar)[a,f]	Mineral wool[b,e]	Steel cladding (buildings)[c]	Clay bricks (lime-based mortar)[a,b,f,o]
Steel rebar (buildings)[c]	Gypsum wallboard[a,b,e,g]	Steel cold formed sections (buildings)[c]	Structural timber[b,e,f,g,i,l]
Steel rebar (other infrastructure)[c,i]	Steel rebar in pre-cast concrete (buildings)[c]	Steel pipes (buildings)[c]	Structural steel (buildings)[c,f,j,m]
Steel connections[c,f]	Structural steel (infrastructure)[c,h]	Pre-cast concrete[a,m]	Concrete building blocks (with lime mortar)[a,f]
Structural concrete (buildings)[d,e,f,g,i,l]	Timber trusses[m]	Slate tiles[p]	Concrete paving slabs and crash barriers[j]
Asphalt (other infrastructure)[d,g,i]	Concrete in-situ[a,j,k,l,n]	Timber floorboards[p]	Clay roof tiles[j,l]
Asphalt roof shingles[e,m]	Concrete fencing, cladding, staircases and stair units[f]		Concrete roof tiles[j,l]
Plastic pipes (water and sewage), roof sheets, floor mats, electric-cable insulation, plastic windows[n]	Glass components (e.g. windows)[d]		Stone paving[f,j,p]
Concrete pipes and drainage, water treatment and storage tanks and sea and river defence units[j]			
Non-ferrous metal components (aluminium window frames, curtain walling, cladding, copper pipes, zinc sheets for roof cladding)[a,i,n]			Stone walling[f,j,p]

[a] WRAP (2008b) (figures based on buildings).
[b] Thormark (2000) (figures based on a residential building).
[c] Cooper and Allwood (2012) (figures based on global steel production).
[d] BIO Intelligence Service (2011) (figures based on European data on potential use of construction materials/components).
[e] Gorgolewski and Ergun (2013) (figures based on an archetype wartime house).
[f] Webster and Costello (2005) (based on literature).
[g] Horvath (2004) (based on literature).
[h] Pongiglione and Calderini (2014) (figure based on a railway station).
[i] Tam and Tam 2006 (based on literature).
[j] Hurley and Hobbs (2005) (based on literature).
[k] Sassi (2004) (based on literature).
[l] Sassi (2002) (based on literature).
[m] Earl et al. (2014) in Nakajima and Russel (based on literature).
[n] Leal et al. (2006) (based on management of CDW in Germany).
[o] Bohne and Waerner (2014) (based on figures from Norway).
[p] WRAP (2008a) (based on figures from the UK).

Appendix 1: Reuse potential of a range of construction components (Iacovidou & Purnell, 2016)

Table 2
Interventions in the construction and demolition sector.

Intervention	References
Adaptive reuse	Webster (2007), Pongiglione and Calderini, 2014, Webster and Costello (2005), Ness et al. (2015), Laefer and Manke (2008), Gorgolewski et al. (2006), Langston et al. (2008), Velthuis and Spennemann (2007)
Deconstruction	Aidonis et al. (2008), Couto and Couto (2010), Sassi (2002), Srour et al. (2012), Schultmann (2008), Schultmann and Sunke (2007), Leroux and Seldman (2000), Leigh and Patterson (2006), Kibert et al. (2001), Guy and Gibeau (2003), Gorgolewski (2008), Schultmann and Rentz (2002), Saghafi and Teshnizi (2011), Roussat et al. (2009), Hosseini et al. (2015), Denhart (2010), da Rocha and Sattler (2009).
Design for Deconstruction (DfD)	Dorsthorst and Kowalczyk (2005); Webster and Costello, 2005; Webster (2007); Sassi, 2004; Gorgolewski, 2008; Sassi, 2008; Rios et al. (2015); Pulaski et al. (2003); Guy and Shell (2002); Durmisevic and Brouwer, 2002; Tingley and Davison (2011); Crowther, 2002; Crowther (2014).
Design for reuse (DfR)	da Rocha and Sattler (2009); Gorgolewski (2008), Berendsen (1997), Bradly and Shell (2002), Chini and Schultmann (2002), Pongiglione and Calderini (2014)
Design for Manufacture and Assembly (DfMA)	Laing O'Rourke 2013; Pasquire and Connolly (2003); Jaillon and Poon (2014)

Appendix 2: Interventions in the C&D sector (Iacovidou & Purnell, 2016)

Table 3
Benefits and constraints of deconstruction.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Environmental	Reduction in the use of virgin raw resources.	x	x			x		x			x						x	x	x	x
	Reduction of waste generated.	x	x	x				x		x	x				x		x	x	x	x
	Proper removal and handling of hazardous materials.	x	x							x										
	High recovery of components for reuse and materials for recycling.	x	x	x				x		x										
	Conservation of embodied energy and carbon of materials and components.			x				x												
	Reduction of environmental impacts from minimisation of the needs for reprocessing of materials			x				x			x				x		x	x	x	
Economic	Higher costs compared to conventional demolition		x			x		x	x		x	x			x	x				
	Creation of local markets for materials recycling and components reuse	x				x		x							x					
	Lack of regional markets for reclaimed components											x								
	Opportunities for small and medium-size enterprises (SMEs) development to handle secondary components for reuse		x					x		x										
	Generation of revenue through selling salvaged components	x	x			x		x		x								x		
	Reduction of costly investments in heavy machinery and equipment	x						x									x			
	Lack of financial incentive for deconstruction	x													x					
	Increased cost of transport and storage of components	x	x		x	x														
	Lower costs of inventory, maintenance, transportation and procurement of new products																		x	
	Long-term economic benefits	x	x												x					
	Increased demand for material - low speed of deconstruction	x	x		x	x			x											
	Fluctuation of value of salvaged components			x						x										
	Reduction in the costs of waste disposal		x	x				x		x						x				
Social	Mitigation of noise, dust, and compaction associated with conventional demolition.		x												x					x
	Creation of new jobs in deconstruction sector	x	x					x		x					x		x	x		x
	Provision of low cost material to low income communities	x	x																	
	Job training in use of basic tools and deconstruction techniques	x	x					x							x					
	Cultural preservation and retention of historical significance of community infrastructure		x					x		x		x								
	Opportunities for self-employment and small business development		x					x							x					
	Consumers prejudice in using second-hand materials and preference to new		x		x							x								
	Aesthetics and commercial desirability		x		x				x											
Technical	Buildings and building components not designed for deconstruction	x	x	x	x						x	x								
	Performance guarantee for reused materials - tests needed to certify performance	x	x	x	x	x														
	Lack of experience and capability on construction techniques used, and available tools to implement deconstruction	x	x		x						x	x			x	x				
	Vast variety in quality of extracted components from buildings	x									x	x		x						
	Vast variety in the size of extracted components from buildings			x								x		x						
	Existence of hazardous substances (fire retardants, coatings, etc.)			x	x						x	x	x	x						
	Lack of information on buildings components											x	x							
	Uniqueness of each building for deconstruction																			
Organisational	Lack of standard specifications and building codes to address the reuse of building components	x		x	x	x			x		x	x			x	x				
	Excessive effort and time required				x				x			x		x	x	x				
	Lack of infrastructure for refurbishment and storage of components				x							x		x	x					
	Tight scheduling of deconstruction projects											x			x					
	Large number of parties involved in deconstruction											x		x						

(1) Couto and Couto (2010); (2) Hechler et al. (2012); (3) Kibert et al. (2001); (4) Tingley and Davison (2011); (5) Guy (2014); (6) Gorgolewski, 2008; (7) Leroux and Seldman (2000); (8) Sassi (2004); (9) Aidonis et al., 2008; (10) Dorsthorst and Kowalczyk (2005); (11) Srour et al. (2012); (12) Schultmann (2008); (13) Schultmann and Sunke (2007); (14) Leigh and Patterson (2006); (15) Sassi (2008); (16) Saghafi and Teshnizi (2011); (17) Denhart 2010 (as cited in Hosseini et al., 2015); (18) Shakantu et al. (2012) (as cited in Hosseini et al. (2015)); (19) Guy and Gibeau (2003) (as cited in Hosseini et al. (2015).

Appendix 3: Benefits and constraints of deconstruction (Iakovidou and Purnell, 2016)

Table 5
Proposed classifications for a typology of recovered structural components.

Level I classifications		Description and example level II + classifications
1	Action	The physico-mechanical role of the component in its previous deployment, e.g. 1.1 structural (primary load bearing, such as beams or columns), 1.2 semi-structural (secondary load-bearing such as cladding, roofing), 1.3 modular (such as bricks, tiles), 1.4 functional (such as staircases, windows, lighting).
2	Material	The material from which the component is made, e.g. 2.1 concrete (plain or reinforced), 2.2 steel, 2.3 timber, and 2.4 glass. In each case, a quality would need to be specified, especially strength grade for the structural materials.
3	Deployment	The structural form or class in which the component was previously used, e.g. 3.1 domestic housing, 3.2 high-rise housing, 3.3 commercial, 3.4 industrial, 3.5 infrastructure.
4	Exposure	The environmental conditions to which the component has been subjected, e.g. 4.1 outdoor, 4.2 indoor, 4.3 marine, 4.4 chemical/corrosive, 4.5 high temperature. These conditions would be associated with quantifications (e.g. weather records, detail of chemical environments, Eurocode EN1992 exposure classes) where appropriate.
5	Loading	The loading history of the component, e.g. 5.1 static loading (live and/or dead), 5.2 fatigue loading, 5.3 impact or transient loading. Each would be associated with a quantification of the loading history where appropriate. For functional components, loadings might be expressed in other terms (e.g. electrical, traffic).
6	Recovery	The methods used to recover the component, e.g. 6.1 general demolition, 6.2 recognised demolition protocol, 6.3 component-specific recovery, 6.4. DfD/DfR/DfMA process. In each case, a likelihood of damage or contamination should be associated or specified.
7	Residual	The structural and functional properties of the component remaining, e.g. 7.1 dimensions, 7.2 structural capacity, 7.3 functional capacity. In each case, it should be specified whether the residual has been directly measured (and how) or inferred from nominal capacity adjusted for age, exposure and loading.
8	Connections	The capacity of the component to be connected to other structural and/or functional components and artefacts, e.g. 8.1 standard connections (bolt or dowel holes, recognised electrical/hydraulic/communications connector), 8.2 no connector (e.g. where component has been sawn from a monolithic connection, or otherwise removed from a non-disassemblable original connection).
9	Availability	Details of when and where a component is likely to be available, and in what quantity, e.g. 9.1 time arising, 9.2 place arising, 9.3 amount arising, 9.4 market maturity.
10	Generation	The number of times the component has already been reused, and whether the proposed new use would represent upcycling, recycling or down-cycling/cascading.

Appendix 4: Typology of recovered structural components (Iakovidou and Purnell, 2016)

Table 1
Exemplary building elements that were either recovered for reuse or not.

Layer	Recovered for reuse	Not recovered for reuse (destructed)
Stuff	Microwaves; Refrigerators; Hot plates; Ovens; Flowerpots; Curtains; Sun screens	Mirrors; Lamps
Space plan	Staircases; Banisters; Door fittings	Interior walls; Doors; Ceiling tiles; Linoleum; Floor plinths; Cable ducts
Services	Sinks; Air conditioning units; Sockets; Door closers; Faucets; Fire hose reels; Meter cupboard	Radiators; Toilets; Luminaires; Electrical wiring; Plumbing; Elevator; Countertops
Skin	Façades; Timber coverings; Foundation plinths	(Non-standard) façades; Sliding entrance doors
Structure	Floor slabs; Columns; Roofs; Wind bracings; Lift pit	(Non-standard) floor slabs; Foundations
Site[a]	Brick pavement; Hedges; Fencing	–

[a] We reinterpret this layer as consisting of elements belonging to the outdoor space rather than the "eternal" legally defined lot.

Appendix 5: Recovered building elements categorized by layer (Van den Berg, 2020)

Stakeholders	The focus of the roles
Private organisations, waste operators, local and regional administrations, business associations, clearinghouses [76]	Facilitating a coordination framework between bodies to access waste
Private organisations, financier, national government, private organisations [19]	Collaboration to coordinate activities around recycling materials in a circular supply chain
Private organisations (e.g. converters, generators, collectors) [77]	Implementation of technologies in the waste value network
Private organisations (e.g. IS promoter, companies), local government agencies, research institutions, media, social organisations (e.g. NGOs) [23]	Public and private partnerships to strengthen institutional capacities
Local government, coordinator, financier, private organisations [13]	Contributors to create, capture, and deliver value from waste
Local government, industry, and research institutions [66]	Regional systematic cooperation developing policy actions and practice-based business

Appendix 6: Stakeholder analysis (Rincón-Moreno, 2022)

8.2. Predictive maintenance by Oxand

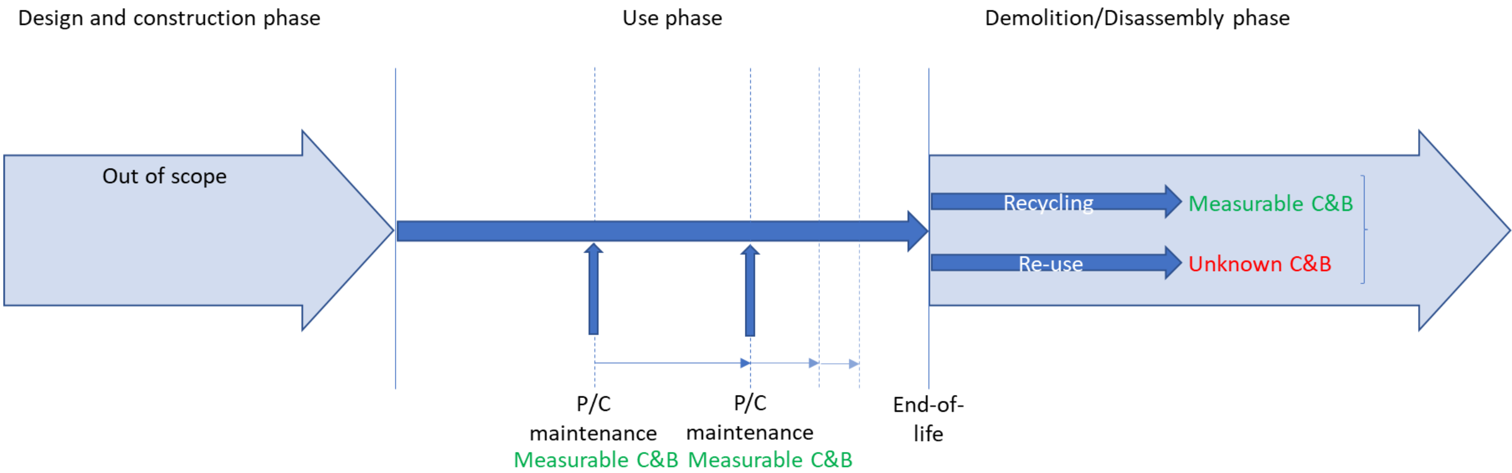

Figure 4: Lifespan extension through maintenance

An asset's lifespan can be prolonged by maintenance, this is made visual in *Figure 1* in the use phase. Traditionally, an asset's value is depreciated to zero and demolition costs are taken into account, perhaps some value can be retained through recycling. However, predicting the costs and benefits of re-using building elements is unexplored by Oxand, which is depicted in red 'Unknown costs and benefits' in Figure 1.

Oxand's problem is that its method of valuation is not equipped to measure value from re-using building elements.

8.2.1. Business process

Becoming able to measure value from re-using building elements requires understanding of current valuation methodologies. Oxand's business process is used as a case study to generalise how assets in the infrastructure and built environment sector are valuated and will be used as starting point to develop a valuation methodology for the re-use of building elements (BC's).

Figure 2 visualizes the development of maintenance strategies at Oxand. Part of this process is the valuation of building elements based on the risk of failure and costs of maintenance in steps 3 and 4. The development of maintenance strategies is done in the use phase depicted in *Figure 1*. The in step 5 developed maintenance strategies to lengthen the lifespan of the asset. The text boxes describe actions Oxand undertakes at each step.

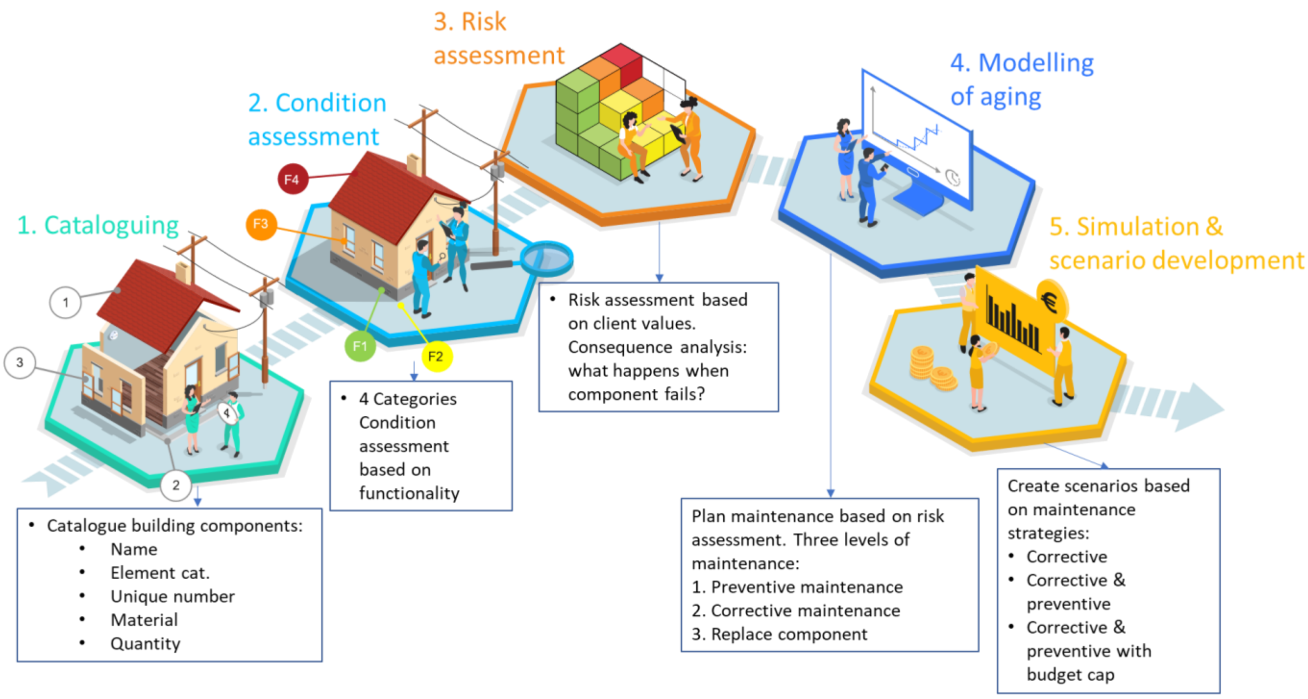

Figure 5: Development of maintenance strategies at Oxand (Derived from internal document Oxand, 2021)

In Step 5. *Simulation & scenario development* Oxand provides the client with three options for conducting long-term maintenance. The corrective scenario refers to a strategy whereby maintenance is only conducted when a building component is in the two highest risk categories (F3 and F4). Including preventive maintenance refers to maintaining building elements to upkeep a sufficient to good condition in order to postpone the need for corrective maintenance. Including a budget cap will result in prioritising preventive maintenance based on level of criticality and costs. The scenarios developed in step 5 are future-oriented on a fixed time frame established in accordance with the client, for instance 15 years. The output of each scenario is the needed value invested in maintenance and the development of the asset's state until the end of the timeframe. The value of the building elements at the end of the timeframe is not quantified or otherwise included in the scenarios. Assumed is that this will incentivise asset owners to carry out a cheap maintenance strategy during the last years before the asset reaches end-of-life, allowing the building elements' conditions to deteriorate before demolition. Including the option of reusing building elements harvested from end-of-life assets is expected to change the financial output of maintenance strategies as value can be gained from assets after the lifespan of a scenario.

8.2.2. Predictive maintenance steps

This section examines how Oxand, an international asset management consultancy company, develops predictive maintenance strategies for their clients.

The service Oxand provides helps the client in deciding between different maintenance strategies. A maintenance strategy is, put simply, always a trade-off between cost of investment and benefit of lifetime extension. The most distinctive difference in maintenance strategies is between preventive or corrective maintenance. Preventive maintenance entails sustaining assets through early signalling and maintaining of defaults, whereas corrective maintenance refers to the strategy of maintaining an asset only when function loss is at risk.

Above description touches upon the predictive maintenance service Oxand provides. To achieve such maintenance strategy proposition, several assessments are performed and used as input for an aging model for various maintenance strategies. These models simulate the deterioration of an asset and the affiliated maintenance costs. From start to end, a predictive maintenance strategy is developed as follows:

Inventorise. Incoming assets are catalogued into objects, elements and building elements. This is a systemic catalogue: an object is formed by several elements and elements are formed by several elements. Objects are defines based on function and are assigned separately in the *Simeo* software. Examples of functional elements of a residential building are 'roof', 'wall', 'foundation', 'sewage', 'electric cable system', 'smoke detector'. Elements are parts of the object that have distinctive material properties: 'windowpane' is an element within the object 'wall' because it has different properties. Also, 'inner wall', 'outer wall', 'isolation' are objects of 'wall'. 'Frame' and 'glass plate' are building elements of the element 'windowpane'. All building elements can be found within their element and object class in the *Simeo* software, see Appendix 1.

Condition assessment. Each building component is assessed based on its condition. There are four condition classes: F1; F2; F3; F4. The classes define respectively: asset is (as good as) new; asset starts showing signs of aging; asset is clearly aging but can keep up its function; asset is no longer functional, Appendix 2.

Risk assessment. In the risk assessment a consequence matrix is made with vertically the severity of the consequence [no effect – very large effect], horizontally the areas of risk [safety, availability, sustainability, social environment]. The consequence of the condition of each component on the areas of risk is plotted in a consequence (y-axis) – condition (x-axis) graph, see Appendix 3.

Modelling of aging. On object level, the overall object condition is plotted against the time. Maintenance actions on element-level can be plotted in the graph, improving the object condition. There are three types of maintenance: early prevention (EP), repair (REP), reconstruct (REC). Early prevention lengthens the condition of the building component on the same level, repair improves the condition by one, sometimes two, levels, reconstruct will implement a new building object with a new level of condition. Accompanying costs are added based on historic data of similar maintenance operations or of requested quotations from contractors, see Appendix 4.

Simulating and planning of scenarios. Different strategies are formulated. Each strategy includes maintenance actions for different strategy purposes. There are two types of maintenance: preventive maintenance and corrective maintenance. Preventive maintenance is usually a less drastic intervention compared to corrective maintenance and is aimed to keep a building component longer in the same risk category. Preventive maintenance is likely to be performed on building elements in risk category F2 to maintain this risk category. Corrective maintenance is performed on building elements with F3 or F4 risk levels, in order to bring the risk level down by one or two levels. Completely replacing a building component will reduce the risk level top F1. There are three maintenance strategies: corrective maintenance strategy; corrective maintenance and preventive maintenance strategy; corrective maintenance and preventive maintenance with budget limit. These strategies entail, respectively: only conducting corrective maintenance; conducting preventive maintenance and corrective maintenance when needed; conducting preventive maintenance if budget allows and corrective maintenance when needed. For each strategy, cost predictions per year are made for a set period, mostly between 10 and 15 years. The client can decide for a strategy as a trade-off between costs of maintenance and benefits of expected lifespan extension. The benefits of extended lifespan extension include postponing replacement costs, preventing future maintenance costs, retaining service of asset. For each strategy, costs per year are shown.

These five steps describe how Oxand analyses assets, models the deterioration of building elements, predicts possible and required maintenance actions and simulates the costs of different maintenance scenarios. The scenario’s timespan ends at the pre-determined end of the asset’s lifespan. In the next section will be analysed how costs and benefits of recovering reusable building elements can be included in Oxand’s business process.

8.3. Interview protocol

Four demolition contractors (DC1 – DC4) offering 'circular demolition methods' on their websites have been interviewed in semi-structured interviews in order to understand what aspects make these strategies possible and what are the challenges when conducting such strategy. Section 10.3.1 shows the interview questions for the demolition contractors.

The results from these interviews were validated with two semi-structured expert interviews: a circularity expert from a large public asset owner (AO) and a business developer for circular projects of a large semi-public research institute (RI). The validating interview protocol can be found in section 10.3.2.

The interview data are categorised in topics in section 10.4.
The automated interview transcripts can be found in the clausula.

Interview 1: Circularity expert of a medium-sized demolition contractor in the NL (DC1).
Interview 2: Circularity expert of a medium-sized demolition contractor in the NL (DC2).
Interview 3: Circularity expert of a small-medium-sized demolition contractor in the NL (DC3).
Interview 4: Circularity expert of a frontrunner medium-sized company in circular demolition (DC4).
Interview 5: Circularity expert of the largest public asset owner in the NL (AO).
Interview 6: *Business developer circularity* of a large semi-public research institute in the NL (RI).

8.3.1. Interview questions Demolition Contractors (DC1-4)

Met het afnemen van dit interview hoop ik inzicht te krijgen in hoe een sloopbedrijf kennis van constructies en materialen toepast om hergebruik van bouwdelen te realiseren.

De interviewvragen zijn ingedeeld in 3 onderwerpen: (1) Waarde van hergebruik (2) Hergebruik van dragende bouwdelen (3) Verschil in materiaal bij hergebruik van dragende bouwdelen. Elk onderwerp begint met een aantal korte-antwoord vragen en eindigt met detail vragen.

Introductievragen

1. Op de website van uw bedrijf staat dat er wordt gestreefd naar circulair slopen. Kunt u uitleggen wat uw bedrijf verstaat onder circulair slopen?
2. Hoe kijkt uw bedrijf naar recyclen t.o.v. hergebruik?
3. Wat zijn de grootste voordelen voor uw bedrijf van circulair slopen?
4. Wat zijn de meest voorkomende uitdagingen voor uw bedrijf bij circulair slopen?

Kort-antwoord vragen

1. Hoe beoordelen jullie de overgebleven levensduur van een bouwdeel?
2. Hoe beoordelen jullie de functionaliteit van een bouwdeel?
3. Hoe beoordelen jullie ouderdom van een bouwdeel?
4. Heeft onderhoudsgeschiedenis invloed op de circulaire waarde?
    a. Hoe uit dit zich in het selecteren van bouwdelen voor hergebruik?
5. Waar en hoe slaan jullie herbruikbare bouwdelen op?
    a. **+ vanuit waar verkoop je deze bouwdelen? (22-11)**

Detail vragen

6. Hoe selecteren jullie op bouwdelen voor hergebruik?
    a. Wat zijn daarin de afwegingen die jullie maken?
7. Maken jullie vooraf een inschatting/berekening van de verwachte financiële waarde van hergebruik?
    a. Zo ja, op basis waarvan?
8. Ik herken 3 fases in circulair slopen: (1) Analyseren waar herbruikbare waarde zit; (2) herbruikbare bouwdelen 'oogsten'; (3) bouwdelen verkopen.
    a. Zou u voor alle drie de delen de meest voorkomende uitdagingen kunnen benoemen?
    b. In een ideale situatie, wat heeft u dan nodig om bovengenoemde uitdagingen te overkomen?
9. **+ Financiën lineair VS circulair slopen**
    a. **Hoeveel duurder is circulair slopen dan lineair slopen?**
        i. **Personeel?**
        ii. **Materiaal?**
        iii. **Opslag?**
    b. **Hoeveel meer levert circulair slopen op dan lineair slopen?**
10. **Circulaire partnerships?**
    a. **Relatie met de klant (en evt. andere partijen) lineair t.o.v. circulair?**

Hergebruik van dragende bouwdelen

Kort-antwoord vragen

1. Heeft u ervaring met hergebruik van dragende bouwdelen?
2. Ziet u herbruikbare waarde in dragende bouwdelen?
    a. Is het anders om deze waarde te realiseren bij dragende bouwdelen t.o.v. niet-dragende bouwdelen?

Detail vragen

3. In de fases van circulair slopen ((1) analyseren (2) oogsten (3) verkopen)
    a. Zou u voor alle drie de delen de meest voorkomende uitdagingen kunnen benoemen wat betreft hergebruik van dragende bouwdelen?
    b. In een ideale situatie, wat heeft u dan nodig om deze uitdagingen te overkomen?

Verschil in materiaal bij hergebruik dragende bouwdelen

Kort-antwoord vragen

1. Ik heb een onderscheid gemaakt voor dragende bouwdelen in baksteen, (gewapend) beton, en staal. Klopt dit?
   <u>Baksteen</u>
2. Bij bakstenen lijkt het realiseren van hergebruik voor mij vrij simpel: metselresten moeten worden verwijderd en schoongemaakt, vervolgens zijn ze klaar voor de verkoop. Klopt dit?
3. Op basis waarvan wordt de afweging gemaakt tussen hergebruik en recyclen van baksteen?
   <u>Beton</u>
4. Worden bouwdelen van niet-gewapend beton weleens geselecteerd voor hergebruik?

5. Worden bouwdelen van gewapend beton weleens geselecteerd voor hergebruik?
6. Is het mogelijk om in-situ gegoten betonnen bouwdelen te hergebruiken?
7. Op basis waarvan wordt de afweging gemaakt tussen hergebruik en recyclen van beton?
   Staal
8. Worden stalen dragende bouwdelen meestal direct hergebruikt, of gerecycled?
9. Op basis waarvan wordt de afweging gemaakt tussen hergebruik en recyclen van staal?

Detail vragen

Beton

1. In literatuur heb ik gelezen dat er bij prefab betonnen bouwdelen twee soorten verbindingen zijn, namelijk mechanisch en chemisch.
   a. Heeft het type verbinding invloed op hergebruik van betonnen bouwdelen?
2. Worden (licht) beschadigde betonnen bouwdelen ooit geselecteerd voor hergebruik?
   a. Zo nee, wat zou u nodig hebben om deze bouwdelen wel te kunnen selecteren voor hergebruik?
   b. Zo ja, hoe beoordeelt u de toestand van het bouwdeel en welke afweging maakt u op basis van deze toestand?

Staal

1. In literatuur heb ik gelezen dat er bij stalen bouwdelen twee soorten verbindingen zijn, namelijk mechanisch en gelast.
   a. Heeft het type verbinding invloed op hergebruik van stalen bouwdelen?
2. Worden (licht) beschadigde stalen bouwdelen ooit geselecteerd voor hergebruik?
   a. Zo nee, wat zou u nodig hebben om deze bouwdelen wel te kunnen selecteren voor hergebruik?
   b. Zo ja, hoe beoordeelt u de toestand van het bouwdeel en welke afweging maakt u op basis van deze toestand?

8.3.2. Interview questions public asset owner (AO) and research institute (RI)

8.3.2.1. Interview questions public asset owner

Deze sectie bevat eerst een stuk met kennis van waaruit ik redeneer (Achtergrondinformatie), daarna volgt hetgeen ik nog wil onderzoeken (Interviewvragen).

Achtergrondinformatie

Uit literatuurstudie is het volgende gebleken:

- Het hergebruiken van bouwdelen is noodzakelijk om de *footprint* van de infrastructuur en ruimtelijke ordening sector te verminderen.
- Er is veel onderzoek gedaan naar het ontwerpen van circulair afbreekbare nieuwbouw.
- Er is nog weinig onderzoek gedaan naar het hergebruik van bouwdelen uit bestaande gebouwen.
- Er is het een en ander onderzocht over materiaaleigenschappen:
  - Bouwcomponenten van hout en staal worden vaak geselecteerd voor hergebruik.
  - Bakstenen kunnen goed worden hergebruikt, na schoonmaken van de bindingslaag.

  - Prefabbeton leent zich goed voor hergebruik, in-situ gegoten beton niet.
  - Het los maken van de connecties tussen bouwdelen moet makkelijk gaan om deze bouwdelen functioneel te kunnen hergebruiken. (Natte versus droge verbindingen.)

Opgedane kennis van interviews met circulariteit experts van sloopbedrijven:

- Circulair slopen neemt een sterke toevlucht.
- Circulair slopen is vaak een voorwaarde, pluspunt, of zelfs vereiste, in een tender.
- Bouwdelen die worden geselecteerd voor hergebruik zijn voornamelijk niet-dragende bouwdelen (sanitair, deuren, kozijnen etc.).
- Wat betreft meer massieve bouwdelen zijn houten balken, staal, en bakstenen geschikt voor hergebruik.
  - Certificering van stalen bouwcomponenten is vaak een uitdaging.
- Betonnen bouwdelen worden zelden geselecteerd voor hergebruik vanwege:
  - Certificering
  - Weinig vertrouwen
  - Hoge demontage- en transportkosten
- Het implementeren van een circulaire sloopstrategie levert langdurige samenwerking op met aannemers en architecten dat ten behoeve komt van het primaire verdienmodel van het bedrijf.

Opgedane kennis van interviews met circulariteit expert van TNO:

- Hergebruik van betonnen bouwdelen gebeurt nog nauwelijks vanwege de hoge kosten
- Technisch gezien is compleet hergebruik van gebouwen mogelijk: zie Prinsenhof A Arnhem.
- Voor maximaal nut van hergebruik moet functiebehoud van de hergebruikte bouwdelen nagestreefd worden.
  - Behoud van *ownership* kan hier een positief effect op hebben: als een *asset owner* zijn gebouw laat demonteren voor hergebruik, dan zal die proberen zoveel mogelijk waarde te behouden uit zijn bouwelementen.
    - Ook: bij transactie van bouwelementen heeft de afnemer vaak minder vertrouwen in de staat en toepasbaarheid van de bouwelementen, oa omdat er geen garantie op zit. Bij behoud van *ownership* speelt dit minder.
  - Behoud van ontwerp kan hier een positief effect op hebben: als een bouwdeel op exact dezelfde manier wordt toegepast dan kan deze zijn functie behouden. Voorbeeld Prinsenhof A Arnhem: Gebouw gedemonteerd en elders opnieuw opgebouwd op exact dezelfde wijze – volledige behoud van functie.

Opgedane kennis van interview met voorspellend-onderhoud adviesbureau in de bouw en infrastructuur sector:

Op de 10R schaal van circulariteit: De hoogste vorm van circulariteit is ‘Refuse’.

- Levensduur verlengende maatregelen treffen <u>gedurende</u> levensduur van asset: preventief onderhoud.
  - Nuanceverschil met “verlenging levensduur”: continue verjonging van asset t.o.v. “extra tijd er aan plakken”. Voorbeeld: Kozijnen van grachtenpanden: eeuwenoud, maar met telkens een likje verf blijven ze goed.
  - Strenge, soms onnodige, eisen stellen werkt dit vaak tegen.

Kennislagune:

- Wat is de strategie van een grote publieke *asset owner* (zoals AO) om hergebruik te stimuleren?
- Hoe kijkt AO naar hergebruik van zware, dragende bouwdelen (beton, staal) t.o.v. hergebruik van lichtere bouwdelen?

- Hoe worden de financiële lasten van hergebruik verdeeld tussen *AO* en de aanbesteder?
- Wie krijgt eigendom over de te hergebruiken bouwdelen?
    - Is dit anders dan bij 'lineaire' bouw- en sloopprojecten?

- Heeft AO een strategie voor 'verjonging' van assets?
    - Wordt er ingezet op preventief onderhoud?
        - Zo ja: zien jullie hierin financiële waarde (besparingen of juist kosten), en/of milieuwaarde
        - Zo nee: zou dit kunnen helpen om:
            - Milieu impact te verkleinen
            - Kosten te besparen
            - Inzicht te krijgen in beschikbare bouwelementen

          Hoe zou bovenstaande kunnen bijdragen aan circulaire strategie ban AO?

https://www.change.inc/circulaire-economie/circulaire-bouwers-krijgen-per-2023-voorrang-van-het-rijksvastgoedbedrijf-38865

"Ook krijgen bouwers voorrang op renovatie- en sloopprojecten als ze een nieuwe bestemming vinden voor materialen die uit het te renoveren pand vrijkomen."

- Wat is de rol van slopers?
    - Worden de rollen van slopers en bouwers meer met elkaar vervlochten?
- Hoe worden de kosten voor demontage verdeeld tussen AO en aannemer?
- Hoe worden de baten voor verkoop van bouwdelen verdeeld tussen AO en aannemer?
- Waarin kunnen aannemers voor circulaire renovatie/sloop/bouw projecten zich van elkaar onderscheiden?

8.3.2.2. Interview questions Research Institute

Uit literatuurstudie is het volgende gebleken:

- Het hergebruiken van bouwdelen is *hot topic*.
- Er is veel onderzoek gedaan naar het ontwerpen van circulair afbreekbare nieuwbouw.
- Er is nog weinig onderzoek gedaan naar het hergebruik van bouwdelen uit bestaande gebouwen.
- Er is het een en ander onderzocht over materiaaleigenschappen:
    - Bouwcomponenten van hout en staal worden vaak geselecteerd voor hergebruik.
    - Bakstenen kunnen goed worden hergebruikt, na schoonmaken van de bindingslaag.
    - Pre-fab beton leent zich goed voor hergebruik, in-situ gegoten beton niet.
    - Het los maken van de connecties tussen bouwdelen moet makkelijk gaan om deze bouwdelen functioneel te kunnen hergebruiken.

Opgedane kennis van interviews met circulariteit experts van sloopbedrijven:

- Circulair slopen neemt een sterke toevlucht
- Circulair slopen is vaak een voorwaarde of pluspunt in een tender
- Bouwdelen die worden geselecteerd voor hergebruik zijn voornamelijk niet-dragende bouwdelen (sanitair, deuren, kozijnen etc.)
- Wat betreft meer massieve bouwdelen zijn houten balken, staal, en bakstenen geschikt voor hergebruik.
    - Certificering van stalen bouwcomponenten is vaak een uitdaging.
- Betonnen bouwdelen worden zelden geselecteerd voor hergebruik vanwege:
    - Certificering
    - Weinig vertrouwen
    - Hoge demontage- en transportkosten
- Het implementeren van een circulaire sloopstrategie levert langdurige samenwerking op met aannemers en architecten dat ten behoeve komt van het primaire verdienmodel van het bedrijf.

Wat wil ik nog weten?:

Hoe kunnen sloopbedrijven meer herbruikbare bouwcomponenten oogsten uit sloopprojecten?

Sloopbedrijven geven aan te weinig tijd te hebben om effectiever te kunnen demonteren. Meestal is het enige tijdsbestek dat een sloopbedrijf heeft het tijdsbestek van het slopen zelf, wat zo snel mogelijk moet gebeuren.

- Voor aanvang van het slopen, wat zou een betrokken partij kunnen doen om het oogsten van herbruikbare bouwcomponenten te effectiever te laten verlopen?

Sloopbedrijven maken een inschatting op basis van expertise van de verwachte verkoopwaarde van herbruikbare bouwdelen.

- Denkt u dat er nog winst te behalen valt op het gebied van circulaire waardebepaling?
- Zo ja, hoe verwacht u dat het kunnen voorspellen van herbruikbare waarde de effectiviteit van hergebruik zal beïnvloeden?

Dragende bouwdelen en andere omvangrijke of zware bouwdelen doen het minder goed als herbruikbaar materiaal dan licht materiaal. Redenen hiervoor zijn certificering, (nog) duurdere demontage, meer gecompliceerde demontage, hoge transportkosten, weinig vertrouwen in de markt.

- Ziet u, of bent u bewust van, mogelijkheden die dit brede scala aan uitdagingen zouden kunnen helpen overkomen?

Beton: Met name (gewapend) beton is lastig te hergebruiken. Ik kan me voorstellen dat certificering, demontage en vervoer een kostbaar risico met zich meebrengt, en er is weinig tijd op het moment dat einde levensduur aanbreekt.

- Zijn er geen mogelijkheden om gedurende de levensduur betonnen bouwdelen te monitoren, en eventueel te laten certificeren, zodat bij einde levensduur er een redelijke garantie is op functioneel hergebruik?

Baksteen: bakstenen worden veel hergebruikt. Eerst moet de bindingslaag (cement) losgebikt worden.

- Het cement wordt vaak nog met de hand gebikt om gebruikte bakstenen schoon te krijgen. Is hier ondertussen geen machinale oplossing voor?
- Kalkhoudend cement schijnt makkelijker los te krijgen zijn dan cement zonder kalk. Is dit een probleem voor een (eventuele) machinale oplossing?

Staal: Voor hergebruik van stalen balken is dikwijls goedkeuring van een constructeur nodig. Deze goedkeuring wordt vaak niet gegeven door een kleine afwijking. Onderhoud aan de stalen balk om hergebruik mogelijk te maken is vaak niet rendabel, dus wordt de balk toch gerecycled.

- Ziet u, of bent u bewust van, mogelijkheden om hoogwaardig hergebruik van stalen balken met lichte afwijkingen te stimuleren?
- Hoe kijkt u naar hergebruikmogelijkheden van gelaste stalen balken t.o.v. mechanisch verbonden (bout-moer) stalen balken?

Hout:

- Hoe kijkt u naar hergebruikmogelijkheden van chemisch verbonden (gelijmde) houten balken t.o.v. mechanisch verbonden (bout-moer) houten balken?

Uit literatuurstudie is het volgende gebleken:

- Het hergebruiken van bouwdelen is noodzakelijk om de *footprint* van de infrastructuur en ruimtelijke ordening sector te verminderen.
- Er is veel onderzoek gedaan naar het ontwerpen van circulair afbreekbare nieuwbouw.
- Er is nog weinig onderzoek gedaan naar het hergebruik van bouwdelen uit bestaande gebouwen.
- Er is het een en ander onderzocht over materiaaleigenschappen:
  - Bouwcomponenten van hout en staal worden vaak geselecteerd voor hergebruik.
  - Bakstenen kunnen goed worden hergebruikt, na schoonmaken van de bindingslaag.
  - Prefabbeton leent zich goed voor hergebruik, in-situ gegoten beton niet.

    - Het los maken van de connecties tussen bouwdelen moet makkelijk gaan om deze bouwdelen functioneel te kunnen hergebruiken. (Natte versus droge verbindingen.)

Opgedane kennis van interviews met circulariteit experts van sloopbedrijven:

- Circulair slopen neemt een sterke toevlucht.
- Circulair slopen is vaak een voorwaarde, pluspunt, of zelfs vereiste, in een tender.
- Bouwdelen die worden geselecteerd voor hergebruik zijn voornamelijk niet-dragende bouwdelen (sanitair, deuren, kozijnen etc.).
- Wat betreft meer massieve bouwdelen zijn houten balken, staal, en bakstenen geschikt voor hergebruik.
    - Certificering van stalen bouwcomponenten is vaak een uitdaging.
- Betonnen bouwdelen worden zelden geselecteerd voor hergebruik vanwege:
    - Certificering
    - Weinig vertrouwen
    - Hoge demontage- en transportkosten
- Het implementeren van een circulaire sloopstrategie levert langdurige samenwerking op met aannemers en architecten dat ten behoeve komt van het primaire verdienmodel van het bedrijf.

Opgedane kennis van interviews met circulariteit expert van TNO:

- Hergebruik van betonnen bouwdelen gebeurt nog nauwelijks vanwege de hoge kosten
- Technisch gezien is compleet hergebruik van gebouwen mogelijk: zie Prinsenhof A Arnhem.
- Voor maximaal nut van hergebruik moet functiebehoud van de hergebruikte bouwdelen nagestreefd worden.
    - Behoud van *ownership* kan hier een positief effect op hebben: als een *asset owner* zijn gebouw laat demonteren voor hergebruik, dan zal die proberen zoveel mogelijk waarde te behouden uit zijn bouwelementen.
        - Ook: bij transactie van bouwelementen heeft de afnemer vaak minder vertrouwen in de staat en toepasbaarheid van de bouwelementen, oa omdat er geen garantie op zit. Bij behoud van *ownership* speelt dit minder.
    - Behoud van ontwerp kan hier een positief effect op hebben: als een bouwdeel op exact dezelfde manier wordt toegepast dan kan deze zijn functie behouden. Voorbeeld Prinsenhof A Arnhem: Gebouw gedemonteerd en elders opnieuw opgebouwd op exact dezelfde wijze – volledige behoud van functie.

Opgedane kennis van interview met voorspellend-onderhoud adviesbureau in de bouw en infrastructuur sector:

Op de 10R schaal van circulariteit: De hoogste vorm van circulariteit is ‘Refuse’.

- Levensduur verlengende maatregelen treffen <u>gedurende</u> levensduur van asset: preventief onderhoud.
    - Nuanceverschil met “verlenging levensduur”: continue verjonging van asset t.o.v. “extra tijd er aan plakken”. Voorbeeld: Kozijnen van grachtenpanden: eeuwenoud, maar met telkens een likje verf blijven ze goed. Zo zou ook naar vastgoed en infrastructuur op grote schaal moeten worden gekeken.
    - Strenge, soms onnodige, eisen werken dit vaak tegen.

- Gedurende de levensduur van een asset een onderhoudsstrategie bijhouden zou kunnen bijdragen aan een effectieve hergebruikstrategie bij einde levensduur: er is dan al een inventarisatie van alle bouwelementen en hun staat van onderhoud.

8.4. Interview Data

Interview 1: Circularity expert of a medium-sized demolition contractor in the NL (DC1).
Interview 2: Circularity expert of a medium-sized demolition contractor in the NL (DC2).
Interview 3: Circularity expert of a small-medium-sized demolition contractor in the NL (DC3).
Interview 4: Circularity expert of a frontrunner medium-sized company in circular demolition (DC4).
Interview 5: Circularity expert of the largest public asset owner in the NL (AO).
Interview 6: *Business developer circularity* of a large semi-public research institute in the NL (RI).

8.4.1. Properties of building elements

8.4.1.1. Properties of building elements - Interview 1 (DC1)

- The best-selling building elements for reuse are wooden beams. Often, a wooden beam can be sold within a day.
- Other materials may be stored for months before they are sold.
- The respondent sees a positive correlation between energy prices and reuse of bricks.
    - This stimulates investing by means of cleaning of cement, transport (if needed), and storage
    - The company has a partner for cleaning the bricks (making them suitable for reuse).
        - The type of cement determines reuse-potential: older masonry is easier to dismantle than new masonry due to the composition of the cement. Modern cement (without calcium) is more difficult to remove.
- In chemical connections, the company tries to take apart the connection and restore it. If this can be done easily, then reuse is possible.
- Damaged building elements are never selected for reuse.
- Reuse of load-bearing steel structures.
    - The company has experience in reusing steel structures
    - Focus is on reuse of complete steel structure. It works best to find a client for the complete structure before disassembly. Then after disassembly it can be transported directly to the client. The prices is agreed upon beforehand.
        - If not possible, then standard-sized steel elements are stored for reuse. Non-standard sized and damaged elements are recycled, this is more financially viable than maintaining or adjusting the component.
        - Price of structure >= cost of man hours + benefits from recycling
- Concrete:
    - Precast and prestressed concrete can be reused, such as hollow-core slabs.
- A requirement for reuse is accessibility of connections, detachability, possibility of transportation and finding a buyer.

8.4.1.2. Properties of building elements - Interview 2 (DC2)

- The company has its own secondary building materials marketplace. The company uses this platform to sell its harvested building elements.
- The company harvests mainly doors, sanitary, technical installations. But also gypsum plates, bricks, wooden beams, and steel beams. Massive construction elements such as concrete are not selected for reuse.
- Regarding steel beams:

  - the biggest challenge is material requirements: does the beam still uphold certifications, is the beam curved/bent? If the beam does not uphold certifications, or is curved, then the whole chain is needed, from architects to constructors, to being able to apply the component again.
  - Reuse potential of steel beams is not dependent on the connection type.
  - Reuse benefits are twice the recycling benefits.
- Regarding connections:
  - Wooden beams with chemical connections are sawed loose for reuse
  - Steel beams with welded connections are grinded loose for reuse
  - Bricks are cleaned from cement by hand for reuse

8.4.1.3. Properties of building elements - Interview 3 (DC3)

- Reusing structural building elements is the absolute goal but the hardest to achieve
- Channel plates are ideal to reuse but difficult to deconstruct as they are often embedded in a monolithic connection, or concrete is poured all over the channel plate floor.
- Complete steel constructions are ideal for reuse, such as industrial halls.
- Welded steel connections will only be cut apart in agreement with the asset owner or potential buyer of the steel, otherwise it will just be cut apart for recycling purposes.
- For deconstructing masonry building elements neatly, a specialist approach and tools are needed. Otherwise it will just be demolished and pulverised. But mostly traders are interested in the bricks so they may hire another party to deconstruct the masonry elements.
  - Reused bricks are mostly used in residential construction.

8.4.1.4. Properties of building elements - Interview 4 (DC4)

- The ideal dimensions of reusable building elements are those that can fill up the maximum transport dimensions of road transport. Elements that do not fit in those dimensions need to be cut into pieces and connected again modularly later.
- The weight of reusable building elements is not an issue.

<u>Prinsenhof A case</u>

- The poured connections are cut loose, afterwards the prefab elements can be removed from the asset using heavy hydraulic tools.
- The connections are restored in a modular way, such that no liquid elements (in-situ poured concrete, glue) are needed. Now, the building elements can be ‘clicked’ together.
- Hollow-core slab floor elements are highly suitable for reuse.
- The hollow-core slab floor elements have been used in multiple other building projects.
- The building did not meet modern-day office requirements (lighting and energy-use). Hence, these standards could be set higher in the design of a new building using the harvested building elements.
- In-situ cast reinforced concrete is very risky for reuse: cutting through would expose the steel rebars, now rust is inevitable.
- Because cast concrete has only been applied on a small scale, and could be cut loose without cutting through the rebars, no maintenance protocol whatsoever has been applied. A maintenance assessment is done by the eye. Every single concrete element from the case study project has been reused and all of them were approved for reuse.

    - All elements were labelled with a unique code and can so be tracked throughout the transport and construction process, and during lifecycle of the newly constructed building.
- In case of glued floor covering: ‘just keep it there and apply your new isolation and covering over the old covering’.

8.4.1.5. Properties of building elements - Interview 5 (AO)

- Analysis of reusable building elements is made prior to publishing the tender to find a new function of the harvested building elements preferably before deconstruction.
- Concrete ‘channel plate floor parts’ are suitable for reuse.
- Reused building elements are always certified by the constructor responsible for approving a new project.

8.4.1.6. Properties of building elements - Interview 6 (RI)

- Research on how technical properties of building elements influence reuse functionality is limited, and it is important to research.
- The reason why concrete building elements are hardly reused is financial value: deconstruction, transport, storage, and refurbishments lead to costs that are higher than the market price for new concrete. This also accounts for prefab elements. Only higher prices for new concrete, for instance through CO2 taxes, can make the reuse of concrete building elements profitable.
- Is makes sense to take bricks into account for reuse strategies, as a large portion of the post-ware buildings have been constructed using brick. This will result in a large stream of secondary building materials.

8.4.2. Reuse strategies

8.4.2.1. Reuse strategies - Interview 1 (DC1)

- The company applies the 10R model in striving for circularity, if the contract with the client allows this.
    - Refuse: An example of refuse is the demolition of a sports hall, whereby the company decided to not demolish the foundation, as its technical life span was well sufficient for the new building plans.
- Costs that reduce the chance of reuse are (1) high dismantling costs (2) lag between harvesting and moment of vending (3) sales process.
    - Overcoming these challenges:
        - In rural areas, reusable building elements can often be stored and sold on-site. This may increase the chance of selecting building elements for re-use.
        - Finding buyers for the products before starting the dismantling process, so harvested building elements can be bought directly from the demolition site.
- A requirement for reuse is accessibility of connections, detachability, possibility of transportation and finding a buyer.
    - Also, reuse of structural building elements must go in accordance with the architect of the new project: structural elements often have no standard dimensions, so a designer must design based on available elements for reuse.
- Reuse of foundation of END-OF-LIFE sport complex:

- The company was part of a team with the architect and contractor. The foundation was still good. The company proposed to keep the foundation. It stood out that mainly the architect was very positive towards this proposal.
- A constructing company did the measurements of the functionality of the foundation.
- Financial analysis:
  - Costs saved on no need for demolition of the foundation
  - Costs added by increased complexity of demolition of the building's body.
    - Impossible to use heavy equipment due to risk of damage to the foundation
  - Eventually the costs and benefits balanced out, but the company won the tender, engaged in a collaboration with potential for the future, and got exposure by working circular.

8.4.2.2. Reuse strategies - Interview 2 (DC2)

- Selling reusable building elements can happen in three ways:
  1. Direct selling of the component to a customer from the demolition site.
  2. Selling of the component to an intermediary from the demolition site;
  3. Transporting the component to the storage and sell from that location.
- Waterproof storage is not important to steel or wooden beams.
- The company is in the process of acquiring and implementing a software tool that can calculate the amount of CO_2 emission reduction based on the reuse and recycling of building elements.
- The company sees potential in the reuse of concrete girders and concrete floor panels as these building elements are durable and often standardized. At the moment, the respondent is trying to establish partnerships with contractors for steady turnover of reusable concrete elements.
- A big opportunity for the respondent's company is internal reuse of elements: the company has a subsidiary steel construction company that can benefit from harvested steel beams. A challenge in this strategy is that each beam needs to be certified by a structural engineering bureau and certification is often rejected due to slight curvatures.

8.4.2.3. Reuse strategies - Interview 3 (DC3)

- Demolition contractors need to offer circular strategies to stay competitive.
- Assessing circular potential of an asset is done by making a materials passport of the asset.
  - They also do this to show to the demanding party (asset owner) what they plan to deliver with their circular strategy.
- Ideally, reuse is in the form of one-on-one reuse of a whole building, instead of dispersing the harvested building elements.
  - Building companies are not far enough to help realize this.
- Example of successful reusing structural building element: leaving the supporting concrete structure (foundation and structure) of a shopping mall for building an apartment complex in that place.
- Buildings built after 2000 are easier deconstructed than real estate built before that time. Buildings built in 1980 are less well deconstructed than buildings built in 2010, that is a fact. So expected is that with the same techniques and experience we have now, deconstructing a building in 50 years' time will be easier, purely on the way it is built.

- Buildings built in the 80's have a lot of monolithic concrete connections that make them difficult to deconstruct.

8.4.2.4. Reuse strategies -Interview 4 (DC4)

- The tender did not explicate a needed level of circularity. It just mentioned a preference for a high level of circularity and let it to the market. The asset owner expected bids to include mainly recycling options, but the contractor in this case proposed 100% reuse.
- Before signing up to the tender, the company made a BIM model of the complete building, using the available documentation and architectural drawings.
- The contractor could stay well under the maximum budget for a 100% reuse strategy and charged about 25% extra compared to a linear strategy. This was financially very attractive to the asset owner and made the project completely financially viable to the contractor.
- The demolition contractor gained ownership over the harvested building elements and reused all of them in new construction projects of their own.
- The respondent identified a disbalance in supply and demand: harvested building elements are often not reused because building contractors do not see the possibilities.
- The asset owner did not blindly trust the ambitious plan of the demolition contractor and asked for a guarantee that all building elements would be reused. The demolition contractor could show building designs using all elements from the asset. Also, all technical installations were to be refurbished, re-packed and sold. This is done by a 'Leerwerk loket': a public-run working area for people having difficulties with entering the labour market. All installations have been sold to date.
- The new building, using reused building elements from the case study, has a steel and concrete load-bearing construction. The steel is also harvested from another project. Extra steel construction was needed because the concrete building elements were 'harmonica'd' and the created gaps were filled with bio-based modular panels.
    - o The constructor of the steel construction has experience using re-used elements: he once built a load-bearing steel construction of a utility building with used train tracks. Everybody said he wouldn't get it through certification but he did.
- The company is working on 4 circular projects now, all using multiple donor buildings to build one bigger building.

8.4.2.5. Reuse strategies - Interview 5 (AO)

- The respondent's organisation is investing in creating knowledge to achieve direct reuse of harvested building elements.
    - o Circularity is officially documented as a theme in the organisation's long-term strategy.
    - o Through issuing ambitious circular strategies in tenders.
    - o Learning from market parties.
- The budget for issuing ambitious circular strategies comes from a subsidy programme for sustainable innovations.
    - o These ambitious circular strategies are those that are not commonly found in the private sector as they are not financially viable.

- The public sector does not explicate in tenders *how exactly* to conduct the circular strategy, but heavily weighs circularity as a criterium, in order to compensate for high deconstruction costs, and then leaves the execution to the market.
    - Public organisations are obliged to give all market parties the chance to participate in the tender bidding. Framing a circular strategy to a certain technique or method does not fit in that obligation.
    - This way, the public organisation can learn from innovations from the private sector.
- The public organisation applies Brand's 6S model (1996).
    - In the tender, the requested circularity strategy is a specified percentage per layer.
    - In concrete-supported buildings: reuse of 'structure' is never put as a request in tenders.
- Market parties can distinguish themselves from each other by offering innovative circular strategies for a tender request.
    - Probably Lagemaat had a unique/innovative idea for reusing the complete building (*ask on 7 dec*).
- The respondent recognizes that market parties are bidding below the financially viable cost price to win innovative circular tenders.
    - To gain experience
    - To engage in interdisciplinary collaborations
    - The respondent's organisation has once accepted a negative bid from a demolition contractor for deconstructing an asset.

8.4.2.6. Reuse strategies - Interview 6 (RI)

- Regarding direct sale from the deconstruction site: this makes sense for vending to individuals or small-scale contractors. However, to achieve a high level of circularity, function retention of building elements must be safeguarded. Dispersion of an assembly of building elements through vending to numerous small buyers is not expected to safeguard function retention.
- Deconstructing a building and rebuilding the complete supportive structure elsewhere is an example of complete function retention. In the reconstruction process, adaptations can be made to the building to make it adhere to current standards in terms of safety, isolation, and energy consumption or even energy production.
- Getting insight in potential reuse value from a building reaching end-of-life will certainly be beneficial for reuse strategies. The question is: who pays for a reuse value analysis, and who benefits? If an asset owner would invest in analysing the financial value of reusable building elements, then it should give the deconstruction company enough time to harvest the functional building elements. The asset owner would compensate the deconstruction company for the extra labour and would benefit from selling the reusable building elements. This is a shift in ownership: traditionally, the demolition contractor would have ownership of the rest materials after demolition of a building, benefiting from recycling and direct vending income and making costs on landfill fees. In a shift towards circularity, it would make more sense that the contractor keeps ownership after deconstruction in order to reuse the asset, or parts of, elsewhere. This happens with the viaducts of *Rijkswaterstaat* already.

8.4.3. Maintenance & lifespan

8.4.3.1. Maintenance & lifespan - Interview 1 (DC1)

- Determining the remaining technical lifespan of building elements: wood is inspected on rot; steel is inspected on rust, but no judgement is made on expected life span. This is up to the customer.
- Functionality or aging of a building component is also not judged or measured. Reuse potential is based on the component properties.
    - The company does look at the building's technical drawings to see whether parts of the building have been added later: the added part may have a longer technical lifespan than the body of the building.
- Reuse value assessment is done based on expertise.
- Regarding maintenance history: for technical installations, regular maintenance is mandatory, therefore it is available and of importance for the reuse potential. For steel, brick and wood the maintenance history is not used to assess reuse potential.

8.4.3.2. Maintenance & lifespan - Interview 2 (DC2)

- Maintenance assessment is done by eye

8.4.3.3. Maintenance & lifespan - Interview 3 (DC3)

- Maintenance history is not included in materials passport

8.4.3.4. Maintenance & lifespan - Interview 4 (DC4)

- Maintenance assessment is done by eye
- Every harvested building component needs to be approved by the constructor, so doing a maintenance assessment is double work.

8.5.3.5. Maintenance & lifespan - Interview 5 (AO)

- There is no maintenance assessment protocol for determining reuse potential

8.5.3.6. Maintenance & lifespan - Interview 6 (Research institute)

- Maintenance assessment goes automatically when inventorying the reusable assets.

8.4.4. Costs and benefits

8.4.4.1. Costs and benefits - Interview 1 (DC1)

- The most relevant benefit from applying circularity is the gained collaboration with the client:
    - Applying circularity requires a more integrated collaboration between contractor and client. The respondent identified that in projects whereby circularity is included in the strategy, inter-disciplinary teams and partnerships arise between client and contractor, resulting in more long-term relationships.
    - Circularity is future-proof: expected is that circular demolition will become the standard.

- Before starting the demolition process, the company makes a judgement on potential financial profit of reuse based on professional experience and trends in the market. A percentage of the profit is returned to the client in the form of discount on the quotation.
    - For applying a circular strategy, the company applies a 10% increase in total costs on the tender, with the promise of a discount afterwards based on financial prospects of reusable elements.
        - This proposition does not earn the company any extra money comparing to linear demolition, sometimes even less, but it is beneficial for winning tenders and creating long-term relations with clients. Also: exposure and image. These benefits cannot be expressed directly in financial value, but the company is expected to benefit from it financially on the long term.

8.4.4.2. Costs and benefits - Interview 2 (DC2)

- The quotation process for circular demolition goes as follows:
    1. Make quotation based on linear demolition, including recycling value based on estimated quantity of materials.
        a. Add clausula for circular option
    2. In final quotation upon completing the demolition, add extra deconstruction costs and add extra reuse benefits.

8.4.4.3. Costs and benefits - Interview 3 (DC3)

- If not required in the tender, then the demolition contractor does not promote a circular strategy because this will not be competitive against other contractors, or it will cost the company itself too much money.

8.4.4.4. Costs and benefits - Interview 4 (DC4)

- Reuse becomes cheaper than new when the deconstruction time is shorter than the fabrication time (roughly).

8.4.4.5. Costs and benefits - Interview 5 (AO)

- The public organisation develops maintenance strategies for different levels of planned lifespan. The lifespan is only shortened or ended when the building has lost its function, or a new function has been assigned to the site.

8.4.4.6. Costs and benefits - Interview 6 (RI)

- Demolition contractors may lose money on ambitious circular projects but this might give them long-term benefits.

8.4.5. Challenges

8.4.5.1. Challenges - Interview 1 (DC1)

- The most relevant challenges in achieving circularity are finance and regulations.
    - Lots of building elements are disregarded for reuse based on regulations, but could be reused in practical sense.

- The most relevant challenges for buyers of pre-used building elements are:
    - Lack of certification
    - Lack of guarantee
    - Getting agreement from other parties (contractors, architects, asset owner)
    - Getting insurance

If regulations would allow it, any building can be reused for 'almost 100%', but only a smaller part of it is financially viable.

8.4.5.2. Challenges - Interview 2 (DC2)

- One of the biggest challenges in reuse strategies is time constraints: the ideal period to sell a reusable building component is before or during the demolition process. However, the demolition contractor often only has access to the site upon start of the demolition process, often due to (anti-squatting) residents still residing in the building. Next, the demolition process needs to be as short as possible, which is not beneficial for any circular strategy.

8.4.5.3. Challenges - Interview 3 (DC3)

- Engineering firms and building contractors are behind in innovation in the field of reuse.
- Demolition contractors are very innovative in reusing building elements from END-OF-LIFE assets, but these elements are not applied by building contractors or engineering firms, so that is the limiting factor at the moment.

8.4.5.4. Challenges - Interview 4 (DC4)

8.4.5.5. Challenges - Interview 5 (AO)

- In an ideal situation, the respondent would have a complete digital model of the asset, with a breakdown into building elements with technical information per component.

8.4.5.6. Challenges - Interview 6 (Research institute)

- Certification is not the issue for reuse of structural building elements, warranty (1) and functionality (2) are: (1) when a contractor buys a harvested building component, there is no warrantee on it from the supplier; (2) a harvested building component is often reused in a lesser function when implemented in a new building due to trust/safety issues.

8.4.6. Stakeholder analysis

8.4.6.1. Stakeholder analysis - Interview 1 (DC1)

- Market: mainly private individuals, demand from architects is increasing, demand from contractors is increasing minimally, demand from housing corporations is increasing rapidly, expected due to rules and regulations (NL circular in 2050).
    - Progressive housing corporations are seeking contact with the company for circular strategies.

8.4.6.2. Stakeholder analysis - Interview 2 (DC2)

- For reuse of structural building elements: partnerships are needed to guarantee turnover → partnerships bring other benefits such as knowledge exchange and increased circularity.
- Housing corporations stand out as parties that actively request circular strategies in demolition tenders and are willing to pay for it. Housing corporations often apply 'fictional discount' in EMVI (*Economisch Meest Voordelige Inschrijving*) tenders on circular strategies. This fictional discount is earned by the demolition contractor that wins the tender, but often the extra costs for circular demolition are higher than the fictional discount; applying a circular strategy is a way to win tenders.
- The respondent's company has unofficial partnerships with fixed buyers of harvested building elements and is aiming to increase the number of fixed buyers. The current group of fixed buyers consists mainly of traders in building materials, but the main target group is contractors. The traders most often demount and transport the building elements themselves. The traders have cheaper labour costs.

8.4.6.3. Stakeholder analysis - Interview 3 (DC3)

- To get as far as possible with reuse strategies, collaboration with many stakeholders is necessary.
    - This is difficult due to competition: competitors often do not want to join each other in a network. There are examples of such networks that broke up due to competitive behaviour.
    - The respondent does see an increase in collaboration between stakeholders over the past years, also between competitors.
- Often circularity is requested in a tender pure for marketing from the asset owner but in the end they choose the net cheapest option.
    - In an EMVI plan this is not possible because of pre-set scoring on certain criteria.
- There are traders in the sector that actively address demolition contractors for harvested building companies such as timber, steel, brick, roof tiles. All non-structural.
    - The demolition contractor has several fixed contracts with traders.
    - The agricultural sector is a large customer for these products: they use these building elements to make sheds, barns etc.

8.4.6.4. Stakeholder analysis - Interview 4 (DC4)

- Constructing companies do not have the circular mindset, therefore the respondent joined circular design teams, advising architects on how to design, and contractors on how to build, with reused building elements.
- The reason that demolition contractors in the Netherlands cannot reach such high levels of circularity is not wanting to join a partnership. Conducting a circular strategy all by yourself will not be successful.
- In 30 years the traditional demolition contractor does not exist anymore: it will be an advisor, a 'remolisher' and a constructor in one.
- Now, from a legal point of view, the demolition contractor becomes owner of the harvested building elements. In the future, the asset owner will keep ownership of the building elements. The 'remolition' company will advise on *how to deconstruct, how to store, transport and build* with the harvested elements.

    - Large housing corporations are already claiming ownership of harvested building elements. However, they cannot claim the role of directing the demolition process, so they need the advice of the demolition contractor.

8.4.6.5. Stakeholder analysis - Interview 5 (AO)

- The public sector is taking a leading role in issuing ambitious circular strategies in tenders.
- The ownership of harvested building elements stays with the asset owner. Before engaging in circular strategies, the respondent's organisation would transfer ownership of the to-be demolished asset to the demolition contractor.
    - Also to make sure they do not happen to buy their own building assets back in a new project.

8.4.6.6. Stakeholder analysis - Interview 6 (RI)

- The asset owners taking the biggest financial risks in achieving high levels of reuse are public actors, such as *Rijkswaterstaat*. This governmental institute has recently deconstructed several viaducts and rebuilt these elsewhere. However, this has proven to be more expensive than to build a new viaduct, because of the cheap concrete prices.