MASS TIMBER SOCIAL HOUSING

Defining barriers and developing strategies to enable mass timber construction for housing associations

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This thesis: “Mass timber social housing: defining barriers and developing strategies to enable mass timber construction for housing associations,” is about a possible solution to the current housing shortage and environmental challenges we face were. As managers in the built environment, we are entitled to change on both these topics.

This thesis is written as part of the graduation phase of the master Management in the Built Environment, part of the faculty Architecture, Urbanism and Building Sciences at the Delft University of Technology. The corresponding scientific domain Design and Construction Management is chosen since the nature of this research is design-based and related to the match of supply and demand within construction management.

Associate professor of this domain, John Heinz, firmly believes that the construction industry needs to break free from its current traditional processes. I share this belief. Two years ago, I started to see the possibilities of mass timber as an enabler of a change towards sustainable and industrialized modular construction. Since John and I were interested in the solution mass timber can provide, I have asked him to become my primary mentor.

This thesis presents barriers and proposes strategies to enable modular mass timber construction for housing associations. As a result, this research provides insights for construction companies, housing associations, and the government.

I would like to thank my mentors John Heintz and Peter de Jong for their guidance during the fuzzy front-end their criticalness throughout the process. Furthermore, I want to thank Lister Buildings and J. Noorda, who provided insights into the uptake of mass timber in practice. Finally, I would like to thank the participants in interviews without whose cooperation I would not have been able to write this research

I hope you enjoy reading.

Thijs van Amelsfort

Amsterdam, September 2021

“Nederland staat voor een paradoxale opgave: we hebben meer huizen nodig, maar we moeten ook minder vervuilen. Bouwen met beton en staal is enorm vervuilend. Het zorgt wereldwijd voor negen procent van de CO2-uitstoot. Houtbouw lijkt de oplossing: een huis van kruislaaghout is even sterk als beton en staal, je zet het razendsnel neer en het dient ook nog eens als opslag voor CO2”

- Daan Kuys (2019)
VPRO Tegenlicht

“Corporaties zijn opdrachtgever van 30% van alle nieuwbouwprojecten. De bouw is nog altijd een van de meest vervuilende sectoren van Nederland. 40% van alle afvalstoffen is afkomstig van de bouw sector. Het wordt tijd dat corporaties ook hun verantwoordelijkheid nemen en de cirkel doorbreken.”

- Nicole van Wijk (2021)

Bestuurder van Woonwaard

ABSTRACT

There is a growing need for social housing in the Netherlands, especially in urban areas. The construction industry faces the difficult task of quickly responding to this demand while also reducing the embodied carbon emissions of new buildings. A proposed solution to these tasks is constructing mass timber buildings, leading to cheaper buildings and faster construction times while also reducing embodied carbon emissions compared to traditional buildings (Amiri et al., 2020). Due to its high strength and low weight, research finds that mass timber is suitable for reinforced concrete replacement. In doing so, a reduction of 2,4 Million Tons of C02 Equivalent annually can be established.

However, mass timber construction faces barriers—especially when addressing social housing associations due to their strong focus on affordability and risk reduction. Since the construction of social 'carbon neutral' housing is a major societal and environmental challenge, this research aims to define the barriers and develop strategies for overcoming these barriers to enable mass timber construction. For this purpose, the central research question is as follows: *"What are the barriers for the construction of modular mass timber social housing, and what might be strategies for overcoming them?*

Since this question is explorative, a qualitative research approach is used with the double design method. In the first diamond, the barriers are discovered and defined. In the second diamond, the strategies for overcoming these barriers are developed. Expectations are that the demand for mass timber buildings is above average in urban areas where a scarcity of land occurs, and municipalities have non-statutory supplementary ambitions regarding sustainability. Therefore, this research focuses on housing associations operating in urban areas. The barriers are identified by analyzing data obtained through a series of consultations with experts and eight semi-structured interviews with social housing associations. Ten barriers resulted from these interviews, which were classified into four categories.

The first category consists of social, cultural, and organizational barriers in adopting mass timber construction. Housing associations experience unclarity about circular decisions, show risk-averse behavior, and are having difficulties changing. The second category contains sectorial barriers. These include a sectoral knowledge deficiency, strategic alliances with the traditional industry, and the unique project-based approach that forms a barrier for modular construction since it limits the degree of repeatability and standardization. The third category are technical barriers. They consist of the perception among housing associations that modular construction results in uniformity, which is further obstructed by different programs of requirements.

The strategies for overcoming these barriers are based upon insights from an online expert panel meeting. The panel consisted of two representatives of mass timber construction companies, an architect, and an expert on bio-based construction materials. There was consensus among the experts about four strategies, of which the most important is to change the conditions for mass timber. This can be done with long- and short-term knowledge increase. Other strategies include the role of the municipalities and universities. However, to enable mass timber construction structurally, the construction costs must be lowered. The industrialization of modular construction could do so. Another way is letting social housing associations review their decision-making process from cost-based to value-based. This can be done by looking at total expenditure rather than building costs. The third strategy lets suppliers create a (open) building system based on standard floorplans with the flexibility for fitting custom facades. An open building system creates the opportunity for an infill industry to arise and allows a shift from a traditional design process towards product thinking. The fourth strategy is to safeguard the future value of components by using materials with common dimensions, which contributes to a total cost of ownership approach. Changing the responsibility of a product's maintenance incentives suppliers to use durable and remountable materials, allowing circular business models.

This research answers the central question by presenting the ten barriers and four strategies. In doing so, this research provides implications for academia by combining modularity, mass timber, and social housing. It has delivered a well-ordered list of barriers that provides implications for practice. However, the presented strategies for overcoming these barriers do not guarantee the uptake of modular mass timber construction. Since this is a relatively new topic in the Netherlands, it also requires time to be adopted and deployed in the market. A TCO approach looks most promising to enable modular mass timber construction. Future research should find how to best incorporate this within a traditional-orientated construction value chain.

Key terms:
Mass timber, social housing, modular construction, barriers, and strategies

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Chapter 3 – Contains the literature review supplemented with information from explorative interviews. This chapter is divided into four paragraphs, each aiming to answer one sub-question. This chapter ends with the main barriers from literature research in the conclusion

Chapter 4 – Uses the insights from eight semi-structured interviews with social housing associations to answer sub-question five. Ten barriers are defined, which are spread over four barrier categories, whit each having its paragraph.

Chapter 5 – Presents four possible strategies for overcoming the barriers. Each strategy contains multiple actions for different stakeholders. The chapter ends with a conclusion in which an answer is presented to sub-question six.

Chapter 6 – Answerers the main question by presenting the barriers and possible strategies for housing associations to enable mass timber construction.

Chapter 7 – Discusses the limitations and validity of the research and presents the implications for academia and practice.

Chapter 8 – Gives three recommendations for further research and provides a list of recommendations for social housing associations, suppliers, and the government.

Chapter 9 – Reflects upon the research approach, design, and methodology.

1 INTRODUCTION

1.1 Background

In times of a growing population, climate change, and labor scarcity, the Dutch construction industry faces the challenge of adding 25.000 social housing units annually (Capital Value, 2021). Research shows that the most significant housing deficiency is found in urban areas where both the large and middle large cities account for 75 percent of the total demand due to the population and household increase until 2030 (CBS, 2016).

Currently, the construction industry is one of the largest emitters in the Netherlands. With 25.6 Million Tons of CO2 Equivalent annually, the industry accounts for 11.4% of the total Dutch emissions (Circle Economy, 2020a). 79% is caused by the construction of new residential buildings (EIB, 2020) of which over 30% is social housing. Consequently, social housing construction accounts for 6 Million Tons of C02 Equivalent annually (Circle Economy, 2020a) (EIB, 2020). 40% of these emissions are caused by non-renewable concrete and steel in structural elements, which comes down to 2,4 Million Tons of CO2eq (EIB, 2020). These emissions need to be reduced to match the circular governmental ambitions. Because of its large share and significant impact, taking climate action in the construction industry is seen as one of the most cost-effective measures according to the Global Alliance for Buildings and construction (2019) But the question is, how can we built more while emitting less carbon? (Robati et al., 2021)

A promising approach for reducing our global sustainability pressure is shifting from a traditional take-make-dispose consumption pattern towards a circular economy (Bocken et al., 2017). The circular economy proposes a design for disassembly where building elements and components are reused rather than ending up as landfill. In addition, product-service systems propose a shift from selling products to selling services (Rios & Grau, 2019). *"We define the Circular Economy as a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling"* (Geissdoerfer et al., 2017)

Mass timber as a construction material fits this regenerative system because it can reduce carbon emissions in the built environment in two ways, first by reducing greenhouse gasses and second by finding ways to store these gasses. Wood can contribute to both these tasks. Forests can capture CO2 from the atmosphere and store it in trees. As a construction material, wood from sustainably managed forests can reduce the carbon footprint compared to traditional buildings. Buildings then function as a carbon reservoir rather than a carbon emitter (van der Lugt, 2020).

Mass timber enables the replacement of concrete. It has a better strength to weight ratio, which increases the advantages for off-site prefabrication. Besides, because of its dry connections, it is very suitable for design for disassembly and thus suitable for the circular economy.

1.2 Problem statement

The Dutch construction industry operates within the principles of the linear economy, which results in substantial pressure on the environment. Besides, the industry faces the challenge of responding to a growing housing demand while the industry is subject to unproductivity, labor scarcity, and rising material prices. As a result, the need for the industry's transition towards a circular alternative is evident (Bocken et al., 2017).

As one of the main clients of the residential real estate markets, housing associations bear a social obligation to construct as sustainable and circular as possible. Since mass timber construction reduces the carbon impact and helps to store carbon in the built environment, it is seen as a possible climate mitigation tool. However, housing associations perceive a variety of problems with embracing mass timber construction. As a result, mass timber construction companies face difficulties with addressing this customer segment. To enable mass timber construction, these barriers need to be researched. Besides, strategies need to be developed to overcome these barriers for allowing mass timber to become a mainstream construction material for housing associations, thus helping to mitigate climate change, and achieving Dutch governmental goals of carbon reduction.

1.3 Knowledge Gap

Different scholars from academia, businesses, and governments advocate for modularization and mass timber buildings as a possible solution for both environmental and demographical challenges. In addition, other countries already successfully apply mass as construction material in other countries. Also, modularization has gained momentum in the last couple of years due to digitization and mass customization. Despite this, the following knowledge gaps were identified in the literature:

- Research on the topic of mass timber in relation to Dutch associations is scarce since mass timber has gained popularity in the Netherlands only recently.
- A modular construction process is seen as the enabler of faster construction times, but the implication for housing associations needs to be further examined.
- No empirical research has been found on addressing housing associations with a mass timber product.

1.4 Objective and deliverable

Since the social housing shortage and carbon reduction are seen as significant societal and environmental challenges, this research aims to define the barriers and develop strategies for overcoming these barriers to enable mass timber construction for social housing associations. Insight into the barriers and strategies is precious for anyone interest in mass timber construction. These actors could be suppliers, advisors, the government, municipalities, universities, and of course, social housing associations.

1.5 Research Questions

The following research question needs to be answered to enable mass timber construction for housing associations.

"What are the barriers for the construction of modular mass timber social housing, and what might be strategies for overcoming them?"

This question is answered with six sub questions divided over three phases. The first phase aims to discover the main barriers, where the second phase aims to define them. The third phase purposes of developing strategies for overcoming these barriers.

Phase 1 - Discover barriers

The first phase discovers the barriers of mass timber social housing by answering the following sub-questions:

1. What contribution can mass timber construction make in the transition towards a circular economy?
2. What is the current demand for social housing and how do housing associations attempt to meet this demand?
3. How can mass timber construction offer a solution, and what are the barriers to doing so?
4. How can modular construction offer a solution, and what are the barriers to doing so?

Phase 2 - Define barriers

The second phase aims to define the main barriers in the construction of mass timber social housing. For doing so, the following sub-question is answered:

5. What are the barriers for the adoption of mass timber construction for Housing associations?

Phase 3 - Develop strategies

The final phase aims to develop strategies for overcoming the barriers by answering sub-question 6:

6. Which strategies could enable the adoption of mass timber construction for housing associations?

1.6 Relevance

A rapidly urbanizing world is increasingly needing sustainable housing solutions. Mass timber could offer a solution, but scientific and practical know-how about the barriers and the strategies for overcoming these barriers are missing. This paragraph elaborates on the scientific, social, and master-track-related relevance.

Scientific relevance

Mass timber suits the circular economy principles. However, a recent article shows that Dutch housing associations conceived a Circular Economy as a new topic. Furthermore, little research about the implementation of the circular economy within housing associations has been done so far (Çetin et al., 2021). This research identifies barriers and proposes multiple strategies to enable mass timber construction, which suits the circular economy principles. Little to no research on this topic has been done so far.

Societal relevance

There is a societal need for social homes and an environmental obligation to construct them as sustainable as possible. Mass timber can contribute to both these tasks. However, there are some barriers with mass timber construction which need to be defined. The development of strategies allows mass timber construction for housing associations. As a result, inhabitants might live in healthier, more sustainable, social homes, which can be seen as socially relevant in today's economy.

Management in the Built Environment

As stated on the website of the TU Delft: *"The department of Management in the Built Environment (MBE) works towards a sustainable built environment where the interests of the end-user and other stakeholders are key."* Since this research topic contributes to a more sustainable, circular, and affordable built environment, it suits the aim of the master program, and therefore it proves its relevance.

2 METHODOLOGY

2.1 Design-Based approach

This research suits the principles of design-based research very well since it proposes possible solutions to practical problems (Reeves, 2006; Ritchie et al., 2013; Van den Akker et al., 2006). A collaboration between practitioners and researchers allows the development of knowledge used in practice (Design-Based Research Collective, 2003). This also provides societal relevance.

Addressing complex problems in real contexts in collaboration with practitioners is one of the main characteristics of design-based research, as proposed by Brown (1992) and Collins (1992). As a result, researchers and practitioners can learn from one another (Herrington et al., 2007; Wang & Hannafin, 2005). This is underlined by Reeves (2006) by stating that *"Design research is not an activity that an individual researcher can conduct in isolation from practice."*

In line with the above, this research is conducted in collaboration with the company Lister Buildings. As a modular mass timber developer, architect, and construction company, they provide access to a network of practitioners and insight into practical problems. In return, this research enables the company and the sector within it operates to learn from each other.

The practical problems are presented as barriers, while the possible solutions are proposed as strategies. Research into these barriers and strategies is conducted reflectively and iteratively, which also suits the design-based research approach (Brown, 1992; Collins, 1992; Herrington et al., 2007; Reeves, 2006; Wang & Hannafin, 2005).

2.2 Double Diamond Design

A well-known design-based research method is the Double Diamond Design method (Design Council, 2005, 2019). Named after its physical appearance, this method is used for overcoming complex problems by offering design-based solutions. Each of the diamonds represents a process of divergent and convergent thinking for discovering and defining a problem first and developing a solution after that by using iterative thinking throughout the process (Design Council, 2015). This improves internal and external validity to develop a better solution (Design Council, 2005, 2019). Each diamond is seen as a stage and uses different data collection methods and techniques, presented in Figure 1 and elaborated upon in the next paragraph.

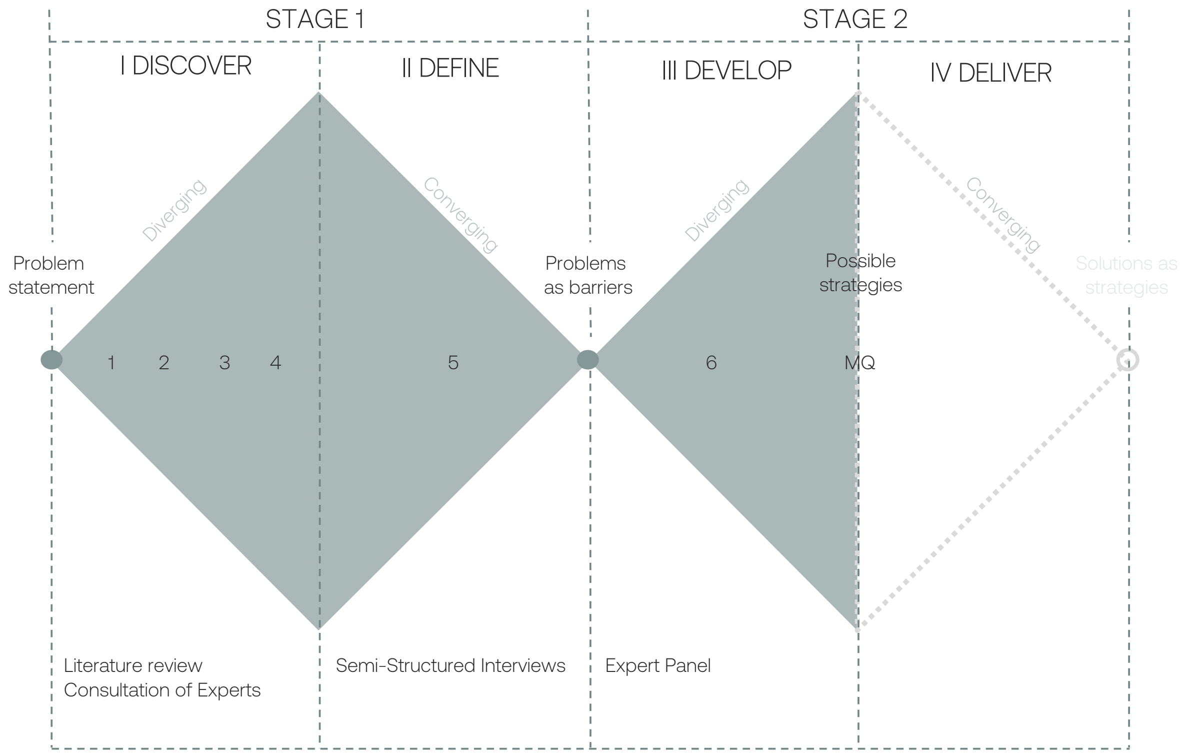

Figure 1: the Double Design Diamond with RQ's and methods. Adapted from Design Council (2015)

2.3 Data gathering methods

A method refers to tools, techniques, or procedures used to generate data (Kaplan, 1964). This research uses different qualitative data gathering methods throughout the three phases of the design diamond. This chapter elaborates on these different data gathering methods and presents six sub-questions to answer the main question, as shown in Figure 1. This figure also shows that the fourth phase – deliver, is out of scope. The different data gathering methods used in phases one, two, and three are shown in Figure 2.

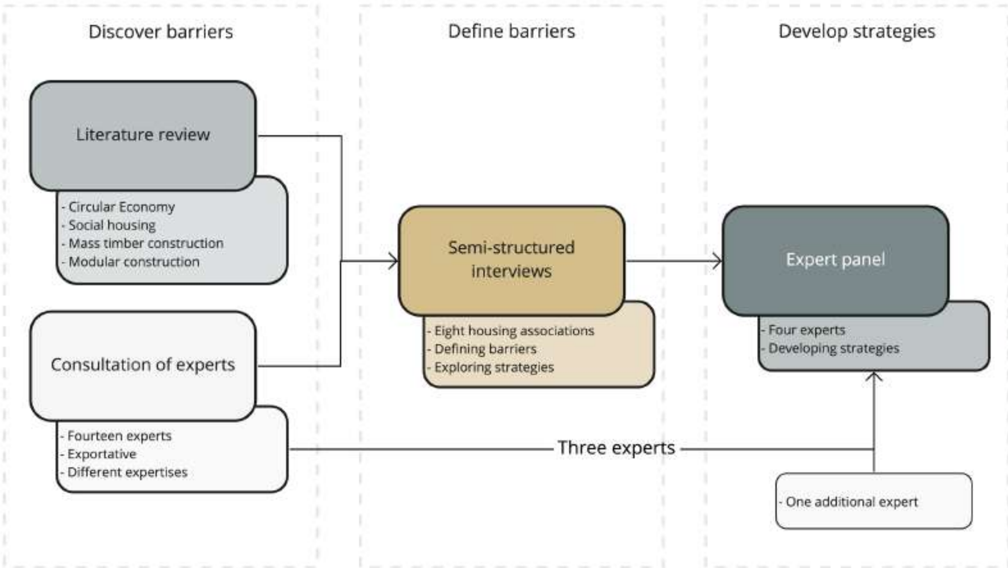

Figure 2: Overview of the different data gathering methods

2.3.1 Phase 1 - Discover the barriers

The first phase discovers the state of the art of the social housing sector, mass timber, and modular construction by answering the following sub-questions:

1. What contribution can mass timber construction make towards the transition to a circular economy?
2. What is the current demand for social housing, and how do housing associations attempt to meet this demand?
3. What is the value proposition of mass timber construction, and what are the barriers to the implementation for housing associations?
4. How can modular construction offer a solution, and what are the barriers to doing so?

This is done by gathering information from desk and field research. The first phase explores and understands the theoretical and practical barriers of modular mass timber construction and the context within which they arise. Clear insight into the theoretical and practical barriers is of utmost importance in design-based research (Reeves, 2006). As Van den Akker (1999) explains, this' preliminary investigation' consists of a more intensive and systematic approach for discovering the barriers. This phase uses the following activities: *"literature review and consultation of experts"* (Van den Akker, 1999).

Literature review

The literature review provides insight into the context and state of the art of multiple topics. This review is conducted with backward snowballing from reference lists and forward snowballing by finding citations to papers. As a starting point, papers from leading journals are used, as proposed by Webster and Watson (2002). The main topics and the corresponding scientific literature used in this literature review are shown in Table 1. This also provides an overview of the supportive grey or trade literature.

Table 1: overview of the main and supporting literature for desk research

Topic	Main literature	Supporting literature
Circular Economy	Bocken et al. (2016); Brand (1995); Jabbour et al. (2019); Lewandowski (2016)	Circle Economy (2021); Ellen MacArthur Foundation (2013)
Social housing	Çetin et al. (2021); Koolma (2009); Elsinga and Wassenberg (2007)	Boelhouwer et al. (2014); Van Bortel et al. (2010); Autoriteit Woningcorporaties (2020); Aedes (2016); Straub (2009); CPB (2019); Rogers (1962)
Mass Timber construction	van der Lugt (2020); T. Nord (2008); Robati et al. (2021)	TNO (2021); Waugh Thistleton Architects (2019)
Modular construction	Lidelöw (2016); Subramanya et al. (2020); Habraken (2003)	Construction Industry Institute (2011); Safapour, Kermanshachi and Kamalirad (2019); Bendi et al. (2020)

Consultation of experts

Fourteen experts were consulted by phone or video call to discover the barriers in supporting sub-questions 1, 2, 3, and 4. Consultation with experts is proposed by Van den Akker (1999) as an activity in a systematic approach to discovering barriers. These consultations were explorative and held with different expertise and general expertise on design and construction management (DCM). An overview is shown in Table 2.

Table 2: Overview of the consulted experts

Company	Expertise	Function
NWA Architects	Architecture	Co-Founder
Alba Concepts	Consultancy	Consultant
TU Delft	DCM	Professor Construction Management
Coen Hagendoorn	DCM	Deputy Director Process management
Lister Buildings	Mass timber construction	Partner
Finch Buildings	Mass timber construction	Director Operations
Gemeente Amsterdam	Mass timber construction	Bio-based building researcher
TU Delft	Modular construction	Professor Architectural Engineering
de Bouwcampus	Modular construction	Consultant
TU Delft	Social housing	Housing Management
FIEN wonen	Social housing	Sr. Development manager
Stichting Woontij	Social housing	Director
de Alliantie	Social housing	Project manager sustainability
de Alliantie ontwikkeling	Social housing	Sr. Development manager

2.3.2 Phase 2 – Define the barriers

The second phase answerers sub-question 5: *What are the barriers for the adoption of mass timber construction for Housing associations?* The data from the previous phase is structured to define the main barriers. This is of utmost importance since the creation and evaluation of potential strategies are based upon these barriers (Herrington et al., 2007).

Semi-structured Interviews

To help define the barriers, housing associations were asked which barriers they encountered in adopting mass timber construction. A semi-structured interviewing technique was used since its conduciveness to interaction allows emerging themes and undiscovered barriers to come up in the interview (Jackson et al., 2007). A prerequisite for taking part in the interview was experienced in mass timber construction. However, few housing associations have built mass timber buildings to date. Therefore, companies currently involved in the initiative phase of a mass timber project were considered 'experienced.' Another prerequisite for operating in an urban densified area, such as the Randstad. Based on these requirements, eight housing associations were found prepared for taking part in the interviews. Table 3 presents an overview of the interviewed housing associations.

The interviews were conducted using online video calls, which allowed recording. This eased the possibility of data analysis afterward. The analysis can be found in Appendix E According to Clausen (2012) thematic analysis can be used when analyzing qualitative data involving the search for recurring ideas, rereferred to as themes. The was done according to the broad-based thematic analysis of Holstein and Gubrium (1995).

Table 3: Operating area and portfolio size of participating SHA's. Data from Aedes (2019)

Housing Association	Size of portfolio (in dwellings)	Operating area
Ymere	72.848	Metropoolregio Amsterdam
De Alliantie	54.074	Metropoolregio Amsterdam
Eigen Haard	55.474	Metropoolregio Amsterdam
Rochdale	36.852	Metropoolregio Amsterdam
Woonbedrijf Eindhoven	32.727	Metropoolregio Eindhoven
Mitros	28.552	U16 (Utrecht)
Woonwaard	16.096	Noord-Holland Noord
Parteon	15.809	Metropoolregio Amsterdam
Total	312.432	

2.3.3 Phase 3 – Develop strategies

The third phase develops and delivers strategies to the defined barriers by answering sub-question 6: *Which strategies could enable the adoption of mass timber construction for housing associations?*

Expert Panel

This phase uses an expert panel for the purpose of developing strategies. *"Expert panels provide a forum in which leading experts in a given field are invited to share their experiences and thoughts"* (Galliers & Huang, 2012, p. 122). The 'consultation of experts' from 'Phase 1 - Discover barriers' served as a pool from which three experts were selected to participate in the focus group. One expert was invited who had not taken part in the ‘consultation of experts’ phase.

These four leading experts joined the expert panel. Two representatives of mass timber construction companies, an architect, and an expert on the topic of bio-based construction materials. The expert panel was held and recorded in the online environment of Microsoft teams. Through screen-sharing, they were presented the main barriers as defined in phase 2. The participants responded with possible strategies for overcoming each barrier individually. After gathering all responses, they had the opportunity to respond to an analysis of the groups' data. This is in line with the proposed method of Lewthwaite and Nind (2016).
Appendix E

2.4 Scope

This paragraph provides argumentation for the scope of this research. To enabling mass timber construction for housing associations, this research focuses on housing associations operating in urban areas.

Housing associations

Housing associations are non-governmental organizations owning 29 percent of the total Dutch housing stock. They must comply with the 'Woningwet,' which is a Dutch law regulated by the Government. This means that the government indirectly influences approximately one-third of the existing and newly built housing stock. This influence can be seen in the energy transition where social housing associations need to improve their current housing stock to energy label B in 2021 and carbon neutral in 2050 (Aedes, 2016). The governmental influence on Housing associations combined with their large share in the housing market provided the argumentation of this research to focus on Housing associations.

Urban areas

In urban areas, the share of the social housing stock can be as high as 55% (Elsinga & Wassenberg, 2007). These are also the areas with the highest demand for new social dwellings. Therefore, this research mainly targets Housing associations operating in urban densified areas, such as Amsterdam and Utrecht's metropole region. As a result of urban densification, it is assumed that the demand for these dwellings will be mostly multi-layer apartment buildings.

Modular mass timber construction

These are also the buildings where mass timber has the highest potential for reducing embedded carbon emissions by replacing non-renewable concrete and steel within structural elements. When mentioning 'mass timber,' this research refers to multiple engineered wood types such as; Glue Laminated Timber (Glulam), Cross Laminated Timber (CLT), and Laminated Veneer Lumber (LVL). Mass timber especially suits modular construction for multiple reasons, which is explained in Chapter 3.4.
Modular construction is defined as: "the use of offsite construction (…) and includes all work that represents substantial offsite construction and assembly of components and areas of the finished project." (Construction Industry Institute, 2011). Combining these topics would result in: 'multi-layer modular mass timber social housing in urban areas. For ease of mind, this is referred to as 'modular mass timber buildings' throughout this research.

Deliver strategies

According to the double diamond design, the fourth phase delivers a solution (strategy) to the problem statement (barrier). However, the delivery of strategies is out of this research' scope due to time constraints. This means that the strategies are not verified and tested in the market. Therefore, they are presented as 'possible' strategies for overcoming the barriers.

2.5 Ethical considerations

This thesis complies with the 'Delft University of Technology Code of Ethics.' The concept of ethical considerations had its most excellent focus on the collection, storage, use, and disposal of data from human beings (Fellows & Liu, 2015). It is also essential to consider the legal aspect of intellectual property, confidentiality, and integrity with data collection. According to the Economics and Social Research Council (ESRC), 'Research Ethics' refers to *"the moral principles guiding research, from its inception through to completion and publication of results and beyond – for example, the duration of data and physical samples after the research has been published."* - Economic and Social Research Council (2005)

The six principles of ethics from the ESRC are considered during and after this research. These are in line with the TU Delft Ethical considerations for research. This means that this research is designed for integrity and quality to be ensured. Furthermore, staff and subjects are informed about this research's purpose, methods, and possible uses. All interviews were prior to an informed consent followed up with a debrief. Besides, confidentiality is assured when participants desire to be anonymized. Also, participating in this research has always been voluntary and harm-free.

This research has been written during an internship with 'Lister Buildings.' They provided insight into practical problems and gave access to a variety of experts in the field. During this research, possible competitors and customers of Lister Buildings have been interviewed. The interview results are not shared with Lister Buildings before this research is made public to avoid conflicting interests. This avoids them having a competitive advantage. On the contrary, company-specific information was not shared with interviewees to avoid competitors having a competitive advantage. This respects the independence of this research (Economic and Social Research Council, 2021)

3 LITERATURE REVIEW

3.1 Modular mass timber in the circular economy

A growing population, together with urbanization and the large-scale use of abiotic construction materials, is causing a high pressure on the ecosystem (United Nations, 2019a). The Dutch construction sector is responsible for 30,1 percent of the total raw material consumption and 11,4 percent of the greenhouse gasses. For reducing this pressure, climate change needs to be addressed in the built environment. The Dutch government aims to reduce its nation's carbon emissions by 55% in 2030 and 100% in 2050 (CBS, 2016).

Figure 3: The impact of the Dutch construction sector (Circle Economy, 2020b)

The circular economy is seen as a promising approach for decreasing the industry's pressure on the environment and improving global sustainability. This chapter focuses on the contribution of modular mass timber in the transition towards a circular construction sector. This is done by introducing modular mass timber as a circular product and proposed solution for reducing carbon emissions in new built social housing

Furthermore, this chapter presents the circular economy framework with three core strategies and five enabling elements. Modular mass timber is assessed within this framework to answer sub-question two in the last paragraph of this chapter.

3.1.1 A brief introduction of mass timber

Engineered wood was introduced throughout the 20th century. Mass timber is an engineered wood type that consists of multiple wooden elements or particles fabricated into one timber product. Examples are:

1. Glue Laminated Timber (Glulam),
2. Cross Laminated Timber (CLT)
3. Laminated Veneer Lumber (LVL).

Mass Timber has different advantages over traditional wooden buildings methods in terms of durability and usability. Furthermore, it has advantages over concrete and steel in terms of weight and embodied energy. Some mass timber products have developed to the stage where they can be considered economic and more sustainable alternatives to traditional materials (Harte, 2017). Figure 4 shows the comparison of mass timber versus other structural systems. Less foundation is needed when a building is constructed in mass timber compared to steel and concrete construction.

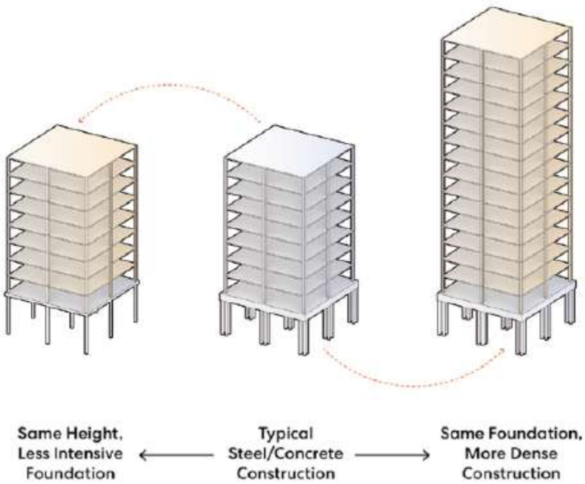

Figure 4: Mass Timber versus other structural systems

3.1.2 Carbon capture and storage

The construction industry accounts for 11.4% of the total emissions of the Netherlands, with 25.6 Million tons of CO2 equivalent emissions annually (Circle Economy, 2020a). 79% of these emissions are embedded emissions caused by the construction of new residential buildings. More than a quarter of these emissions are caused by concrete in foundations and structural elements. In concrete and other steel products, reinforcement steel is responsible for 40% (EIB, 2020; Robati et al., 2021).

These emissions could be lowered in two ways by substituting a traditional reinforced concrete construction with a mass timber alternative, first by reducing these emissions and second by finding ways for storing these gasses. Forests can capture CO2 from the atmosphere and store it in trees. As a result, wood from sustainably managed forests can reduce the carbon footprint compared to traditional buildings. Buildings then function as a carbon reservoir instead of a carbon emitter (van der Lugt, 2020).

In this light, mass timber can become an increasingly important construction material since its structural characteristics equal those of traditional construction materials. The research found that the most significant reduction of carbon emissions can be made by replacing concrete as a bearing structure (EIB, 2020).

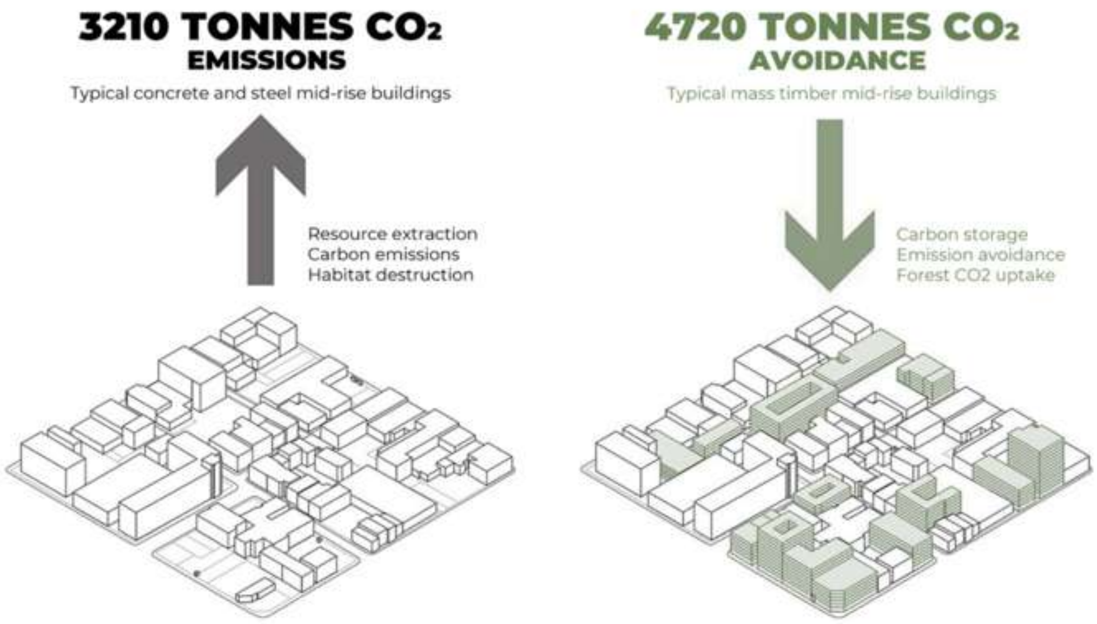

Figure 5: CO2 avoidance by replacing a concrete and steel bearing structure (Think Wood, 2021)

3.1.3 The Circular Framework

Not-for-profit organization Circle Economy developed a framework to make the concept of a circular economy more accessible since an exact definition of a circular economy lacks consensus (Chamberlin & Boks, 2018; Kirchherr et al., 2018). This is done by mapping fundamental themes into three core strategies directly related to material flows: prioritize regenerative resources, stretch the lifetime, and use waste as a resource.

These themes are supported by five enabling elements that can remove difficulties in achieving a circular economy. The framework is presented in Figure 6. The three fundamental themes are elaborated upon in this paragraph. They are related to common existing frameworks, such as the 10R and 5R framework, which prioritize the cascading from refuse, reuse to repurpose, and everything within (Ellen MacArthur Foundation, 2015; Jabbour et al., 2019; Lieder et al., 2018). This can be seen in Figure 7.

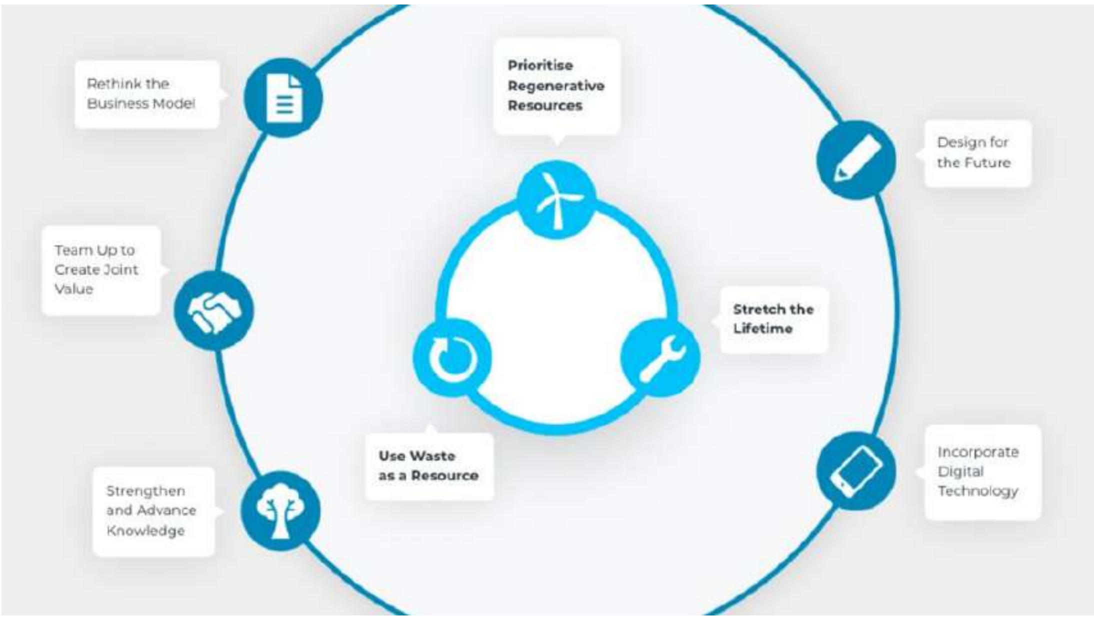

Figure 6: The Circular Economy Framework (Circle Economy, 2021)

CIRCLE ECONOMY'S CORE ELEMENTS	STRATEGIES FOR RESOURCE CYCLING[13]	10R FRAMEWORK	5R FRAMEWORK
Prioritise Regenerative Resources	Regenerate flows		
	Narrow flows	Refuse	
		Reduce	Reduce
		Rethink	
Stretch the Lifetime	Slow flows	Reuse	Reuse
		Repair	Repair
		Refurbish	Refurbish
		Remanufacture	
Use Waste as a Resource	Close flows	Repurpose	
		Recycle	Recycle
		Recover	

Figure 7: Relation to common frameworks (Circle Economy, 2021)

3.1.4 Three core strategies

Prioritize Regenerative Resources

"Renewable, reusable and non-toxic resources in water, material and energy cycles replace non-regenerative resources, with corresponding processes to support regeneration." (Circle Economy, 2021).

Regenerative materials entail bio-based, reusable, non-toxic, and non-critical materials, such as mass timber. In addition, the most efficient use of these materials in the production process needs to be safeguarded. Finally, waste needs to be eliminated. Mass timber suits these criteria by being a bio-based and non-toxic product that allows off-site manufacturing to achieve an efficient production process and eliminate waste as much as possible.

P. van der Lugt supports the suitability of mass timber to this core strategy in the following quote: *"The ideal durable circular material is bio-based, grows back several times during its lifetime, can substitute materials from abiotic resources in terms of performance, is made from 100% bio-based content, has no restrictions in the end-of-life phase, and is preferably biodegradable. This is exactly why mass timber products show so much potential for circular building"* (van der Lugt, 2020, p. 26)

Stretch the lifetime

"Resources and products are maintained, repaired, and upgraded to maximize their lifetime and usage intensity." (Circle Economy, 2021).

The lifetime of products can be extended by cascading them or their materials. Also, new business models with a second life through take-back strategies can help achieve this core strategy (Bocken et al., 2016). According to Downes et al. (2011), stretching the lifetime of products can reduce the negative carbon impact. This can be done by maintenance, refurbishments, or remanufacturing of building components (Andrews & Whitehead, 2019). Mass timber suits this core strategy since its suitability for design for disassembly.

Different scholars advocate looking at buildings as a composition of components in different layers based on the "6S" framework of Steward Brand (1995). As a result, different strategies on maintenance, remanufacturing, and refurbishment can be devised to stretch the lifetime of different components. This can be done by separating the long-lasting elements from the short-lasting elements so that the latter can be easily changed. A flexible mass timber building design contributes to the separation of such. Research has shown that companies can economically benefit from lifetime extension. However, the potential of such is not often fully understood. High investment costs prevent companies from doing so (Abdulrahman et al., 2015; Govindan et al., 2016; Hatcher et al., 2011; Vasudevan et al., 2012)

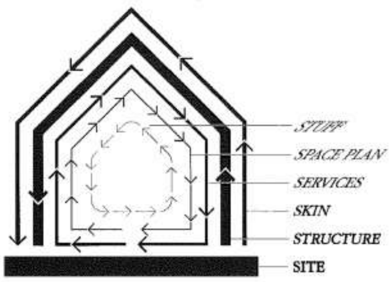

Figure 8: Shearing layers of change (Brand, 1995)

Use waste as a resource

"Where waste creation is not avoidable, recover it for recycling, using waste streams as a source of secondary resources." (Circle Economy, 2021).

Whenever there is no option to apply lifetime extension or use regenerative resources and waste is inevitable, it should be recovered and used as input for the production process of a new product (Bocken et al., 2016).

This is called cascading. Cascading can happen on different levels, for example, by managing the design process so that the product owner is responsible for cascading the product. Besides, organizations can transact their waste streams in the market or source secondary resources for different production processes (Jabbour et al., 2019). Ideally, resource loops can be closed entirely by using the waste of a product as a resource to produce the same product.

If all construction waste materials are recycled, there are only enough materials to fulfill 41% of the new homes. This is called the circular gap (Metabolic, 2020). This means there is an inevitable need for new construction materials to enter the economy. These materials should be designed so that they can be re-used at the end of life. It is therefore crucial that all new buildings are designed for disassembly.

3.1.5 The contribution of modularity

As seen in the previous paragraph, mass timber suits the principles of the first core strategy: renewable resources. The suitability for off-site manufacturing and design for disassembly provides mass timber with the potential to fully fit the three core strategies of the circular economy framework. For doing so, mass timber needs to be constructed in a modular way.

Modular construction is defined as: "*the use of offsite construction (including a segregated area onsite) and includes all work that represents substantial offsite construction and assembly of components and areas of the finished project."* (Construction Industry Institute, 2011).

Mass timber and modular construction are very suitable for connecting parts in a dry manner, which means a connection with screws and bolts. X-RAD is an innovative dry-connection system that allows quick assembly and disassembly of cross-laminated timber panels (Polastri et al., 2017). These dry connections allow mass timber to suit all three core principles of the circular economy. Besides, modular construction can lower on-site greenhouse gases and noise dust due to reduced on-site labor (Amiri et al., 2013). This also produces less waste compared to traditional construction (Kawecki, 2010).

In addition, modular construction has multiple advantages over traditional construction. It can be less expensive and more effectively produced (Ambler, 2013). It proposes a 40 percent construction time reduction and 10 – 25 percent lower construction cost (Construction Industry Institute, 2011; Ferdous et al., 2019). These result from standardized design procedures, fewer transportation movements, and a decrease in on-site labor (Cartwright, 2011; Subramanya et al., 2020).

3.1.6 Five enabling elements

The previous paragraphs have shown that modular mass timber suits the three core strategies. The following paragraph looks at the enabling elements of the circular economy framework as shown in Figure 6 and how they relate to modular mass timber.

Design for the future

"Design systems to facilitate regeneration, restoration, repair, reuse, or disassembly, or utilizing waste as a resource" (Circle Economy, 2021).

One of the main enabling elements for the implementation of all core strategies is the circular product design. This contains the easiness with which a product is recycled, disassembled, or reused (Circle Economy, 2021). According to Bocken et al. (2016) the circular product design is one of the essential activities to close and narrow material loops. The design determines the core circular economy strategies' financial viability, scalability, and quality (Circle Economy, 2021). An important example is a design for renovation and disassembly rather than demolition. This enables construction materials and components to be collected and reused in other projects. These design strategies open the possibility of new business models that ensure longer lifetimes of products (Circle Economy, 2021). According to the Ellen MacArthur Foundation (2013) a circular product design:

- has optimized material choice for circular setup,
- is designed to last,
- uses modularization and standardization,
- allows easy disassembly,
- uses increased production process efficiency.

Rethink the business model

"Shift incentives and adjust business models to price the entire life-cycle of products and capitalize on cooperation and long-term relationships." (Circle Economy, 2021).

There is a profound body of existing research on circular business models (Kraaijenhagen et al., 2016; Lewandowski, 2016; Manninen et al., 2018; Urbinati et al., 2017). Where linear business models often endeavor to minimize costs and maximize sales (Andrews, 2020; Reinecke et al., 2019), circular business models strive to create value for the whole value chain (Circle Economy, 2021). Unlike a linear business model, a circular business changes the value proposition from selling a product to allowing access to its functionality (Lieder et al., 2018). This requires a transition towards service or lifetime-based models in which the supplier services the product to gain profits over the product's lifetime (Bocken et al., 2016). For example, Antikainen et al. (2018) and Lewandowski (2016). Alternatively, by utilizing a complimentary maintenance service. This creates an incentive for the supplier to ensure longer lifetimes of products (Whicher et al., 2018).

Figure 9 displays a ladder of circular incentives for the product supplier. The highest score is a pay-per-use business model where a product is servicitized, while the lowest score is awarded for a linear business model of selling a product. These business models have the potential of encouraging circularity by providing incentives for businesses to prolong the service life of products and becoming more cost- and resource-effective as a result (Tukker, 2015). Preferring 'use' over 'ownership means that ideally, the contractor remains responsible for the building. This incentivizes the contractor to construct a circular product design.

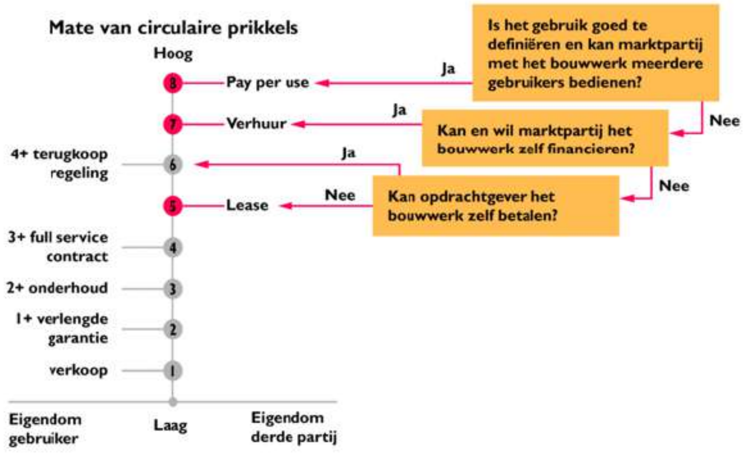

Figure 9: Ladder of circular incentives (Copper 8, 2019)

Incorporate digital technology

"Employ digital technologies to facilitate connecting actors and keeping track of resources." (Circle Economy, 2021).

The core circular strategies can be further enabled by digital technologies, such as tracking material flows and digital platforms for stakeholder engagement (Circle Economy 2021). Data collection of resources is essential for providing insight into inefficiencies in the production process (Andrews & Whitehead, 2019; Jabbour et al., 2019). This is seen as an opportunity to extend the lifetime and close product loops using remanufacturing and recycling. For example, urban mining reduces the need for new resources by identifying the available resources in a city, which becomes an urban mine as a result (Metabolic, 2020)

A practical example is a Dutch company New Horizon which operates according to these principles. These materials could be offered on digital platforms, such as Madaster, to facilitate matchmaking of people and materials. Furthermore, a platform could function as a marketplace for exchanging knowledge (Circle Economy, 2021). In addition, digital platforms could connect actors in the value chain. This is seen as a valuable tool in overcoming the main barriers about the lack of knowledge among actors about possible synergies and interactions with other value chains (Jabbour et al., 2019)

Collaborate for joint venture creation

"Work together with actors to implement circular economy strategies on the systems level." (Circle Economy, 2021).

Continuing previous paragraph, the collaboration between actors is required for overcoming barriers on the systems level, such as a lack of knowledge, a lack of capital, and problems with entering a new market (De Mattos & De Albuquerque, 2018; Mishra et al., 2019; Ngan et al., 2019). Collaboration is assumed to be an essential enabler for the circular economy since it provides access to knowledge while increasing interdisciplinary learning (Lozano et al., 2016; Mishra et al., 2019). This can lead to alliances that form an essential foundation for facilitating the circular economy.

Strengthen and advance knowledge

"Develop research, structure knowledge, encourage innovation networks, and disseminate findings with integrity" (Circle Economy, 2021).

Strengthening knowledge on the circular economy is seen as a highly significant enabling element. However, additional research shows that a lack of knowledge regarding the circular economy results in a hurdle for its success (Kirchherr et al., 2018; Klapalová, 2019). The average level of knowledge on the circular economy is low since different proficiency levels are shattered in varying industries among different stakeholders (Verboon & Wardenaar, 2016). This leads to stakeholders being unaware or pessimistic about the potential of circular solutions.

Increasing this knowledge can take place in different ways. By pioneering leaders and executives, the knowledge disseminates and increases in circular economy networks (Brown et al., 2019; de Abreu & Ceglia, 2018). Furthermore, online platforms could be used for managing, sharing, and showcasing knowledge (de Abreu & Ceglia, 2018; Klapalová, 2019). An example can be seen in the circular innovation program of Amsterdam, which showcases innovative projects and developments aiming to accelerate the circular transition.

3.1.7 Contributing to the circular economy

This chapter has shown that mass timber construction helps to reduce carbon emissions in the built environment. Besides, it suits the first core strategy of the circular economy framework with being a regenerative resource. The suitability for off-site manufacturing and design for disassembly provides mass timber construction with the potential to fit the other two core strategies of the circular economy framework.

Modular construction allows stretching the lifetime of products and using waste as a resource in the future. Therefore, the combination of mass timber and modularity suits the three principles of the circular economy framework and helps achieve a circular economy. This also answers the first sub-question of this research: "*What contribution can mass timber construction make in the transition towards a circular economy?"*

Furthermore, this chapter explored five enabling elements of the circular economy. These elements provide a solid basis for this research when looking into barriers and strategies to enable mass timber construction. It shows multiple ways to strengthen and advance knowledge, and the need for collaboration between actors to overcome barriers on the systems level is emphasized. Also, the potential of digital technologies is explored, which could drive online platforms and material exchanges for keeping track of materials. One of the main enabling elements for the implementation of all core strategies is the circular product design. This allows new business models to arise, which ensures longer lifetimes of products.

3.2 The social housing sector

The previous chapter presented the importance of the transition of the construction sector towards a circular economy. This chapter focuses on the widely discussed challenge of adding one million homes (Elsinga et al., 2020). The large share (29%) of social housing in the Netherlands is the highest in Europe, making the social housing sector an important actor in the one million homes challenge. This is especially true in urban areas, where this number can be as high as 55 percent (Elsinga & Wassenberg, 2007).

This chapter presents the fundamentals of housing associations with a brief history, an overview of the current supply and demand, and insight into their attempt to meet this demand. This chapter answers sub-question two: *"What is the current demand for social housing, and how do housing associations attempt to meet this demand?"*

3.2.1 A brief history on Housing associations

A housing association is a private entity designated with the public task of providing affordable housing by the 2015 Housing act (Boelhouwer et al., 2014; Czischke & van Bortel, 2018).

The central organization of Dutch housing associations defines them as follows: "non-profit enterprises that pursue social goals within a strict framework of national laws and regulations by involving local government, tenants and other stakeholders in their policies and are accountable to the society" (Aedes, 2016).

At the end of the 19th century, many housing associations started as private or church initiatives to provide better housing for lower-income households. To date, Housing associations are still seen as an essential part of providing housing. The social housing sector is considered a Service of General Economic Interest (SGEI) (Czischke & van Bortel, 2018). The government determines that housing associations bear the social obligation for constructing, renting, and managing social housing for lower-income households and improving the quality of life in neighborhoods (Aedes, 2016).

The maximum household income ceiling to be eligible for social housing in 2021 is set to €44.196 and adjusted annually (Rijksoverheid, 2021a). Allocated social housing has a rent below €752 per month and is provided by a housing association.

Supply

According to Elsinga and Wassenberg (2007) the Dutch housing market is dominated by housing associations. No other European country has a higher percentage of social housing than the Netherlands. This number can be as high as 55% in urban areas (Elsinga & Wassenberg, 2007). On a national level, 29% of the national housing stock is social housing (CBS, 2020). This comes down to nearly 2.3 million homes, representing 68.5% of the total rental supply (Capital Value, 2021). These homes are provided by 310 housing associations, some of them having a portfolio of more than 50,000 homes.

These figures show that the Dutch social housing sector is a significant client in the construction sector. However, after the crisis in 2008, housing associations were having difficulties in constructing new social homes because of a deteriorating economy and governmental policy regarding the landlord levy (verhuurderheffing) from 2013 onwards (Aedes, 2017).

Landlord levy

In the crisis, the landlord levy was introduced to reduce the national debt. All Housing associations with more than 50 social homes are subject to the landlord levy. Every home above the threshold is subject to the levy. This is based on the portfolio's average property value (WOZ-waarde), with a maximum property value of 315.000 per dwelling. Dwellings with a property value above 315.000 are calculated as having a property value of 315.000. For 2021, this percentage is set at 0.526% (Rijksoverheid, 2021b).

For example, a portfolio of 5.000 social dwellings with an average property value of €200.000 is obliged to pay a levy of 4050 x €200.000 x 0.526% = €4.260.600 annually. This landlord levy only applies to social housing. This gives Housing associations an extra incentive to sell or liberalize these homes, leading to less investment capacity. Both cases resulted in a decline of the social housing stock in the Netherlands. An example can be seen in Amsterdam in Figure 10 where the social housing stock was 60 percent of the total stock in 1995 to 40 percent in 2019.

Housing associations currently discredit the landlord levy. However, Minister Ollongren of the Interior and Kingdom Relations has previously indicated that she wants to leave the decision for abolishing the landlord levy to the next cabinet (Buijs, 2020)

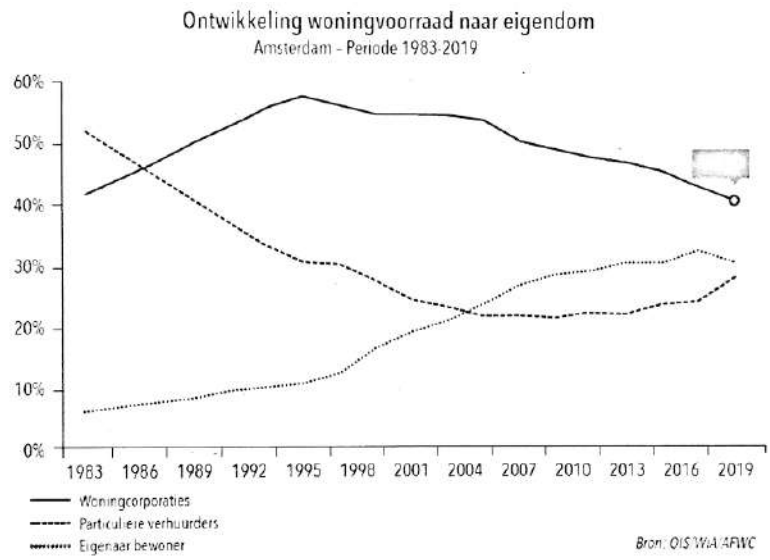

Figure 10: A decline in the social housing stock in Amsterdam (Geus, 2021)

Demand

In the coming years, the total supply needs to increase because of high demand. In September 2020, Minister of the Interior and Kingdom Relations Kasja Ollongren reached administrative agreements with Aedes to accelerate social housing construction to 25,000 homes annually from September 2022 onwards. This number needs to contribute to the collective need of 150,000 homes in the period 2020 - 2024 (Rijksoverheid, 2020b). The current prognosis of social homes in the same period is 112,400 (Autoriteit Woningcorporaties, 2020). The need for these homes is distributed as seen in Figure 11.

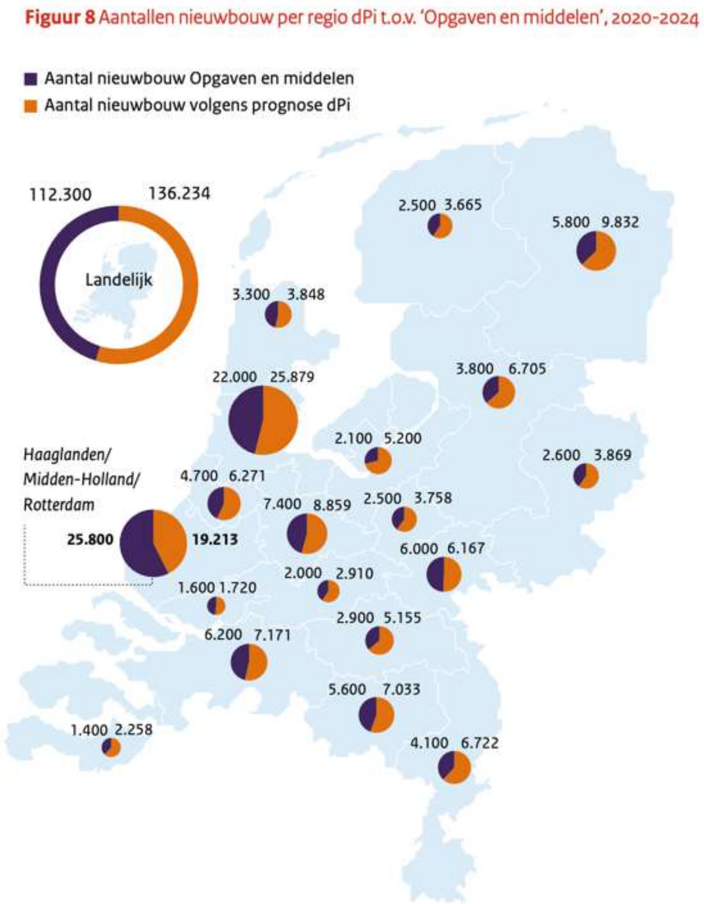

Figure 11: Demand of social housing in 2020 2024 (Autoriteit Woningcorporaties, 2020)

3.2.2 Behavior

Since housing associations are subject to the Housing Act, they are restricted from developing housing in certain regions. In doing so, they have copied corporate behavior from private companies. As a result, mergers and acquisitions created larger organizations with a declining number of associations while their average portfolio became bigger (Koolma, 2009). This phenomenon can be seen in Figure 12. In this shift, some small autonomous organizations became multi-tiered hierarchical organizations compared to private bureaucratic institutions. According to Van Bortel et al. (2010), only a small part of these mergers had the goal to achieve economies of scale. This affirms the idea that efficiency has not been recognized as a significant issue by housing associations. (Veenstra et al., 2017).

A second explanation of why efficiency is not used to its optimal is the absence of commercial companies in the playing field, which leads to market competition (Koolma, 2008). As a result, additive market capacity deteriorates, and the focus on product innovation diminishes (Koolma, 2009). Nonetheless, the attention on commercial areas such as financial returns increased (Nieboer & Gruis, 2011)

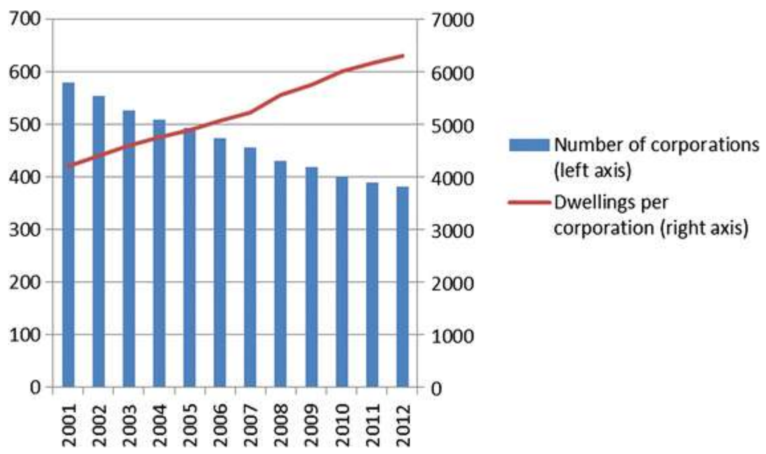

Figure 12: The number of associations and stock (Koolma, 2009)

3.2.3 Construction process

The role of the housing association in the construction process has changed since the adjustments in the Housing Act 2015. Since the act does not allow investments other than those in the Service of General Economic Interest, their real estate development department declined (Joren & Kunen, 2019).

Strategic alliances

Housing associations are obliged to construct, rent, and manage social housing. As a result, they are often more interested in adding turn-key dwellings to their portfolio than in developing it themselves (CPB, 2019; Joren & Kunen, 2019). In doing so, they obtain strong connections with contractors and maintenance providers. They have begun to develop strategic alliances for constructing and maintenance services (Straub, 2009). More recently, they introduced partnering agreements with maintenance companies. Some use strategic alliances with contractors and award the project since they are not obliged to conduct a public tender (CPB, 2019). Such long-term agreement provides them with a product that better suits their requirements and helps to accelerate projects (Plasschaert, 2019).

Traditional procurement

If a housing association chooses to tender, traditional procurement is still the most common process for most projects (Çetin et al., 2021). This separates the client (housing association) from the contractor and allows the client to make demands regarding the quality of the project. Choosing the lowest price is often seen as the best option since housing associations have a fixed program of requirements. This has low transaction costs and competitive prices as a result (Pianoo, 2021).

However, composing specifications for the tender is time-consuming and results in only partly optimized horizontal integration (chain integration), wherein the design and construction phase are tendered separately. This has an extensive process in which a total cost of ownership (TCO) is not always considered (Pianoo, 2021).

3.2.4 Investment capacity

Investment in sustainability closely relates to the investment capacity of housing associations. Whenever they have too little financial capacity to fulfill their social task to add social housing, they must consult with municipalities and tenants to discuss what they find most important to invest in (Autoriteit Woningcorporaties, 2020).

Rising costs

As a result of rising building costs and extra costs for implementing sustainability measures, the initial investment for a new social dwelling (including land) has risen to more than €200.000 per home. Since the income per dwelling is limited by the free market cap, an unprofitable investment of €120.000 per unit occurs on average. In this circumstance, it is almost impossible to make a market entry due to the exploitation scheme where a negative investment occurs the first 10 to 15 years after construction (Koolma, 2009). The higher energetic quality lowers the monthly energy bill but does not create financial returns for associations. This raises the question of whether current investment decisions should be looked at on project or portfolio levels (Autoriteit Woningcorporaties, 2020).

Critical LTV ratios

There is enough investment capacity for constructing new homes in the coming years. Research shows that the social housing sector has an investment opportunity of 87 million euros to develop social housing. (Ministerie van Binnenlandse Zaken en Koningsrelaties, 2020). However, this is expected to change when the sector average loan-to-value raises above the threshold of 85 percent. The ability for structural intensification of investments is limited to this threshold. For region Haaglanden/Midden-Holland/Rotterdam, this will be reached in 2024 already. Expectations are that 79 percent of the Dutch housing associations will reach this threshold by 2028. This is shown in Figure 13 (Ministerie van Binnenlandse Zaken en Koningsrelaties, 2020).

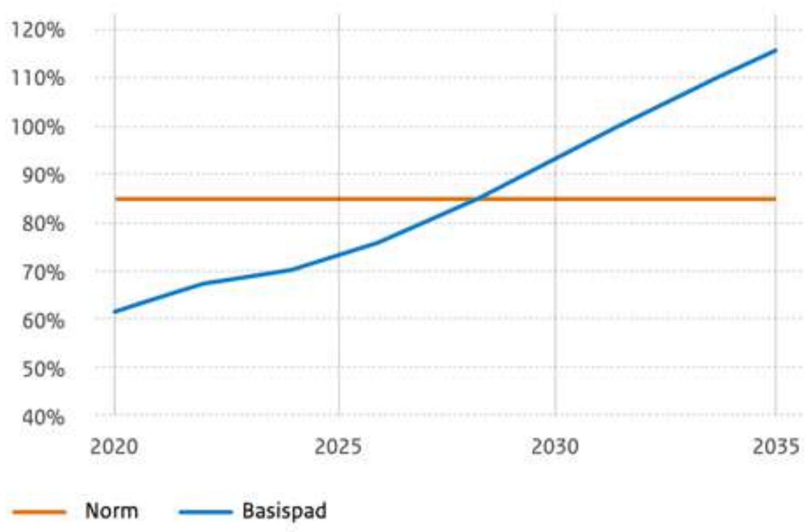

Figure 13: outcast LTV on sector level until 2035 (BZK, 2020)

3.2.5 Investment decision

Housing associations spend more on the 50-year exploitation phase of a dwelling than on the initial construction costs. However, as seen in paragraph 3.2.3 construction costs are often decided upon rather than exploitation costs. Insight into the lost rental income, maintenance, and the residual value of a dwelling can allow an investment decision based on the exploitation phase (De Circulaire Bouweconomie, 2020).

Lost rental income

Shorter construction times result in earlier rental incomes. In the case of temporary (replacement) housing, the period without rent is also shorter. A six-month reduction in construction time easily yields several thousand euros in additional rental income

Maintenance

As a result of a long-term portfolio strategy, maintenance forms a large part of the exploitation. The exploitation scheme in Figure 14 shows an annual rent income per dwelling of €6,324 and expected maintenance costs of €1,916. This means that 30% of annual income is spent on maintenance. This underlines the importance of maintenance.

In general, the bearing structure of the building does not require maintenance. This applies to both mass timber and concrete structures. As a result, the maintenance costs are mainly determined by technical installations, façade cladding, and window frames.

Tabel 6 Vastgoedexploitatie- en operationele kasstroom per sociale verhuureenheid, 2018-2019

	2018	2019	%stijging
Huur	6.196	6.324	2,1%
Nettobedrijfslasten	-1.180	-1.165	-1,3%
Onderhoud	-1.781	-1.916	7,6%
Verhuurderheffing	-714	-703	-1,5%
Overig	1	0	-
Netto vastgoedexploitatie kasstroom	**2.521**	**2.540**	**0,7%**
Renteuitgaven	-1.317	-1.209	-8,2%
Sectorspecifieke heffing	-65	-6	-90,6%
Vennootschapsbelasting	-204	-279	37,0%
Overig	76	57	-
Operationele kasstroom	**1.011**	**1.102**	**9,0%**
Prijspeil 2018			
Netto vastgoedexploitatie kasstroom	2.521	2.475	-1,8%
Operationele kasstroom	1.011	1.074	6,2%

Figure 14: Exploitation and operational costs per unit (Autoriteit Woningcorporaties, 2020)

Residual value

Housing associations generally calculate the residual value after 15-years. The residual value is based on the market value, which is subject to the overall quality of the building. At this moment in time, the materialization of the bearing structure does not affect this calculation. This means that a mass timber building is valued the same as a concrete alternative. The overall value is improved by choosing high-quality materials with a long lifespan (De Circulaire Bouweconomie, 2020).

Total cost of ownership

A total cost of ownership is a methodology and philosophy that looks beyond a purchase's price to include many other purchase-related costs (Ellram, 1995). This allows comparing the total cost of the exploitation phase compared to the initial construction costs.

3.2.6 Attempting to meet the demand

This chapter aims to answer sub-question two: "*What is the current demand for social housing and how do housing associations attempt to meet this demand?"*

This chapter shows that the current demand for social housing comprises 25,000 homes annually from September 2022 onwards. Housing associations approach this demand as authorized institutions with the social obligation to construct, rent, and manage them with a maximum rent level of €752 per month. Mergers and the lack of competition decreased their focus on product innovation while focus on financial returns increased.

Consequently, traditional procurement is still the most common process for most projects. This is done while obtaining strategic alliances with contractors and maintenance companies. Maintenance expenditure consumes 30 percent of their annual income. This results from a long-term portfolio strategy, which underlines the importance of maintenance and efficient real estate management. However, a TCO approach is not always considered an option.

As a result of sector-level barriers, the LTV ratio of 85 percent is expected to be reached by 79 percent of all Dutch housing associations by 2028. Rising building costs lay pressure on social housing associations in the short term, while a low cash flow and the rising loan-to-value form barriers in the longer term.

3.3 Mass timber construction

Mass timber is increasingly proving itself as one of the most important materials within bio-based and circular economic models. Comprehensive Life Cycle Assessments (LCA's) confirm the low environmental impact of mass timber products compared to concrete and steel alternatives. Recent developments in mass timber technology allow industrially manufactured elements and components that enable architects and constructors to build better, bigger, and higher (Jeffree, 2020). To understand the possibilities and the barriers of mass timber construction, this chapter aims to answer sub-question three: "*How can mass timber construction offer a solution, and what are the barriers in doing so?*"

- This chapter explains different options of using wood as construction material and aims to provide insight into the proposed solution of mass timber.
- This chapter also gives insight into timber building conceptions, revealing the barriers for mass timber construction.
- It concludes with why and what type of timber buildings can offer a solution to the Dutch housing need to answer sub-question 3

3.3.1 The rise of mass timber

Mass timber construction has been known in other countries for a long time. Only recently it is becoming popular in the Netherlands. There is a rise in mass timber construction. The 30-meter tall 'Patch 22' building completed construction in 2016. Two years later, Hotel Jakarta (32 meters) was completed, and' Stories' (45 meters) will follow this year. Currently, 'HAUT' (72 meters) is under construction and will be the highest mass timber building in the Netherlands. However, plans for higher mass timber buildings are already made (Dijksterhuis, 2021).

The Dutch growing interest in timber construction becomes clear from the Green Deal of Metropole Region Amsterdam, wherein the ambition is stated to construct at least 20 percent of the housing stock in timber by 2030 (Metropool Regio Amsterdam & Amsterdam Economic Board, 2020). Other municipalities, such as the city of Utrecht, currently discover the use of mass timber (Ooijevaar, 2020).

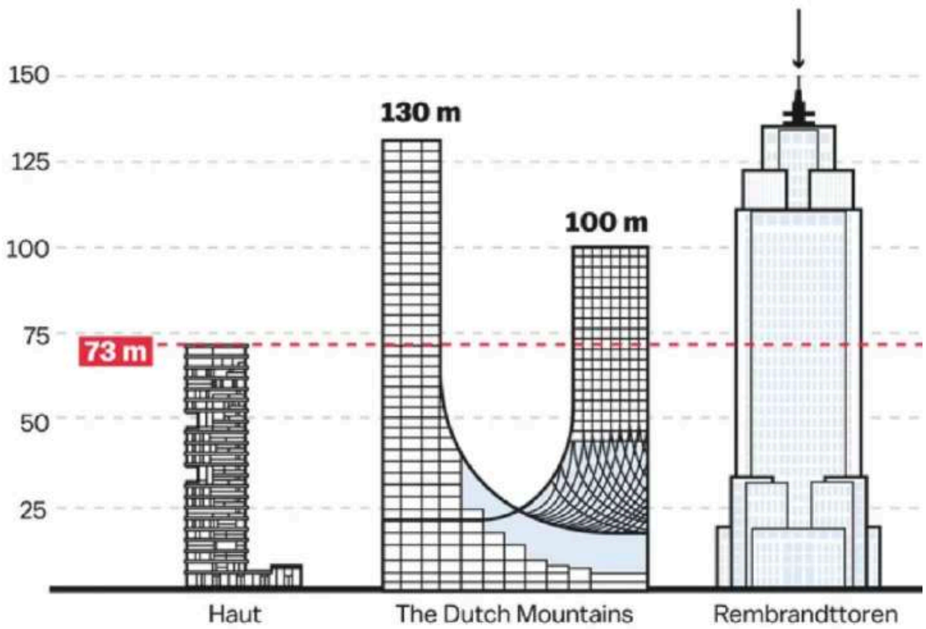

Figure 15: Mass timber construction in the Netherlands (Dijksterhuis, 2021)

3.3.2 Advantages of mass timber construction

Mass timber is a regenerative resource that fits the core strategies of the circular economy. It offers multiple advantages over traditional construction materials like steel and concrete. Mass timber provides long-term CO2 capture and enables design for disassembly, which eases reuse in the future. A mass timber structure also allows a quicker and quieter construction process due to prefabrication. Since mass timber weighs less than steel and concrete, it saves considerably on transport movements, emissions, and costs. Mass timber also allows for a less massive foundation which saves both material and costs. Consequently, mass timber is suitable for inner-city city developments (Waugh Thistleton Architects, 2019).

Carbon sequestration

Wood products contribute to the reduction of CO2 eq and carbon sequestration. Trees absorb CO2 through photosynthesis and act as a vital carbon buffer. By using this wood in mass timber products, a reduction in both artificial and embodied carbon emissions is achieved. Especially when replacing energy-intensive materials such as steel and concrete.

Health benefits

The concept of healthy buildings was introduced by Ho et al. (2004) and defined as a "built environment that encourages positive well-being of human beings." Since people spend 60 – 90 percent of their time indoors, a building should provide a healthy indoor environment.

An essential concept for improving the health of buildings is biophilic design. A growing body of research shows that connection to natural environments can positively affect inhabitants' physical and mental well-being, such as higher levels of concentration, improved mood, and personal productivity (Knox & Parry-Husbands, 2018).

"Access to nature and natural materials like wood is found to be a key benefit. Research points towards increased positive feelings and decreased stress, implying reduced risks from depression and impaired immune system functioning, and improved long-term health." (ARUP, 2019)

Suitability for prefabrication

There are many advantages of prefabrication in mass timber compared to pre-cast concrete panels. Machined mass timber components have a higher accuracy of 1mm compared to 10mm in concrete. In addition, no extra structural frames and drying times are needed, which speeds up the production process. Furthermore, mass timber is easier to handle during manufacturing, transportation, and erection on-site due to its lightweight. The production process also allows CNC-based factory processes and BIM implementation (ARUP, 2019).

Design for disassembly

Design for disassembly is one of the enabling elements of the circular economy framework (Circle Economy, 2021). An innovative new connection system, X-RAD, allows for the quick assembly and disassembly of mass timber parts (Polastri et al., 2017). Such systems support easier jointing and fixing for both the sub-assembly and the fit-out of the building. This enables construction materials and components to be reused in other projects and opens the possibility of new business models, ensuring longer product lifetimes (Circle Economy, 2021).

A construction industry report from the University of Cambridge describes the future scenario of a platform approach. This platform is enabled by an industry-wide DfMA (Design for Manufacture and Assembly) protocol that supports building components' interchangeability (Wood, 2018).

The Alphabet company Sidewalk Labs provides an example of DfMA in their “PMX building.” Their kit of parts refers to a basic set of building components that can be made in a factory and assembled quickly at a construction site. It includes floor cassettes, structural beams and columns, and façade panels combined with “fit-out” items procured from third partners, such as kitchen pods, bathroom pods, and elevators (Huang et al., 2021).

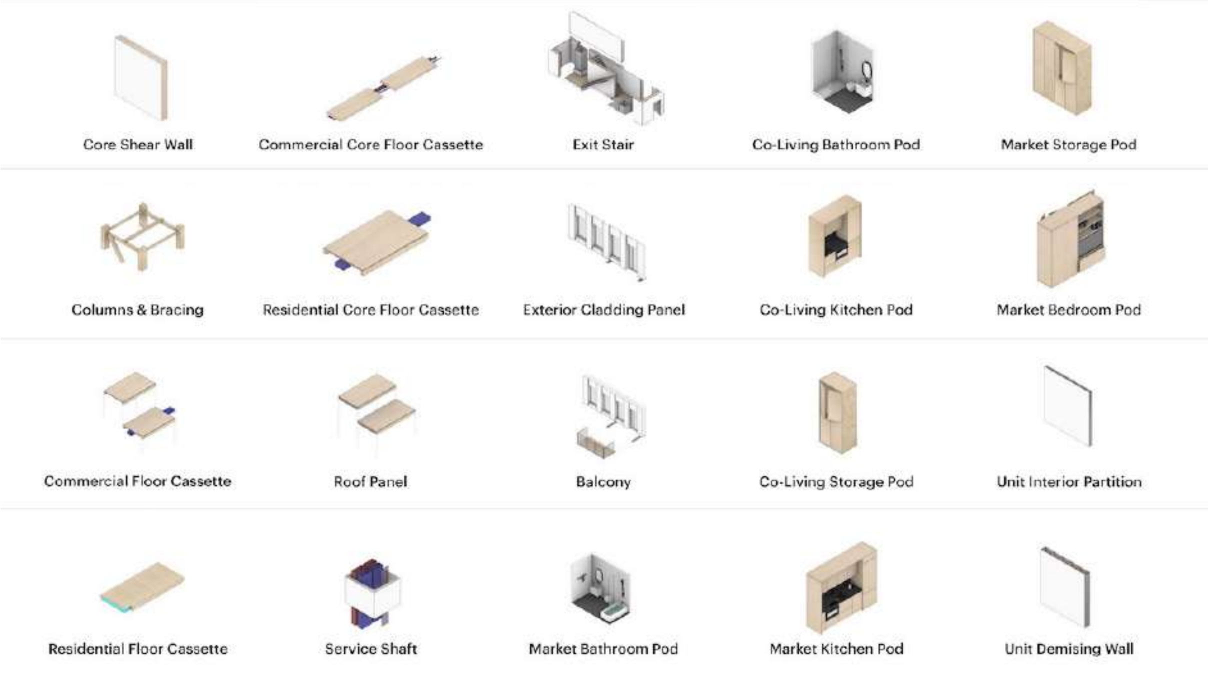

Figure 16: The kit of parts that form the PMX building (Michael Green Architecture)

Figure 17: A potential interior kitchen design for the PMX mass timber model (Sidewalk Labs)

Design for adaptability

The concept of design for adaptability is underpinned by the Open Building approach., which holds a fundamental sense of flexibility (Askar et al., 2021). This is further elaborated upon in paragraph 3.4.2. The adaptability of buildings, or the ability of buildings to change over time, is of significant interest to scholars and practitioners (Kendall & Ando, 2005). This is caused by the potential to avoid demolition and preserve the value of materials, embodied energy, and the costs bound to the production of new materials (Honold et al., 2019; Ross et al., 2016).

Adaptability allows the preservation of a significant part of the building with lifetime extension and a higher residual value consequently (De Circulaire Bouweconomie, 2020; Gosling et al., 2013). However, this can only be achieved if adaptability is related to other strategies such as design for disassembly, standardization, modular design, and material passports (Askar et al., 2021).

3.3.3 Barriers in mass timber construction

Price

The main point of consultation with experts is that mass timber construction is 10 - 20% more expensive than traditional alternatives (J. Hollander, personal communication, 2020; R. Mol, personal communication, 2020). This is mainly due to traditional procurement and strategic alliances with the traditional industry. Traditional construction companies incorporate a risk fee in their cost calculations for mass timber construction. As a result, mass timber cannot compete in the case of a cost-based tender (J. Hollander, personal communication, 2020; R. Mol, personal communication, 2020).

Unknown residual value

As read in the previous paragraph, adaptability can lead to a higher residual value. However, it is challenging to calculate the benefits of adaptability since the future value of components is not quantified. Besides, a long lifespan is only possible with evidence of the different end-of-life scenarios (Graham, 2005). Also, clients undervalue the long-term benefits of mass-timber construction because these are experienced as unknown territory. In addition, the concept of life cycle costing is not sufficiently understood (Ooijevaar, 2020).

Lack of standardization

Developers can experience a challenge when selecting mass timber components in a market where international standards are not yet established (ARUP, 2019). These standards are available in steel and concrete industries. However, the lack of standardization in the mass timber industry forms a barrier for the uptake. *"As the market matures, the most widely used, effective, and versatile timber components will gain market share, and economies of scale will lead to standardization and lower unit prices. What looks promising for timber is that rewards from optimization and standardization are still largely to come, given multi-story mass timber is still relatively new"* - ARUP (2019)

Insufficient knowledge

Multiple technological challenges are experienced with mass timber construction regarding noise, fire safety, and moisture. These are the result of insufficient knowledge in the construction value chain. Sweden experienced these challenges in 1996 and started a research program for the wood-based housing industry. This program included forest industry representatives, research funding organizations, and politicians to increase the basic knowledge of using timber in larger structures. This led to a timber expertise centrum and insight for overcoming technological challenges (T. Nord, 2008).

Dutch research institute TNO is currently researching architectural innovations, sustainable calculation methods, and modular construction. This research is conducted within the innovation program Bio-based Bouwversneller (TNO, 2020). These types of research are comparable to the Swedish research program for overcoming these technological barriers.

Non-level playing field

Currently, temporary CO2 sequestration is not included in the Life Cycle Analysis-method. This results in a higher MPG impact for a mass timber building than for a traditional concrete building. Research institute TNO showed that the temporary sequestration of carbon positively affects buildings' carbon footprint and affects the governmental measurement tools MKI and MPG (TNO, 2021). This can be seen in Figure 18.

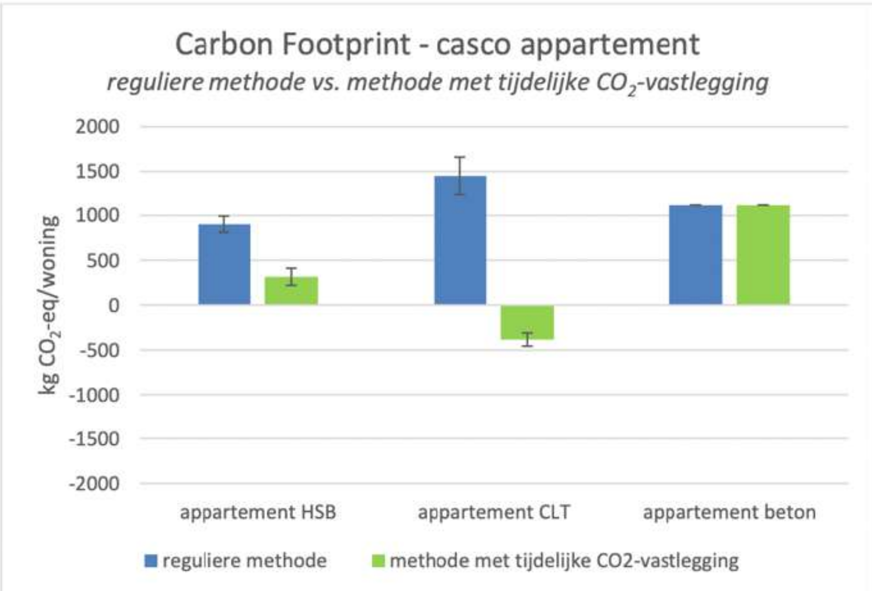

Figure 18: Carbon Footprint, regular method vs temporary sequestration method (TNO, 2021)

Volatile organic compound (VOC)

Emissions of volatile organic compounds (VOC) from indoor sources are significant determinants of indoor air quality and residents' health. Mass timber uses adhesives such as formaldehyde. Research by Yauk et al. (2020) showed that an outdated CLT panel released a concentration of formaldehyde above the threshold of 9.0 µg/m3.

This off-gassing of volatile compounds can result in health problems. Some fabricators have responded by switching to a soy-based cold-set adhesive or polyurethane (PUR) (ARUP, 2019). One way to avoid off-gassing is using Dowel Laminated Timber, which does not use an adhesive at all (Yauk et al., 2020). The research shows the importance of looking at the emissions of volatile organic compounds and that an alternative to formaldehyde must be sought.

3.3.4 Misconceptions

There are different misconceptions about mass timber buildings regarding availability, price, and production. Also, there are misconceptions regarding technological challenges, such as fire safety and acoustics. This paragraph goes into those conceptions and briefly explains them.

Not enough supply

The second conception comes from people worried that deforestation occurs when more buildings are built in wood. However, the contrary is the case. When the demand for wood rises and the construction sector uses wood from sustainably managed forests, the forest area expands instead of declines. It is estimated that every EU citizen can live in a wooden house without harming the existing forest (van der Lugt, 2020)

Increasing demand

At the start of the COVID crisis in 2019, many sawmill operators in the United States expected the demand for wood products to plummet. However, the opposite was the case. Demand for lumber (collective term for harvested wood) increased, but sawmills were at a standstill. The price peaked in May 2021 and started to cool down since. *"Despite the recent drop in prices, lumber still costs about 80% more now than it did before the pandemic — a premium that builders say is adding tens of thousands of dollars to the price of a new home."* - Horsley (2021)

The run on lumber sparked concerns about the inflation of a range of similar goods (Horsley, 2021). Whether the prices of mass timber have indeed increased as a result remains to be investigated through market research. A preliminary conclusion is that contractors have made (price) agreements with suppliers to be assured of their share of mass timber products (J. Boers, personal communication, 2021)

Production capacity

The Netherlands is self-sufficient in its timber production for around 7%. However, this is mainly for board production, paper production, and biomass. The cause for the absence of a well-functioning Dutch timber supply lies in the small-scale nature of wood production. Scattered production forests and the absence of a sawmill facility make it seem unlikely that the Netherlands will be able to use mass timber from its production forests in the short term (Klaassen, 2020).

Durability

There has been a time in the Netherlands where wood was perceived as non-durable material due to its need for maintenance, says Gert-Jan Nabuurs in Cobouw (Belzen, 2021). Partly due to the emergence of mass timber and the climate debate, people increasingly understand the potential of mass timber construction, and misconceptions about durability are fading away. However, there are still questions about the durability of wood among tenants. This is seen in a questionnaire among 120 tenants of housing association FIEN wonen, where the use of timber is not seen as durable material (R. van der Kuij, personal communication, 2020)

3.3.5 Early innovators

Recently, housing associations are increasingly emphasizing the governmental program for a fully circular economy in 2050. According to Çetin et al. (2021), an increased focus on circularity emerges on their agendas. This pattern is advocated as the starting point of a new acceleration in the circular economy transition. Several housing associations already started exploring the possibilities of bio-based social housing. They can be seen as early innovators, according to the innovation curve of Rogers (1962).

For example, Fien Wonen decided to construct all homes from bio-based materials from 2020 onwards on the condition that they are less than 10 percent more expensive than traditional construction (R. van der Kuij, personal communication, 2020). Buildings then become carbon banks, which store CO2. Director of Elisabeth ter Borg aims to acquire and sell the emissions rights of the stored carbon in their homes (Kuys, 2019).

A different example is Woonwaard, who commissioned Finch Buildings to construct 38 prefabricated homes in Alkmaar. Furthermore, Wooncompagnie constructed 62 CLT apartments in Monnickendam, also with the modules of Finch Buildings. Designing the homes for disassembly allows their components to be reused after their service life, increasing their lifespan and possibly their residual value.

Figure 19: 62 CLT apartments in Monnickendam (render by: Finch Buildings, 2020)

Figure 20: 38 prefabricated homes in Alkmaar (picture by: Finch Buildings, 2020)

3.3.6 Proposed solution and corresponding barriers

This chapter aims to answer sub-question four: *How can mass timber construction offer a solution, and what are the barriers in doing so?*

Timber can be a solution for part of the housing demand. From the total demand, 80% is demanded in urban areas as explored in chapter 3.2. These areas often have a scarcity of land and high land prices. Therefore, there is a higher need for multi-floor construction to be developed. This chapter shows that mass timber is especially suitable for low to mid-rise apartment buildings rather than single-family homes. This makes mass timber specifically suitable for inner-city developments where it can replace concrete in the bearing structure.

However, the transition to timber as a primary construction material on a large scale requires some effort. First, a different way of thinking and a new design approach is needed. It also requires solutions for technological challenges, as seen in chapter 3.3.3. This knowledge is abundant in other countries. Furthermore, it requires thinking in Total Cost of Ownership rather than in building costs. Finally, governmental ambitions to achieve a 55% circular economy in 2030 will increase the need for building with bio-based materials, such as the carbon tax.

The Netherlands may not have abundant knowledge of building in wood; it does know logistics and automatization. This knowledge can be used for modular construction in the construction sector, for which the next chapter goes into detail.

3.4 Modular construction

Dutch construction companies Van Wijnen, Bouwgroep Dijkstra Draisma and Plegt Vos recently announced an investment in modular construction. Van Wijnen is the first Dutch company to receive investment from a private equity company, according to van de Groep (2020). In addition, the Japanese housing market leader of modular construction Daiwa House Industry bought a share of 80 percent in one of the largest modular builders in the Netherlands, Jan Snel. These investments and acquisitions underline the potential for modular construction (J. van der Doelen, personal communication, 2020)

The examples above indicate the potential of modular construction and prefabrication. This is underlined by multiple studies, which show that the productivity and quality in the building industry can be improved by increasing the portion that is prefabricated (Council, 2013). To explore other advantages and possible barriers, this chapter aims to answer sub-question 4: How can modular construction offer a solution, and what are the barriers in doing so?

3.4.1 Building systems

The previous chapter explored the advantages of mass timber. It showed that mass timber is very suitable for prefabrication. This paragraph explores the most adapted building systems. Geometrically, there are three categories: 2D modules, 3D modules, and post and beam systems (Lidelöw, 2016). A combination is also possible. This is called a hybrid system.

2D modular prefabrication

2D modules are 'planar building elements' as walls and floors with up to 20 levels of structural capabilities. A combination of timber-frame and mass timber elements is also possible. Timber-frame panels can be used for the façade and indoor walls, while mass timber can be used as the bearing structure (Lidelöw, 2016). An example is RC panels, which deliver prefabricated facades and roof elements.

3D modular prefabrication

A 3D modular system is a volumetric module from which the main principle is that all services of the module, such as walls, cladding, floors, kitchens, and bathrooms, are prefabricated in a factory and transported to the site where the module is placed. This reduces the construction time on site but increases the engineering time upfront (Li et al., 2014). On the contrary, this opens the opportunity to control the building process from design to completion. Each module can have multiple rooms, but the maximum size of the modules is determined by maximum manufacturing and transportation widths. Modular systems are especially suited for hotels, student housing, and apartments. Two examples are Sustainer Homes and Finch Buildings, which both offer volumetric units.

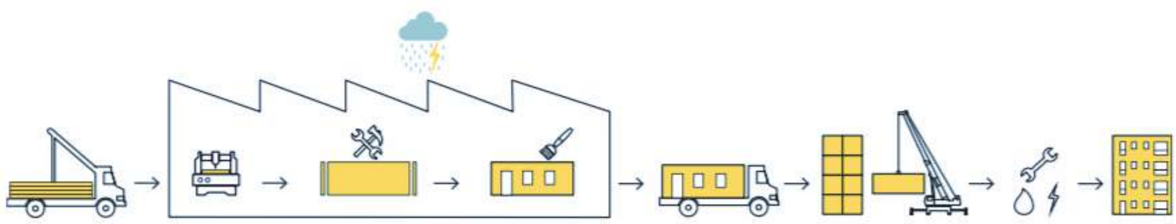

Figure 21: 3D modular prefabrication construction process (Waugh Thistleton Architects, 2019)

Post and beam systems

This system is widely used in traditional construction for commercial and industrial buildings and residential buildings because of its greater span ability than the first or second category. A greater span is useful when function freedom is desired.

Hybrid systems

Furthermore, there are combinations of different systems. For example, a post and beam structure with floor elements (2D) and volumetric bathrooms (3D). Also, combinations with different construction materials can be made, such as wood and steel or reinforced concrete and mass timber. This is often the case with higher buildings where a concrete core is used for stability, and wooden elements are used around the core for saving weight and increasing construction speed.

Decision factors

It is the art of choosing the right system for the right location, says Hans Wamelink in VNG Magazine (Muskee, 2021). "Modular construction is about striving for repeatable and standardized options. This can be achieved with both 2D and 3D prefabrication. The added value of prefabrication finds a place within industrialized environments rather than prefabrication on-site" (Wamelink, 2021). Figure 22 displays the decision factors for different example projects.

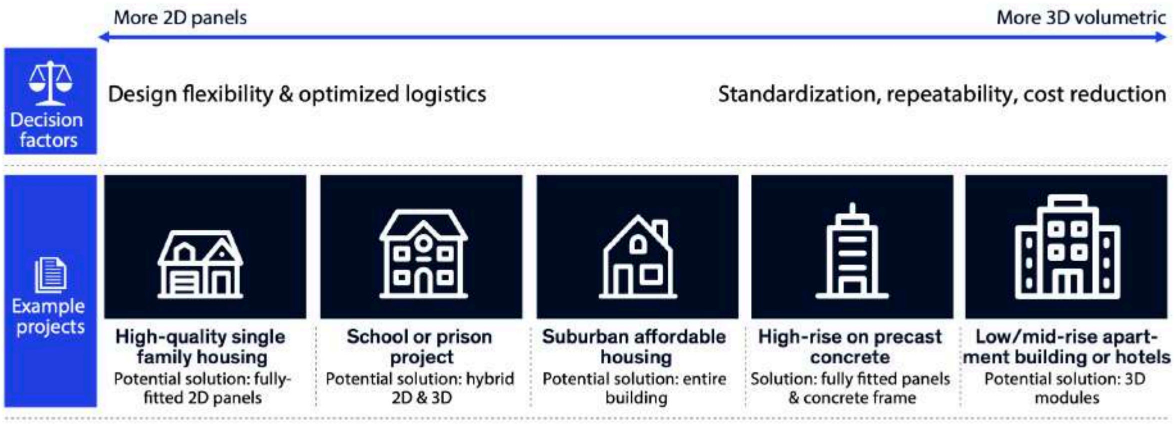

Figure 22: Decision factors for building method per typology (McKinsey & Company, 2019a)

The benefits of standardization, repeatability, and cost reduction are mainly found in volumetric prefabrication in low to mid-rise apartment buildings. According to Rob Verhaegh, senior structural engineer of Arup, the demand for this typology will increase in the coming years because it optimally uses the advantages of engineered wood (Circle Economy, 2020a).

3.4.2 Open building approach

A proposed solution for providing mass timber construction in a cost and risk competitive manner is a scalable building product, provided by standardization of building components. This can be achieved with an 'open building' design approach where the structure is separated from its infill. This increases the adaptability and reusability of a building and its components with an extended lifespan t (Brand, 1995; Habraken, 1985). In turn, the costs and risks of a project are reduced. From the users' perspective, an open building approach seeks to deliver flexibility by offering flexible floorplans, allowing adaptation apartments over time (Habraken, 2003). To do so, it is essential to design an adaptable building without load-bearing walls. This is possible with mass timber as one of its advantages is design for adaptability, as can be read in paragraph 3.3.2.

For example, the installations could be transported in a hollow floor as done in 'Patch 22' and 'Top-Up' (T. Frantzen, personal communication, 2020). A different approach is to transport HVAC in suspended ceilings in the main transportation areas of the building, as proposed in 'Elzenhagen Blok 3' (T. Leemhuis, personal communication, 2021). Furthermore, from a technical perspective, open buildings allow maintenance or replacement of short-life span components, such as kitchens or bathrooms, with minimal user interference (Habraken, 2003). These aims supplement each other and increase the value of an open building design for housing associations. Examples of an open building approach are Casco-Lofts Houthaven and MaMa One by Marc Koehler Architects, Stories by Olaf Gisper Architects, and Fenix 1 by Mei Architects and Planners.

"Right now, we would like to have small apartments in urban areas. Twenty years ago, that need was different. Back then, we mainly built single-family homes in Vinex areas. Our needs will probably change again in twenty years from now due to an aging society and a population decline. We then suddenly desire senior courtyards (seniorenhofjes). Alternatively, are they out of fashion, and have we come up with something new again?" - (Geus, 2021)

3.4.3 Advantages

Most of the advantages of modular construction are cost and time savings and increased productivity and quality. This paragraph briefly explains the advantages.

Time savings

Modular construction proposes a construction time reduction of 40% (Ferdous et al., 2019). This is especially useful for projects which require a quick turnaround. This feature could be valued by housing associations whenever they demolish a building and construct a new one. However, whenever there is a project with increased complexity, the time-saving feature diminishes due to the increased pre-construction activities (Ramaji & Memari, 2016)

Costs effective

A 10 – 25% construction cost decrease could be established due to modular construction (Construction Industry Institute, 2011). This is mainly achieved due to reduced transportation costs and decreased on-site labor (Subramanya et al., 2020). A standardized design procedure requires less time than a traditional design process which also contributes the cost savings (Cartwright, 2011)

Safety

According to Ahn et al. (2016), modular construction decreases the number of construction-related health and safety problems, which can be as high as 80%, as American research showed. (Peñaloza et al., 2017).

Productivity

Prefabricated modular construction can be less expensive and more effectively produced than traditional construction (Ambler, 2013). This is the result of construction in a weather-controlled environment which improves the handling of materials. Besides, skilled laborers repeatedly perform the same procedures and processes (Bendi et al., 2020; Jiang et al., 2018; Kermanshachi et al., 2018). This lowers the failure costs and increases productivity (Bendi et al., 2020)

Mass customization

Historically, there has been a tradeoff between high quality or low costs and efficiency or customization. In the past, the decision has always been seen about mass-manufactured, low-cost products (the assembly line) on the one hand and premium-priced, personalized, highly differentiated offerings on the other hand.

However, mass customization is a proposed approach to give companies the ability to produce customized, affordable, high-quality goods and services, but with the shorter cycle times and lower costs historically associated with mass production and standardization. (Hart, 1995). The capabilities of mass customization are further supported by digitization and robotization. This allows modular mass timber construction to be mass-produced while fulfilling specific client demands.

Environmentally friendly

As a result of on-site labor reduction, the corresponding greenhouse gases, noise, and dust decreases (Amiri et al., 2013). In addition, modular construction creates less waste compared to traditional construction (Kawecki, 2010).

3.4.4 Barriers

Modular construction proposes a solution for the uptake of mass timber construction in the Netherlands but also faces downsides on the planning, transportation, perception, investment costs, and project coordination. These topics are discussed in this paragraph.

Planning

The design phase and planning of modular construction take approximately 37% longer than traditional project planning (O'Connor et al., 2016). This results from re-complex planning consisting of offsite and on-site planning, rather than only on-site planning (Wang et al., 2014). But also the prefabrication process takes longer because more components are designed and prefabricated (Li et al., 2014)

Alfred Vos, CEO of VolkerWessels, says that the capacity for upscaling construction with off-site prefabrication is already there. The problem lies with the municipalities and the trajectory for granting the construction permission. Their capacity is limited, takes longer, and is too complicated (Verbraeken, 2021).

"We try to imitate the car industry, but while a car manufacturer only needs to request approval from the RDW for each model, we have to do that for every project and with every municipality. That should not be the case for industrialized construction." (Dijkstra, 2021)

Transportation

special transportation could be required in 3D modular prefabrication, which adds complexity and might result in delays and extra cost (Wei et al., 2014). However, this is not a problem for smaller 3D prefabricated elements, such as bathrooms or flat (2D) elements. Besides, the lower weight of mass timber compared to concrete allows more elements per truck, making transportation more efficient.

Negative Perception

There is a negative perception about 3D modular construction among the public and experts (Rahman, 2014). Also, housing associations have this perception. 3D modular construction can save costs, but housing associations rarely commission this type of prefabricated dwellings because they strictly adhere to their program of requirements and are not flexible in making concessions. (Plasschaert, 2019). This negative perception can change by showcasing the advantages of modular construction and showcasing reference projects (Wu et al., 2019). As a result, wide-scale adaptation can take place.

Investment costs

According to Sendanayake et al. (2019) there are still uncertainties about the specific positive effect of modularization since financial evidence is often not publicly accessible. Therefore, studies need to be conducted about the costs and effectiveness of investments in industrialization and modular construction (Kamali & Hewage, 2017).

Collaboration

Modular construction requires experienced suppliers, contractors, designers, and engineers to collaborate (Enshassi et al., 2019). A lack of knowledge for one of the stakeholders could be a significant barrier to implementing a modular construction process (Ferdous et al., 2019). Structural collaboration amongst actors is required to implement core circular economy strategies systemically. Collaboration can overcome barriers such as a lack of capital, knowledge, and tools for efficient operations. By merging resources, a new market can be entered (de Mattos & de Albuquerque 2018; Mishra et al. 2019; Ngan et al. 2019)

Coordination

The coordination between the stakeholders and the transition from one construction phase to another is crucial for finishing the project on schedule within budget (Kamalirad & Kermanshachi, 2018; Kamalirad et al., 2017; Nipa et al., 2019; Rad et al., 2018; Safapour, Kermanshachi, & Kamalirad, 2019; Safapour, Kermanshachi, Kamalirad, et al., 2019). Since the coordination in modular construction is different from traditional project coordination, this is likely to result in a challenge (Bendi et al., 2020; Hu et al., 2019). However, The complexity and scale of modular construction vary per building system (McKinsey & Company, 2019a).

3.4.5 Proposed solution and corresponding barriers

As a result of its low weight, high customizability, and dry-connection methods, mass timber is very suitable for off-site manufacturing, and therefore, modular off-site construction. This has several advantages over traditional on-site construction, such as faster construction times, higher productivity, better quality, and lower unit costs. However, modular construction also faces limitations such as increased planning activity, high investment costs, and an increased need for expert knowledge. Nevertheless, research by Subramanya et al. (2020) concludes that the advantages of modular construction outnumber its limitations. This can be seen in Table 4.

Table 4: Modular off-site versus traditional on-site construction

	MODULAR	TRADITIONAL
TIME	40% quicker construction	37% longer planning
COSTS	10 -25% savings	-
SAFETY	80% safer	-
PRODUCTIVITY	automatization and controlled environment	unproductive
ENVIRONMENT	GHG, noise, and dust decrease	negative impact
TRANSPORTATION	varies per building system	inefficient
PERCEPTION	negative	neutral
INVESTMENT COSTS	high initial investment	little initial investment
COLLABORATION	structural collaboration required	less need for collaboration
COORDINATION	need for knowledge	relatively easy

3.5 Conclusion

This literature review has answered the first four sub-questions. Chapter 3.1 shows that mass timber construction can contribute to the transition towards a circular economy by replacing reinforced concrete as a bearing structure. However, to fully fit the three core strategies of the circular economy framework, mass timber should be constructed according to modular principles.

Chapter 3.2 showed that the annual demand for 25.000 social homes is mainly concentrated in urban areas. Rising building costs lay pressure on social housing associations in the short-term while a low cash flow and the rising loan-to-value rates form a barrier in the longer term. For acquiring long-term gains, housing associations obtain strategic alliances with contractors and maintenance companies. However, traditional best-price procurement is still the most common. Alternative construction processes and valuation methods are facing the barrier of the social housing associations' institutional behavior. This behavior hinders the uptake of mass timber construction, as seen in Chapter 3.3.

This chapter further explores barriers but also shows the advantages of mass timber construction. In general, it was found that the advantages of carbon sequestration, health benefits, suitability for prefabrication, design for disassembly, and design for adaptability are not sufficiently valued to overwin the main barrier of a 10 to 20 percent building cost increase. Other barriers, such as insufficient knowledge, a non-level playing field, and an unknown residual value, also hinder the uptake of mass timber construction.

Modular construction also faces many barriers, as shown in chapter 3.4. However, the advantages outweigh the barriers. It could be seen as an enabler for mass timber construction since it allows building cost and construction time reduction while also increasing safety, productivity and allowing mass customization. However, this is only possible if negative perceptions are taken away and collaboration and coordination increase while the upfront planning and design phase becomes more efficient.

4 BARRIERS

This chapter presents the main barriers to the adoption of mass timber construction for housing associations by answering sub-question 5: "*What are the barriers for the adoption of mass timber construction for social housing associations?*"

Based on the literature review and the consultation with experts in chapter 3 it is expected that SHA's mainly experience barriers regarding mass timber construction due to their institutional, risk-averse behavior. The expected result is that not every housing association is ready for the adoption of mass timber construction. Besides, negative preconceptions are expected to result from a lack of knowledge about modular construction and mass timber products. This is likely to result in unfavorable market conditions for mass timber entering the market, resulting in another barrier to adopting mass timber construction.

The data from eight semi-structured interviews suggest that the SHA's had different experience levels regarding mass timber and modular construction. As a result, barriers occurred in different phases in the design and construction process, as shown in Figure 23. An overview of the different barriers within these categories is provided in Figure 24. This chapter elaborates on these barriers individually and provides the foundation for developing strategies for overcoming these barriers in chapter 5.

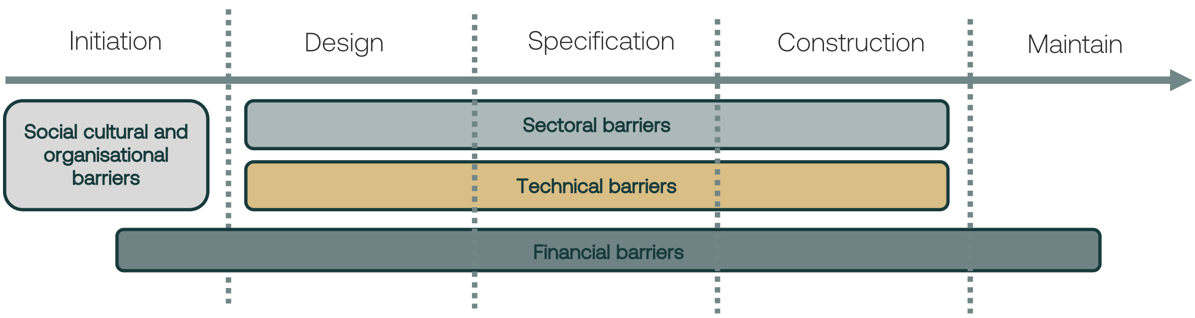

Figure 23: Barrier categories placed in the construction process

Figure 24: The barriers in the construction process as adapted from the semi-structured interview

		Mentioned in interview:							
		A	B	C	D	E	F	G	H
	Social, cultural and organizational barriers								
SHA	Unclarity about circular decisions	X			X				
SHA	Risk averse behavior	X			X			X	
SHA	Having difficulties to change				X				X
	Sectoral barriers								
SEC	A sectoral knowledge deficiency	X	X		X	X			X
SHA	Having strategic alliances with traditional industry	X	X	X	X			X	
SHA	Preferring a project-based approach					X		X	
	Technical barriers								
SHA	Faillure to recognize the potential of mass customization	X	X	X	X				X
SUP	Using dfferent program of requirements							X	
	Financial Barriers								
SUP	The absence of a proof of concept	X			X	X	X	X	X
SHA	Unknown effect on maintenance	X	X			X			

4.1 Social, cultural, and organizational barriers

The literature review in chapter 3.1 shows that housing associations have become bigger due to mergers and acquisitions. In addition, the absence of competition among housing associations results in a reduced focus on product innovation (Koolma, 2008). The analysis of data obtained through a series of semi-structured interviews underlines these literature findings. It shows that housing associations experience unclarity about circular decisions, show risk-averse behavior, and find it difficult to change. These social, cultural, and organizational barriers are clarified in this paragraph.

4.1.1 SHA – Unclarity about circular decisions

As a result of a reduced focus on product innovation, "*It is not yet entirely clear what the right choices regarding new sustainable solutions are, such as mass timber construction*" (interview D). This can be a reason for not commissioning mass timber construction. This is underlined by interview A: *"Architects are increasingly designing mass timber buildings, but the question is, who will commission them to build in wood?".* Thus, the unclarity of circular decisions can obstruct the uptake of mass timber for housing associations.

4.1.2 SHA – Risk-averse behavior

The long-term financial exploitation is under pressure due to the change of regulations in the Housing Act. As a result, associations are naturally inclined to show risk-averse behavior in purchasing products (Interview D). Regarding mass timber construction, Interviewees respond that they fear or perceive a higher risk compared to traditional construction methods (Interview A). Traditional building methods are perceived as less risky. Besides, *"our corporation has made big steps regarding sustainability, but not yet as far as with circularity. This makes it new and, therefore, riskier"* (Interview G).

4.1.3 SHA – Having difficulties to change

Remarkably, the housing associations who already completed a social housing mass timber project were small organizations compared to those still discovering the product. One of the directors of the associations explained that especially the board of housing associations encounter difficulties in taking the first step in a transition (Interview H). This can be related directly to institutional behavior. This is supported by (Interview D) by saying that it is easier to do than change what you are used to. In other words, associations are facing the difficulties of a transition.

4.2 Sectorial barriers

4.2.1 SEC – A sectoral knowledge deficiency

A knowledge deficiency regarding mass timber construction is found in the whole value chain in a range from architects, advisors, construction companies, and housing associations.

[...] Architects have been designing very economically over the past years but are not aware how to do this in mass timber [...] Everyone starts designing with concrete and thinks traditionally" (Interview A), and "Nobody knows what the best building typology is to be used in our project" (Interview E). *"There are parties who say that they are pioneering with an architect, but there too, the knowledge is lacking. 90% of the know-how is there, but the last ten percent has to be found elsewhere"* (Interview H)

Advisors can be used for the remaining 10% of knowledge. However, one interviewee, currently designing a mass timber building, indicated that they are reaching the limits of what advisors know. The lack of knowledge from advisors is also perceived by (Interview B) as can be seen in the following: *"Sometimes advisors have insufficient knowledge about mass timber. As result structures are covered in gypsum 'just to be sure' while it would not be necessary according to the building code".* In addition, the available knowledge is not always effectively used in new projects (Interview D). The reason can be found in the business model of advisors, who are selling their knowledge repeatedly. This is underlined with the following: *"We try to gather knowledge, but advisors only gradually giving it because they want to be contracted before they provide further information"* (Interview E).

A construction company of modular mass timber buildings with over 50 years of experience with timber construction in the Netherlands needed to contact their wood supplier for specific knowledge regarding fire safety and acoustics (interview H). This represents that even experienced companies experience a knowledge deficiency.

For housing associations, the lack of knowledge occurs on the impact of the tenants living quality. This needs to be further researched as mass timber construction is only possible if tenants can continue to use the building as they are used to (Interview B). This is underlined with the following quote: *"Associations should either prevent the users from misusing the material or prevent the material from being used incorrectly"* (Interview H). Mass timber buildings must be used differently, but it is difficult to change the behavior of residents, and the specific effects of new material are unknown (Interview H)

4.2.2 SHA – Having strategic alliances with traditional industry

A competent and experienced mass timber architect is sought first in a traditional design process (Interview A, Interview D). Based on this preliminary design, a construction company is tendered. Often, only partners from strategic alliances can enter those tenders (Interview A, Interview G). These suppliers are primarily inexperienced with mass timber, and they incorporate a risk premium as a result (J. Hollander, personal communication, 2020; R. Mol, personal communication, 2020)

These procurement methods expose the strong ties housing associations are having with the traditional industry. For example, one housing association conducted a two-stage tender for an architect based on a preliminary design. After that, for a contractor based on a final design. A precondition for taking part in the tender was to be part of their long list. A track record had to be shown for entering the long list, which excluded new market entrants. This resulted in only having traditional contractors on the list. (Interview G). Consequently, a traditional design process fails to function in mass timber (Interview B, Interview C).

4.2.3 SHA – Preferring a project-based approach

Cost-based procurement is commonly used among associations because it provides insight into the costs of a mass timber building. *"We did not have any insight in the building costs of a mass timber building, so we chose a cost-based procurement method which allowed us to see what the market is capable of"* (Interview G). A different interviewee gives another example: *"We make the final design with a design team and then procure for the best price. The reason for this is that our experience taught us that we do not get the best price with a building team"* (Interview E)

In both cases, the lack of insight into building costs resulted in a cost-based procurement based on a preliminary design. This (unique) project-based approach forms a barrier for modular construction, resulting in a limited degree of repeatability and standardization.

4.3 Technical barriers

4.3.1 SHA – Failure to recognize the potential of mass customization

There is a perception among housing associations that modular construction results in uniformity and mass housing (Interview A, Interview C, Interview D). This is underlined by the following: *"There are negative preconceptions about where modular construction leads to"* (Interview C) and *"Modular construction is limited to outer-city locations since the municipality is afraid for mass housing in inner-city developments"* (Interview B). They instead choose a traditional 'unique project approach' in which they are sure how to fulfill the requirements of the aesthetics committee as seen in the following: *"there are no prefabricated homes for a 6-to-7-layer high-rise building. Thus, a traditional process needs to be used for our building"* (Interview B).

A different interviewee states that the customization of the facades in a modular construction process disables the economies of scale concept: *"A prefabricated home appears to be a standardized product, but a facade is devised for each location separately. In a technical sense, it is a modular home, but the construction process remains traditional. As a result, there is no advantage to be gained from a modular process and the corresponding economies of scale"* (Interview H). As a result of this perception, modular construction does not yield the desired cost reduction or quality improvement benefits.

According to the interviewees, mass housing is causing problems with the aesthetics committee and the urban planning department who despise uniformity (Interview A, Interview B). It shows that associations are failing to recognize the potential of mass customization in modular construction. The current modular construction companies have been unable to take away this negative preconception regarding uniformity. This results in a barrier for modular mass timber construction.

4.3.2 SUP – Using different programs of requirements

Another barrier for modular construction is that 'programs of requirements' differ per municipality. *"The modular homes of Van Wijnen do not fit, because they based their design on the 'Amsterdamse Bouwbrief' and since we are not operating in Amsterdam, it does not fit our program of requirements"* (Interview G). Although their floorplans are primarily the same, they differ on minor details. Different programs of requirements make it difficult for suppliers to design a modular home that is universally suitable for all housing associations.

4.4 Financial barriers

4.4.1 SUP – The absence of a proof of concept

Most importantly, mass timber construction needs to be cost-competitive with traditional alternatives (Interview A). The few empirical figures for mass timber construction show a 10 to 15% price increase (Interview E, Interview H, Interview G). After subsequently turning out to be more expensive, the trust in the product evaporates: *"Hey, that is not the desired product, because it was more expensive"* (Interview G).

Despite the costs, many multi-story mass timber construction companies entered the market last year. However, interviewees emphasize that the supply is scarce. *"There are many single-family prefabricated homes available, but we are looking for apartments or multi-story buildings of which the supply is scarce"* (Interview F). The abundance of companies on the one hand and the perception of a scarce supply on the other indicates that the supply does not match housing associations' demands. This is supported in another interview: *"There are not enough suppliers, and there is a need for market competition"* (Interview H). The need for market competition emerges from the desire to lower the price of the product. This shows that the barrier is a lack of affordability, especially for associations in the Randstad due to the financial position they are currently in (Interview A).

As a result, there is no proof of concept. There are multiple examples of mass timber projects for housing associations in the Netherlands. However, these projects are not acknowledged as proof of concept by SHA's. The reason for this is the lack of affordability. According to Interview A and Interview D, there needs to be a proof of concept before mass timber can be widely adopted in the social housing sector. This is underlined with: *"Mass Timber does not have a proof of concept in the Netherlands. The transition is still in its early phase"* (Interview F). According to Interview G, an 10% increase in buildings costs prevents SHA's from investing since they must justify whether they instead invest 10% in mass timber or get 10% more dwellings for the same investment.

4.4.2 SHA - Unknown effect on maintenance

Cooperations are experienced in maintaining their traditional buildings stock, but the effects of mass timber on the maintenance are unknown and therefore perceived as riskier. *"The durability of a building is uncertain, as well as maintenance of components within"* (Interview E). As a result, it is proposed that mass timber construction must be tested in pilots before it can be carried out at large (Interview B).

The impact of maintenance plays a substantial role in the exploitation of buildings, especially for associations, who maintain the buildings for an extensive period. Thinking about maintenance, therefore, is essential. Preferably in the design phase, where design decisions can reduce the cost for maintenance in the future. However, associations show a different behavior, as expressed in the following quote: *"During the design phase, the idea prevails that a building and its components will be built for eternity, however during its lifespan, a lot of these components need to be maintained and replaced"* (Interview A). A proposed decision-making tool is the total cost of ownership (TCO) approach. However, housing associations do not always see the potential of such an approach because *"People find it difficult to appreciate the value of something in the future right now"* (Interview A). Additionally, associations foresee different problems in the adaption of such approach: *"We have an existing infrastructure for our maintenance which is not set up for a TCO approach, so we do not know how to implement it"* (Interview E). and *"We are not yet calculating with TCO, because it has not yet proven itself"* (Interview E).

4.5 Conclusion

This chapter presented ten barriers for the construction of mass timber social housing divided over four categories. The first category includes the unclarity of circular decisions among housing associations. This is the result of the institutional risk-averse behavior of housing associations. Because of their lack of product innovation, they prefer traditional construction methods over new ones. Added by having difficulties in changing, this forms a barrier for commissioning mass timber construction.

The second category is sectorial barriers. This category contains the barrier of knowledge deficiency, which is found in the whole value chain from architects to advisors, construction companies, and social housing associations. This results in an increased risk that does not suit the risk-averse behavior of social housing associations and hinders the commissioning of a mass timber building. If a mass timber building is commissioned, a cost-based procurement among strategic alliances is used to reduce these risks, which counter-intuitively leads to higher building costs.

The third category is technical barriers. The first is that social housing associations fail to recognize the potential of mass customization in modular construction. Current modular mass timber construction companies have been unable to take away the negative preconception regarding uniformity. In modular construction, social housing associations found that suppliers offer a prefabricated building that is not suitable for multiple programs of requirements. These different programs of requirements make it challenging to design a modular home that is universally suitable for all housing associations.

The final and most important category consists of financial barriers. Housing associations experience a lack of proof of concept since current examples of mass timber construction are not price competitive with traditional construction. A ten percent costs difference prevents social housing associations from investing. Innovative decision-making tools as a total cost of ownership approach are rejected because mass timber has an unknown effect on the maintenance infrastructure of the housing associations.

While the uptake of mass timber construction is necessary for reducing carbon emissions and modular construction can help achieve affordability, there are still many barriers to be overwon. The next chapter presents strategies for overcoming these barriers to enable mass timber social housing for housing associations.

5 STRATEGIES

This chapter presents possible strategies for overcoming the barriers presented in the previous chapter by sub-question six: "Which strategies could enable the adoption of mass timber construction for social housing associations?".

In answering this question, the aimed result is a range of strategies for different stakeholders in the construction process, such as suppliers, governmental parties, housing associations, and knowledge institutions, such as universities. The barriers and strategies allow answering the central question in the conclusion chapter.

Based on the barriers and the literature review, it is expected that the strategies could enable change of social, cultural, and organizational barriers of social housing associations. However, it needs to be kept in mind that behavior is also complicated to change. With the invitation of a construction company who already delivered a modular mass timber building for a housing association, it is expected to find a strategy for overcoming the barrier regardless of the difficulties of behavioral change.

The ideation of multiple strategies is done through a brainstorming session with an expert panel. The outcome is translated into a range of strategies, some conceptual, while others are based on a tangible example from practice. All strategies aim for a contribution in solving one or more barriers, as the sub-question indicates. The expert panel analysis from which these strategies are derived can be found as APPENDIX E – Expert Panel results. Further explanations of the different strategies can be found in the following paragraphs. The four strategies for overcoming barriers are as follows and can be found in the next paragraphs:

1. Improving knowledge and changing conditions
2. Allowing a market entry
3. Developing a standardized and flexible building system
4. Enabling circular business models

5.1 Strategy 1: Improving knowledge and changing conditions

Some SHA's indicate there is unclarity about circular decisions within their organization. Combined with organizational characteristics of risk-averse behavior and cultural and social characteristics of having difficulties in changing, this results in a barrier to adopting mass timber construction.

Therefore, the first strategy is to change these market conditions by improving short-term and long-term knowledge. This strategy contains four actions and applies to multiple stakeholders, as displayed in the table below.

Table 5: The first strategy with its corresponding actions and the leading actor

	Supplier	Housing association	Sector	Government
Strategy 1: Improving knowledge				
- Showcasing examples				
- Underscoring advantages				
- Change regulations				
- Increase mass timber education				

5.1.1 SUP - Showcasing examples

Associations are naturally inclined to show risk-averse behavior. Besides, they fear or perceive a higher risk compared to traditional construction methods. The expert panel shares the opinion that this risk perception is unjustified. According to P. van der Lugt, this risk perception can be reduced by showcasing existing examples. This is already done by Finch Buildings and Sustainer Homes in webinars and news articles. Also, housing associations are showcasing mass timber projects for scoring publicity. However, it is not in their nature to do so since they are not commercially driven. Therefore, it is more logical to expect suppliers to take the lead in showcasing examples.

5.1.2 SUP - Underscoring advantages

Underscoring the advantages of mass timber construction, such as the suitability for industrial and modular construction, carbon reduction, and health benefits can remove social, cultural, and organizational barriers for housing associations. J. Noorda and P. van der Lugt emphasize this action and provide multiple practical examples where mass timber construction advantages are underscored, such as the Tomorrows Timber book and a growing number of related webinars.

5.1.3 GOV – Change regulations

Mass timber construction is competing traditional construction materials in a non-level playing field. This results from regulations that exclude the temporary carbon sequestration of mass timber in a buildings' carbon footprint.

To create a level playing field, the government should change its regulations regarding biogenic carbon storage in the NMD (Nationale Milieu Database). This stimulates the use of biobased materials, such as mass timber, and is likely to increase the adoption of mass timber construction. The next step would be to introduce a carbon tax for construction materials. As a result, traditional construction materials will become more expensive and less attractive, while mass timber construction becomes relatively cheaper and less risky.

5.1.4 GOV – Increase mass timber education

There is a significant knowledge gap for mass timber construction in the Netherlands, says P. van der Lugt in the expert panel. Increasing the knowledge reduces the perception of the risks, as underlined in (Interview D, Interview C). This urges universities, higher education, and online education programs such as the MOOC (Massive Open Online Course) to offer a biobased construction course.

Market parties should cooperate with these institutions by providing practical examples and giving guest lectures by leading experts from within the field. All stakeholders in the construction value chain should be gaining this knowledge. This should be seen as an investment they have to make to keep up in the future, says T. Leemhuis.

This knowledge must end up at a suitable desk within housing associations. It is therefore essential to also involve conservative departments, such as finance and maintenance, in these types of examples to dispel negative preconceptions (P. van der Lugt). An example is given by the project Elzenhagen Blok 3, where all involved stakeholders in a building team committed to doing case study research into the possibilities and limitations of changing the traditional project into a mass timber alternative.

5.2 Strategy 2: Allowing a market entry

A housing associations' cost-based decision-making process favors cheaper traditional construction methods over mass timber construction. This forms a barrier in the commissioning of mass timber construction. For overcoming this barrier, the goal of the second strategy is to allow a market entry of affordable Mass timber buildings. This strategy contains four actions regarding the costs, decision-making process, the target group, and a pilot location for multiple stakeholders. This can be seen in Table 6.

Table 6: The second strategy with its corresponding actions and the leading actor

	Supplier	Housing association	Sector	Government
Strategy 2: Allowing a market entry				
- Target early adopters				
- Providing a pilot location				
- Lower the costs				
- Review the decision-making process				

5.2.1 SUP – Target early adopters

A precondition for a proof of concept is its price competitiveness with traditional construction. There is consensus among housing associations that a proof of concept improves the convenience of mass timber construction. However, a price-competitive proof of concept is currently still lacking.

For constructing a proof of concept, it is best to target housing associations that are open to innovation and see a mass timber project as an option for doing so. This innovation is necessary to learn from (T. Leemhuis). Therefore, the proposed target group for a market entry can be best classified as early adaptors according to the definition of Rogers (1962).

5.2.2 GOV – Providing a pilot location

P. van der Lugt foresees an action for the municipality in providing a pilot location for constructing a proof of concept from which lessons can be drawn. Negative preconceptions can be taken away by showcasing these pilot projects and providing insight into the lessons learned. This also lessens the risk perception, which T. Leemhuis refers to in the case study on project Elzenhagen Blok 3 in Amsterdam.

5.2.3 SUP - Lower the costs

Another action could be to use the industrialization of modular construction to lower construction costs. There is consensus among the expert panel that standardization and industrialization can decrease per unit with economies of scale. This needs to be supplemented with a professional design and construction team since industrialization uses a more complex upfront engineering process. It is crucial to behold the flexibility of custom facades, as seen in paragraph 5.3. In addition, obtaining the advantages of industrialization while allowing custom facades requires high capital investments in a factory, which could only be justified with a project pipeline that rises above the break-even point.

5.2.4 SHA – Review the decision-making process

While suppliers could lower the costs, social housing associations could review their decision-making process to value total expenditure to allow market entry. Modular mass timber construction is proposed to compete on total expenditure costs with traditional construction due to having lower additional costs. This includes lower failure costs, lower construction site costs, and - at sufficient scale - a lower share of labor costs (R. Mol & J. Noorda). In addition, homes are available earlier, which generates a quicker turnover (R. Mol).

5.3 Strategy 3: Create a standardized and flexible building system

The third strategy is to create a building system based on standardization of building components for beholding scalability and flexibility for customized facades. This should allow fitting standard floorplans while also fulfilling the requirements of the aesthetics committee. One of the actions suppliers can undertake is separating structure and infill in the design of mass timber projects. Another is to establish an infill industry. This can only be achieved when social housing associations choose to go from project to product thinking. These actions are displayed in Table 7.

Table 7: The third strategy with its corresponding actions and the leading actor

	Supplier	Housing association	Sector	Government
Strategy 3: Create standardization and flexibility				
- From project to product thinking				
- Separate structure and infill				
- Establish an infill industry				

5.3.1 SHA – From project to product thinking

By articulating the correct design parameters for standardization and mass customization, architects and designers can work on finding design solutions collaboratively (McKinsey & Company, 2019b). To do so, the traditional design process must change towards product thinking.

Product thinking is enabled by digitization and building information modeling (BIM) in particular. For example, parametric design of the building configuration saves time in the design phase (NWA Architects). This suits the desire to have design freedom while working with standard floorplans without mass housing (Interview B, Interview F, R. Mol). For example, the company RC panels produce unique modular facades. The need for such is confirmed by Interview G: "We want standardization, but with a different facade. It should not look like uniformity, but it should be behind the front door."

5.3.2 SUP - Separate structure and infill

The expert panelists suggest that suppliers could develop a standardized and flexible building system by separating the structure from the infill. P. van der Lugt refers to the 6 Layers principle of Steward Brand and the prefabrication of the structure, infill, and façade, which is made possible in an open building approach (Habraken, 2003). This allows structure standardization while facades, intersections, and escape routes remain tailor-made (J. Noorda and R. Mol).

In this approach, a mix of 2-D and 3-D elements enables the scalability of mass timber construction. Multiple grid size options enable different typologies which suit most cooperation's standard floorplans. These typologies can be supplemented with specials to construct a unique building that could be required by land or zoning regulations. Examples can be seen in Figure 25 where most of these unique buildings consist of standard elements.

Figure 25: The composition of buildings and specials

5.3.3 SUP - Establish an infill industry

A separated structure and infill allow establishing an infill industry. This industry can prefabricate 2D elements and 3D modules based on digitization and robotization. These elements can be designed and constructed according to design for disassembly principles, which eases the process of maintenance and replacement in the future (T. Asselbergs, personal communication, 2021). This infill consists of wall partitions surrounded by services as kitchens, bathrooms, and installations. The demountability of the infill makes it attractive for housing associations to look at the concept of TCO and circular kitchens (Interview E). An example is provided by the company 'The new makers'

5.4 Strategy 4: Enhance collaboration

The last strategy is to enhance collaboration between suppliers and social housing associations to overcome the barriers to a TCO approach and circular business models. The corresponding actions are to establishing a future value of building components. This eases the total cost of ownership approach. The second action is to separate the liabilities between actors, allowing new circular business models to arise.

Table 8: The fourth strategy with its corresponding actions and the leading actor

	Supplier	Housing association	Sector	Government
Strategy 4: Enhance collaboration				
- Establish future value				
- Separating liabilities				

5.4.1 SEC – Establish future value

Housing associations are interested in looking into a Total Cost of Ownership approach (Interview C, Interview D, Interview F, Interview A). According to some, a TCO approach becomes interesting when there is evidence or insight into the future value of building components (Interview A, Interview H).

However, the future value of building components is unknown. They can be safeguarded by using standard dimensions. This enables future reusability and suits the value proposition of the open building approach with the standardization of elements. In addition, a collaboration between suppliers and housing associations can help provide end-of-life solutions for building components, for example, by giving materials a material passport. This also helps to establish future value.

5.4.2 SEC – Separating liabilities

By separating the façade from the structure and infill, the possibility arises to separate liabilities for building components. The expert panel proposes a shift wherein one company becomes responsible for the structure and a different one for the facades during its lifetime. This allows sale and buyback or as-a-service business models which suit the principles of the circular economy. For example, a sale-and buyback structure surrounded by services, such as façade-as-a-service and the circular kitchen example (T. Asselbergs, personal communication, 2021). However, since associations can access cheap government loans, it might be undesirable that private market parties own building components. Nonetheless, the separation of liabilities enables circular business models, enabling modular mass timber construction adoption.

5.5 Conclusion

This chapter presents four strategies for overcoming barriers and answers sub-question six: "Which strategies could enable the adoption of mass timber construction for social housing associations?". Each strategy is based on the output of the expert panel and insight from semi-structured interviews.

The first strategy is to change current market conditions by improving short and long-term knowledge. In the short term, the suppliers can take the lead in changing conditions by showcasing examples and underscoring modular mass timber construction advantages. In the long term, it is mainly the government and knowledge institutions that can lead by changing regulations and increasing mass timber education.

The second strategy should allow the enter the market with affordable modular mass timber construction. This is already possible in the current market when targeting early adopters. Municipalities can contribute to this by providing a pilot location for pilot projects. In the long term, construction costs could be lowered by using the industrialization of modular construction. Another way for enabling modular mass timber construction over traditional ones is by reviewing the social housing associations' decision-making process from cost-based to value-based, by looking at total expenditure rather than building costs.

The third strategy mainly focuses on suppliers creating a standardized building system based on standard floorplans with the flexibility for fitting custom facades for suiting the requirements of the aesthetics committee. This is achieved by separating the structure from the infill with the possibility of adding specials. This opens the opportunity for creating an infill industry based on digitization and robotization. As a result, suppliers and SHA's can shift from a traditional design process towards product thinking.

The fourth strategy is to enhance collaboration between suppliers and SHA's to overcome barriers for a TCO approach and allow circular business models. Suppliers can safeguard the future value of components by using materials with standard dimensions. This corresponds with the third strategy. By changing the responsibility of a product's maintenance, suppliers are incentivized to use durable and remountable materials. This enables a sale and buyback business model for the structure, which as-a-service business models for the infill can surround.

6 CONCLUSION

The previous chapters presented strategies to enable mass timber construction for social housing associations in the Netherlands. This chapter relates these strategies to the barriers of chapter four and presents an answer to this research's central question, *"What are the barriers for the construction of mass timber social housing, and what might be strategies for overcoming them?".*

The institutional nature of housing associations characterizes the first category of social, cultural, and organizational barriers. This has unclarity about circular decisions as a result. Their risk-averse behavior generally prefers traditional construction methods over innovative ones. The first strategy aims to change these current conditions through short- and long-term knowledge increases. Showcasing examples and underscoring advantages can reduce the risk perception and eases a market entry. For long-term knowledge increase, it is mainly the government and knowledge institutions that can lead by changing regulations and increasing mass timber education. This can take away two barriers. First, the barrier of a sectoral knowledge deficiency, and second the unknown effect of mass timber on maintenance.

Other sectorial barriers are the result of housing associations' strategic alliances and cost-based procurement. Interviewees indicate that a proof of concept is absent for as long as modular mass timber construction is more expensive than traditional construction. This financial barrier could be overwon when housing associations review their decision-making process by focusing on total expenditure rather than construction costs. Also, suppliers could lower the costs with industrialization and modular construction. However, these strategies are long-term. For immediate results, suppliers could target early adopters, and the municipalities could provide pilot locations.

The technical barriers are the failure to recognize the potential of mass customization and having different programs of requirements. Necessary changes to the façade because of municipal guidelines lead to a traditional 'design phase,' which takes away the advantages of modular construction. Suppliers should consider developing a scalable building system that allows design flexibility for multiple standard floorplans and facades to overcome this barrier. This is achieved by separating the structure from the infill with the possibility of adding specials. As a result, suppliers and SHA's can shift from a traditional design process towards product thinking. This requires enhanced collaboration between social housing associations, suppliers, and product designers.

The fourth strategy is to enhance this collaboration to overcome barriers for a TCO approach and allow circular business models. Using standard dimensions increases the future value of building components. By changing the responsibility of a product's maintenance, suppliers are incentivized to use durable and remountable materials. This takes away the barrier of unknown effect on maintenance and helps to enable circular business models.

7 DISCUSSION

This chapter discusses the validity of this research. Furthermore, the implications for scholars are pointed out for scientific understanding, where the practical implications mainly focus on placing this research in a real-life context.

7.1 Implications

7.1.1 Implications for academia

Insights from various disciplines within economics and the built environment are used. First, a circular framework has been presented. Subsequently, research was conducted into the context in which the circular economy should be deployed, namely the housing association sector. After that, the specific characteristics of the proposed circular product mass timber were examined. Finally, it was investigated how this product could help to emerge the construction sector from its existing dogma of underperformance and unproductivity

Framework

The future of the economy is a circular economy. In recent years, this topic has increasingly been mentioned as a possible solution to move away from our take-make-waste economy. Various circular principles and frameworks have been introduced, but there are difficulties in embracing the circular economy in practice. The proposed framework aims to make the concept of the circular economy more accessible and shows that modular mass timber construction suits the circular economy principles. This insight formed the starting point of this research.

Housing

The Dutch social housing sector is facing multiple challenges. A lot has been written about the housing shortage. Social housing associations have also been subject to research regarding the landlord levy, which severely impacted their financial position. Also, the obligation to make the current housing stock more energy efficient has been challenging. In addition, there is the social obligation to add 150.000 dwellings in the coming four years.

The next big challenge is to lower the carbon emissions in the construction sector. With the circular economy as a proposed solution, recent research showed the barriers to embracing its principles in their portfolio management. Until now, no research has been done about strategies for overcoming these problems. This includes an absence of research into the proposed modular mass timber construction solution for social housing associations.

Mass Timber

Mass timber construction is an often-mentioned solution for lowering the carbon impact and contributing to the governmental goals of establishing a circular economy. However, the recent attention for mass timber construction has not yet led to much scientific research into this material in the Dutch built environment. Literature from abroad finds that mass timber construction is price competitive with traditional construction, but these results are not necessarily transferable due to the Dutch context in which this research operates.

Modular construction

Modular construction aims to increase productivity in the construction sector. Recent developments in industrialization and mass customization enable an increase in modular construction in the coming years.

Already since 1961, a group of researchers has been researching increasing productivity. It started with the research of the Dutchman John Habraken, 'the carriers and the people; the end of mass housing' (1961), in which a separation of structure and infill is proposed. Steward Brand designed the well-known 6-layer concept based on this publication, which also emerges in this research.

These two concepts have not been very successful until now. However, the increased focus on a circular economy is putting this research in a new light. In addition, digitization enables mass customization, eliminating the disadvantages of modular construction, resulting in mass housing in its early days. However, this research shows that there are still negative preconceptions about modular construction.

Affordable modular mass timber housing

While most of the above subjects have been frequently investigated individually, a combination or connection of the subjects is still underexposed in the scientific literature. The combination of the topics which form the basis of this research is based on two hypotheses. The first is that housing associations experience barriers with mass timber construction. The second hypothesis is that mass timber construction can solve carbon reduction and the housing shortage. No literature has been found about these two hypotheses. Also, the combination of the topics circular economy, social housing, and modular mass timber construction has been found in the literature on a global or national level.

7.1.2 Implications for practice

This research aims to provide strategies that can function as enablers for overcoming barriers with modular mass timber construction in the Netherlands. To do so, first is to look at the barriers encountered by social housing associations to design enabling strategies for these barriers. A well-ordered list of these barriers is of interest to mostly all construction value chain actors engaged in constructing modular mass timber buildings. The insights help suppliers to better serve the social housing associations when offering their products. It might also be interesting for housing associations themselves. Insight into the current problems creates awareness, resulting in a more robust demand for modular mass timber construction. The following section discusses the implications for the practice of modular mass timber construction in the Netherlands. These practical matters are related to existing systems and the behavior of actors in those systems.

Knowledge

Concrete is a well-known building material, but that is not yet the case for mass timber. Market forces do not contribute to the dissemination of knowledge because the revenue model of stakeholders is based on this knowledge. This example can be seen with advisors, whose business model is to repeatedly sell the same knowledge to different parties. This phenomenon is also seen in contractors, who have high costs for developing a construction system and then face the challenge to recoup this. Preferably before anyone copies their system. Housing associations have the advantage that they only compete for a limited amount. Therefore, mutual knowledge sharing among housing associations is essential for increasing knowledge of mass timber construction.

Transitions

It became clear that housing associations try to integrate innovations, such as mass timber construction, into existing processes and systems. It is striking that completed projects result from relatively small-scale housing associations that work with new partners, while larger housing associations collaborate with traditional construction companies in strategic alliances and often perceive difficulties in taking the first step towards mass timber construction. It is difficult to change the behavior of these large housing associations and their systems and processes correspondingly, while mass timber construction best suits a new system and requires a different construction process. The advent of timber construction requires a transition. A transition is needed to a greater extent than previously thought. It turns out that technology, no matter how good it is, cannot simply flourish in an existing system. External factors can unexpectedly accelerate these transitions. As an example, there is the COVID-19 virus. Two years ago, the Municipality of Amsterdam could not make video calls, but since the lockdown, the entire organization has changed. The technology was already there; COVID-19 gave it a boost. The same applies to timber construction. The government can play a role by tightening up regulations or financially compensating housing associations when building mass timber.

Municipality

Since the municipality determines the land price and draws up municipal ambitions, she has all the means to scale up mass timber construction. The Municipal interest in limiting CO2 emissions and eliminating waste combined with the need for social housing result in a perfect demand for mass timber construction. A good example is the municipality of Amsterdam, which is currently acting on each of the above examples. Therefore, it is not logical that some barriers are experienced within the urban land department and the aesthetics committee, municipal departments. Perhaps these departments are also traditionally structured and are having difficulties in transitions as a result.

Regulations

The Japanese law says that it is mandatory to be able to separate the structure from the infill. As a result, Japan is one of the countries with the highest number of modular prefabricated homes. Looking into the Japanese regulation as a case study might benefit the government for achieving circular ambitions.

Residual land value

"Housing associations, investors (...) and private individuals no longer receive financing for a newly built home," says Hans Verbraeken (2020) in a recent news article in the FD. It speaks about the possibilities for reducing construction costs using industrialization, robots, and prefab elements. The tenor is that the construction costs have risen and that 10-20 percent lower construction costs will help enormously make housing affordable again. However, Rob de Geus states that this will not happen because the land is the factor that makes housing expensive. He believes lower building costs will only result in higher land prices (Geus, 2021). This is indeed the case with residual land calculation. It is therefore important to consider alternatives land calculations when striving for lower construction costs.

Capitalism

The circular economy does not thrive in an economic system based on financial returns. The current labor tax on materials motivates companies to increase materials' production rather than reuse materials. This is also disadvantageous to mass timber construction. An essential advantage of mass timber construction should be its design for disassembly, but when new materials are cheaper than a second-hand alternative, a lack of incentive for reusing the material occurs. From this perspective, it does not make sense to invest in more expensive modular products because the cheaper traditional alternatives offer a higher financial return.

Open Building approach

Multiple scholars have advocated the open building approach since 1961. The past has seen many opponents of this system. Nowadays, the open building approach seems to have gained momentum. Digitization and robotization allow mass customization. This improves the value proposition of an open building approach, further strengthened by the need for 'design for disassembly' for suiting the circular economy.

7.2 Limitations

This research is unable to encompass the entire construction value chain. Therefore, it mainly focuses on social housing associations and mass timber construction companies. Furthermore, this research has a limited view of the construction process since urban planning, land acquisition, and maintenance are out of scope. It is assumed that housing associations own land. Furthermore, it is beyond the scope of this study to understand the financials of housing associations and construction companies. In addition, the reader should bear in mind that this research is highly explorative. The research findings are based upon a limited number of interviews. Due to limited time, the findings are not thoroughly examined in practice and worked out in detail. For example, no research has been conducted on specifically entering the market as a construction company or how housing associations can embrace mass timber (or other innovations) if every project is individually based upon cost and risk.
Furthermore, multiple findings suggested that the barriers are more humanistic than technical of nature. However, this research is conducted from a technical management point of view. Anthropologists probably would have found different problems. This limits the research findings.

7.3 Validity

To evaluate the quality of this research strategy, a golden standard from Guba and Lincoln is used (1981; 1995). This standard contains the elements credibility, conformability, dependability, and transferability. Possible provisions are made to address the golden standard for trustworthiness, reflected hereafter (Shenton, 2004).

As a result of an internship at Lister Buildings, a mass timber construction company, the credibility is safeguarded by prolonged engagement. Furthermore, a colleague conducted a member check on the results, which also increased credibility. The relationship with this company could harm the confirmability of this research because of bias. However, reporting on the researchers' perspectives in the preface aimed to tackle this problem using reflectivity. In addition, it is important to consider the period in which this research is conducted. Since mass timber is currently widely discussed, current problems are not necessarily up to date in the future. The dependability is partly secured since there were multiple interviews with the TU Delft professors, which allowed them to challenge the research process and findings. Unfortunately, the transferability of this research is only moderately achieved because this research is based only on the perceived problems of eight Housing associations. These eight were deliberately chosen for their experience in mass timber construction and their focus on urban areas. Therefore, not all strategies are generalizable for the entire housing association sector but only on concept level for Dutch housing associations that are already intrinsically motivated for constructing mass timber buildings.

The results show that housing associations perceive barriers with the uptake of mass timber construction. This hypothesis formed the basis of this research and the assumption that strategies could provide a solution. Halfway through this thesis, Çetin et al. (2021) published a paper about the five critical barriers to the circular economy's more comprehensive implementation within Dutch housing associations. The research underpinned the actuality of this thesis' subject. In addition, the results of this thesis mainly correspond to the results of the study, which increases the validity.

8 RECOMMENDATIONS

8.1 Recommendations for further research

As far as known, this research is the first research into modular mass timber construction for Dutch social housing associations. Therefore, it is recommended to conduct further research on the outcomes of this research by looking into the individual barriers and strategies.

First, it is recommended to research the suitability of housing associations' current decision-making process for circular products. Since they show institutional behavior in the initiation and construction phase, the advice would be to gain in-depth knowledge about their organizational structure and culture first, study the relationship with municipalities and governments afterward and focus on their attitude and ability for innovation finally. Also, the suitability of their decision-making process for implementing circular products, such as mass timber, can be researched. Preferably, this research would be conducted as part of a social sciences study, rather than a technical study, since the solution is expected to be found in organizational behavior rather than in providing technical solutions

The second recommendation is to research the effects of changing from a complex and fragmented project-based construction approach towards a more standardized, consolidated, and integrated product-based approach. Since mass timber allows prefabrication and mass customization, it very well suits a product-based approach. This approach is especially suitable for processes where there is some degree of repetition. Their fit-out is usually the same for housing associations, and floorplans are mainly standardized, making it an interesting customer for a product-based approach. However, the implementation and organizational effects are largely unknown.

The last recommendation is to conduct design-based research into the barriers and possibilities of a circular business model for housing associations when applying a modular mass timber building system. The future value becomes known by guaranteeing the take-back of components and elements, which eased a TCO approach. This approach is found highly interesting by housing associations, and it fits the principles of the circular economy.

8.2 Recommendations for practice

The results of this research can be used in real-life scenarios by stakeholders in the construction value chain of modular mass timber. For overcoming the barriers that stakeholders face in practice, the actors can use a step-by-step approach to apply the strategies in their organizations

Social housing associations

1. Invite suppliers to convince your organization for choosing modular mass timber construction
2. Collaborate with the municipality for providing a pilot location
3. Collaborate and coordinate for a universal program of requirements.
4. Be flexible with your demands in the program of requirements
5. Value long-term benefits over short-term cost savings (TCO)
6. Look for innovative construction companies to enter your tender
7. Strive for a long-term relationship in the form of a strategic alliance, or partner
8. Open-up financial books to research possibilities of circular business models

Suppliers

1. Continue to improve knowledge in the value chain
2. Create a standardized and flexible building system
3. Use standard dimensions as much as possible
4. Target innovative social housing associations at first
5. Aim for larger social housing associations thereafter.
6. Try to separate the structure from the infill and allow an infill industry to take care of the infill.
7. Conduct strategic alliances in the value chain

Government

1. Create a level-playing field by including biogenic carbon capture in the NMD
2. Create a carbon tax for construction materials
3. Increase knowledge in modular mass timber construction through universities
4. Act as a strong leader in commissioning mass timber buildings

9 REFLECTION

This chapter reflects on this research approach, design, and methodology. Therefore, the relationship between research and design is reflected upon first. After that, an elaboration is made on the research method and approach. This is done in relation to the master program Management in the Built environment and the studio: Design and Construction Management. Third, a reflection on the existence of and the impact of ethical issues and dilemmas is given. This chapter ends with the scientific and practical relevance concerning the broader social, professional, and scientific framework

This research method consisted of desk and field research. Especially field research is more in line with qualitative research than quantitative research (Fellows & Liu, 2015). The unknown barriers at the start of this research, combined with the involvement of multiple stakeholders in the modular mass timber construction process, make the problem definition at the start of this research a complex problem (Alford & Head, 2017). According to Herrington et al. (2007) and Ritchie et al. (2013), a suitable research approach for designing a solution to a complex problem is design-based research. This research uses the double diamond design (Design Council, 2019) which provided a helpful research structure to deliver strategies by the definition of Mintzberg (1987). Furthermore, design-based research encourages enhancing theoretical and practical contributions of educational technology research (Wang & Hannafin, 2005).

The initial goal of this research was to develop a business model which enabled mass timber construction for housing associations. However, the barriers for mass timber construction were more profound than initially thought. This led to an increased focus on the barriers rather than the development of a solution. It was also found that developing a business model without (company) specific financial information is not feasible. For that reason, the goal of this research shifted towards developing strategies for overcoming barriers.

The strategies were developed with an expert panel. This expert panel was conducted to generate as much input for these strategies as possible. With hindsight, it can be said that this resulted in a one-way information flow where a lack of interaction occurred. The interaction is needed to generate insight into the argumentation behind the comments rather than the comments themselves. Furthermore, the developed strategies were not tested in the market. This affects the validity of this research and will be done differently in future research. Despite these possible improvements, it can be said that the double diamond design gave structure and guidance in this research. However, it was not the most effective and appropriate way of researching since it was less about designing things and gaining insight.

This graduation topic fits the master track 'Management in the Built Environment' because of its relationship with the different stakeholders in the built environment and supply, demand, and circularity. It, therefore, suits the 'Design and Construction Management' chair of the study.

The results of this research can be transferred to other market segments to a certain extend. The focus on homes and social housing associations disables a one-on-one transfer due to specific market characteristics. Although, general strategies such as changing the conditions by increasing knowledge allow a transfer to other markets or market segments. When transferrable results are sought, it is essential to respect the market characteristics this research is based on. The transferability to practice is strengthened by design-based research. According to the Design-Based Research collective, this method uses collaboration between practitioners and researchers and develops knowledge that can be used in practice (2003). According to Herrington et al. (2007), designing and delivering a potential solution to the problem definition should focus on the entire study. However, it is also essential to spend time researching the problem first. Albert Einstein underlines this with the following well-known quote: "spend 90% of the time thinking about the problem and 10% about finding the solution."

All information from the participants is treated with the greatest care, and no specific ethical issues were perceived during this research. In addition, the absence of conflicting interests made the transfer from the interviews to the barriers and strategies relatively straightforward. However, some of the information regarding the strategies for the supply side was acquired during an internship at the company 'Lister Buildings.' Partly, this information had to be treated confidentially due to the company's aim for competitive advantage. The competitive advantage among social housing associations was perceived to be less abundant since they serve the same goal of providing social housing. Besides, they operate in different urban areas. This enables them to collaborate rather than compete. As a result, no ethical dilemmas occurred.

The construction industry currently faces the social and practical challenge of adding 1 million homes while reducing its environmental carbon impact. The addition of homes provides a solution for a current problem. Carbon reduction becomes more relevant for future generations every day. Therefore, it is of utmost importance to shift the abiotic construction industry to a biobased alternative. Since this research aims to provide strategies to enable this shift, it can be classified as societal as professional, relevant research.

This research topic is perceived as a 'hot topic in the market. It is likely to assume that the Governmental interest in modular mass timber construction will grow in the coming years. An example can be seen in France already. Due to a growing focus on ESG's, it is presumable that institutional investors will increase their funds in sustainable and circular real estate. At the beginning of this research, the focus was to find the perceived problems regarding mass timber construction. However, the market caught up, and multiple webinars pinpointed the general barriers. It was found difficult not to get distracted by market developments since everything was found interesting. In the end, it was a good decision to focus on housing associations solely. This resulted in practical and theoretical insights, which provide a breeding ground for follow-up research.

"We cannot solve our problems with the same thinking we used when we created them."
Albert Einstein

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APPENDIX A – Definitions

Mass Timber	The overarching term for industrialized combined wood-products, such as Glulam, CLT and LVL which are *"Large engineered structural wood panels and beams made from multiple layers and/or elements of strength graded timber. Mass timber has the potential to substitute steel and concrete in structural applications, opening up new mass markets for timber"* - van der Lugt (2020)
Glulam	Glue Laminated beams are made with a press by inserting glued sawn and dried laminations together after the laminations are finger jointed into the right length (van der Lugt, 2020)
CLT	Cross-Laminated Timber, also known as X-Lam. It is made of sawn timber which is glued together in a layered structure with the boards placed perpendicular to the layer above and below (van der Lugt, 2020)
LVL	Laminated Veneer Lumber is made from veneer sheets glued together to create structural panels (van der Lugt, 2020).
Prefab	*"A process wherein elements or full-fledged homes are produced inside factory and assembled on site. Also called modular construction"* - (Circle Economy, 2020a)
Modular construction	*"the use of offsite construction (including a segregated area onsite) and includes all work that represents substantial offsite construction and assembly of components and areas of the finished project."* (Construction Industry Institute, 2011).
Mass customization	mass customization is a proposed approach to give companies the ability to produce customized, affordable, high-quality goods and services, but with the shorter cycle times and lower costs historically associated with mass production and standardization (Hart, 1995)
Parametric design	*"Lets you specify the key parameters of your project and make changes interactively, with the model updating automatically. It can be used for architectural showmanship […] more efficient designs, explore more options, and optimize buildings."*- ARUP (2020)
Integrated design process	*"Can be defined as an interdisciplinary design approach with the emphasis on collaboration. All the stakeholders involved in the project met during the design of the plans and specifications to develop optimum solutions for each discipline. This is a comprehensive process that concentrates as much on design, construction and operation as on the occupancy of the building."* - Arnaud Rogiez (2019)
Greenhouse Gas (GHG)	*"Gas that contributes to global warming through absorption of infrared radiation, expressed in CO2 equivalent (CO_2eq), for example, methane (CH_4), nitrous oxide (NO) and Ozone (O_3), and most notably carbon dioxide (CO_2)"* - van der Lugt (2020)
Embodied emissions	*"Are emissions that contribute to the greenhouse phenomenon […] this is estimated by multiplying material masses with the corresponding ECO2 coefficients (kgCO2/kg)"* - Syngros et al. (2017)
Urbanization	*"The gradual shift in residence of the human population from rural to urban areas"* - United Nations (2019b)

Urban areas	"An urban area is a conglomeration of one or more urban agglomerations and the surrounding rural areas, which are bound together by certain relationships. There are 22 urban areas in the Netherlands." - CBS (2007)
Embodied carbon emissions	*"Embodied carbon is the carbon footprint of a material. It considers how many greenhouse gases (GHGs) are released throughout the supply chain and is often measured from cradle to (factory) gate, or cradle to site (of use)"* - Circular Ecology
Milieu Prestatie Gebouw (MPG)	The Environmental Performance Buildings (MPG) is mandatory for every application for an environmental permit. The MPG indicates the environmental impact of the materials used in a building. This concerns new office buildings (larger than 100 m²) and new-build homes – translated from Rijksoverheid (2020a)
Life Cycle Assessment (LCA)	*"a cradle-to-grave or cradle-to-cradle analysis technique to assess environmental impacts associated with all the stages of a product's life, which is from raw material extraction through materials processing, manufacture, distribution, and use."* Muralikrishna and Manickam (2017)
Total Cost of Ownership (TCO)	*"Includes the purchase price of a particular asset, plus operating costs over the asset's lifespan. Looking at the total cost of ownership is a way of assessing the long-term value of a purchase to a company or individual"* Alexandra Twin (2020)
Sustainable development	*"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* - Brundtland (1987)

APPENDIX B – Analysis of perceived problems per association

			A	B	C	D	E	F	G	H	Sub-total	Total
CS	Mass Market	Not suitable for mass timber	1								1	1
	Niche Market	-										
	Segmented											
	Diversified											
	Multi-Sided platforms											
CH	1. Awareness											
	2. Evaluation											
	3. Purchase	Cost driven	1								1	5
		Project based building approach in mass timber leads to higher prices		1	1					1	3	
		Price becomes known too late in the process								1	1	
	4. Delivery											
	5. Aftersales	No guarantees	1				1				2	2
CR	Personal assistance											
	Dedicated personal assistance											
	Self-serivce											
	Automated services											
	communities											
	co-creation	Partnerships with traditional industry	1	1		1	1		1		5	7
		Used to maintenance of traditional buildings		1			1				2	
VP	Newness											
	Performance	Knowledge deficiency	1	1			1	1		1	5	7
		Mass timber influences living quality for users		1						1	2	
	Customization	Afraid for mass housing	1	1	1						3	11
		Not enough multi-layer concepts available		1				1		1	3	
		Problems in regard to the aesthetics committee		1	1					1	3	
		Concepts are not suitable for inner city developments		1		1					2	
	"Getting Things Done"											
	Design											
	Brand/Status	Prejudices lead to resistence	1		1	1					3	4
		Misconception where conceptual building leads to			1						1	
	Price	Higher investment costs	1			1	1				3	6
		Concepts are affordable, but traditional building in timber isn't		1							1	
		Is mainly looking for affordableness				1					1	
		Price will rise due to higher demand					1				1	
	Cost Reduction	Higher material prices aren't compensated by a shorter building time								1	1	1
	Risk Reduction	High risk is perceived	1		1	1			1		4	4
	Accessibility	Not affordable	1								1	1
	Convenience/usability	No proof of concept	1	1	1			1	1		5	5
KR	Physical											
	Intellectual	Intellectual knowledge isn't shared				1	1				2	2
	Human	Organisational change is difficult		1		1				1	3	3
	Financial											
KA	Production	The whole value chain is conservative ('unique projects approach')			1		1				2	2
	Problem Solving											
	Platform/network											
KP	Optimization and economies of scale	Misconception that only scale can lead to lower prices			1						1	1
	Reduction of risk and uncertainty											
	Aquisition of particular resources and activities											
R$	Asset sale											
	Usage fee											
	Subscription fees											
	Lending/renting/leasing											
	Licencing											
	Brokerage fees											
C$	Cost-Driven	Current focus on initial investment	1			1	1	1	1		5	9
		Future value is uncertain	1							1	2	
		Mass timber is too expensive in urban areas		1							1	
		Lack of experience with building costs								1	1	
	Value-Driven											
	Fixed costs											
	Variable costs											
	Economies of scale											
	Economies of scope											
	Advertising											

	A	B	C	D	E	F	G	H
1 Institutional behavior								
Unclarity about circular choices				what is wise?				
Difficult to change	traditional thinking			difficult to change				Difficult first step
Bad experience							turned out to be expensive	
2 Customization								
Prejudices about industrialization	True	problems with aesthetics committee	True	True				problems with aesthetics committee
Value proposition						Scarce suplly of multi-layer catalogue homes	floorplan doenst suit catalogue home	traditional facade with modular product = no use of scale & lack of competition
3 Increased risk								
Risk averse behavior	MT is percieved as higher risk			Risk averse behavior in purchasing products			MT is new and therefore riskier	
Knowledge deficiency		Advisors lack knowledge | unclarity about user impact		Knowledge is not effectively used	Unclarity about best building typology | Advisors dont share knowledge			Architects lack knowledge | materials need to be user proof
Lacks proof of concept	Is needed for wide scale adoption			is needed for wide scale adoption		True		
4 Higher price								
Incorporated risk premium		Traditional results in higher prices	10% risk premium					
High construction costs	Few empirical costs figures available | ones that are available are unatractive				Examples show: 10% more expensive			Examples show: 10% more expensive | Lack of competition to lower the price | traditional = same construction time
5 Traditional construction methods								
Tender for lowest costs	problems finding an experienced architect	MT is unable to compete	MT is unable to compete	problems finding an experienced architect	Traditional is used to provide insight in costs		Traditional is used to provide insight in costs	
Strategic alliances with traditional industry	Strategic alliances with traditional industry						Strategic alliances with traditional industry	
Different program of requirements							Doesn't fit all catalogue homes	
Changes in design phase			No constant flow of demand		In traditional process, different suppliers have different construction methods			Price becomes known too late in the process
Unkown effect on maintenance	The costs of maintenance are not foreseen in the design phase	Yes, therefor percieved riskier						
Total Cost of Ownership	Difficult to appreciate future value				Doenst suit existing company infrastructure and hasn't proven itself			Difficult to appreciate future value

APPENDIX C - Analysis of perceived problems within CE framework

	Changing conditions			Enter the market		Design Freedom			Providing mass timber		Cost and risk reduction		
Problems	Eliminate risk perception	Emphasize the need for change	Long term knowlege increase	Showcasing exsiting projects	Construct proof of concept	Structure	Infill	Skin	Collaboration	Network of actors	Total expenditure	Circular business model	TCO
1 Institutional behavior													
Unclarity about circular choices	showcase benefits	showcase health											
Difficult to change		pitch to board		target early adopters									
Bad experience	emphasize stranded assets	emphasize carbon tax											
2 Customization													
Prejudices about industrialization				construct p.o.c									
Value proposition						standardized + specials	infill industry	tailor made & open source					
3 Increased risk													
Risk averse behavior			involve conservative department							cross-fertilize knowledge			
Knowledge deficiency			cooperate in education	connect corporations	carry out lessons learned					network of actors			
Lacks proof of concept					construct p.o.c					share p.o.c			
4 Higher price													
Incorporated risk premium									no traditional contractors				
High construction costs						industrialization					set up new models		
5 Traditional construction methods													
Tender for lowest costs									join trad. contractors				
Strategic alliances traditional industry									create trust				
Different program of requirements						PMC's							
Changes in design phase									early involvement				
Unkown effect on maintenance												make supplier responsible	
Total Cost of Ownership												as-a-service & buyback	common dimensions

APPENDIX D – Analysis of solutions by housing associations

			A	B	C	D	E	F	G	H	I	II	III	Sub-total	Total
CS	Mass Market	Not suitable for mass timber													
	Niche Market	Focus explorative and progressive corporations													
	Segmented														
	Diversified														
	Multi-Sided platforms														
CH	1. Awareness														
	2. Evaluation														
	3. Purchase	Cost driven													
		Different building method (with functional or circular tender)	1		1									2	
		Early contractor involvement		1										1	5
		Build a catalogus with the different options and prices								1				1	
		Tender for lowest price based on 'bestek'					1							1	
	4. Delivery	Look for an integrated developer	1							1				2	2
	5. Aftersales	Provide guarantees				1		1						2	3
		Use smart data to limit the maintenance				1								1	
CR	Personal assistance														
	Dedicated personal assistance														
	Self-serivce														
	Automated services														
	communities														
	co-creation	Create new partnerships with the timber industry		1					1					2	
		Create partnerships based on incentives				1			1					2	
		Used to maintenance of traditional buildings													7
		Collaborate with other corporations (eg. with pilots)		1			1			1				3	
VP	Newness														
	Performance	Knowledge deficiency													2
		User proof fitout solutions		1						1				2	
	Customization	Mass customization (unite architects and industrial engineers)	1	1					1					3	
		Not enough multi-layer concepts available													
		Problems in regard to the aesthetics committee													3
		Concepts are not suitable for inner city developments													
	"Getting Things Done"														
	Design	Collaborate with experienced timber architect	1			1								2	2
	Brand/Status	Broaden knowledge (within and outside organisation)	1		1	1	1							4	4
		Misconception where conceptual building leads to													
	Price	Adress the governmental MIA/VAMIL subsidy for 5% discount								1				1	
		Concepts are affordable, but traditional in timber isn't													
		Is mainly looking for affordableness													1
		Price will rise due to higher demand													
	Cost Reduction	Higher material prices aren't compensated by a shorter building time													6
		Product thinking (eg. standard floorplans)	1		1		1	1	1	1				6	
	Risk Reduction	Risk reduction with future flexibility (design for dissasembly)	1			1								2	3
		Risk reduction by choosing for a concept								1				1	
	Accessibility	Lower the costs with industrialisation	1							1				2	2
	Convenience/usability	Construct a proof of concept	1	1		1			1					4	4
KR	Physical														
	Intellectual	Intellectual knowledge isn't shared													
	Human	Organisational change is difficult													
	Financial														
KA	Production	A different development process (combining demand)	1											1	3
		Standardise elements and build in factory, market will develop specials			1		1							2	
	Problem Solving														
	Platform/network	Start a factory with low kapitalisation costs and expand slowly			1									1	1
KP	Optimization and economies of scale	Misconception that only scale can lead to lower prices													
	Reduction of risk and uncertainty	The 'Bouwstroom' can establish this			1	1				1				3	3
	Aquisition of particular resources and activities														
R$	Asset sale	Sale CO2 certificates	1											1	1
	Usage fee														
	Subscription fees														
	Lending/renting/leasing														
	Licencing														
	Brokerage fees														
C$	Cost-Driven	Tender five banks for best commercial loan								1				1	1
		Mass timber is too expensive in urban areas													
		Lack of experience with building costs													
	Value-Driven	Invest on Total Cost of Ownership (TCO)	1		1		1	1	1					5	8
		Establish proof of future value	1				1			1				3	
	Fixed costs														
	Variable costs														
	Economies of scale														
	Economies of scope														
	Advertising														

APPENDIX E – Expert Panel results

Q	A	Participant	Slide no
1	Institutational behavior		
	Hoe overtuig je corporaties in hout te bouwen?		
	duurzaamheidsagenda: CO2 / klimaat NOx uitputting grondstoffen circulariteit Snel en toekomstbestendig bouwen: - kortere bouwtijd (bij voldoende prefabricage) gezondheidsaspecten van bouwen in hout (welzijn, hygrothermisch gedrag, biophilic design) business case in long run (welzijnvoordelen, CO2 tax, toekomstwaarde, etc) proberen te monetariseren	PL	4
	Laten zien dan collega's al in hout bouwen, dus het kan. Breng de twijfelaars in contact met de collega's die al in hout hebben gebouwd. De garanties zijn hetzelfde als bij traditionele bouw. Wijzen op de 'voortrekkersrol' die van Woninstichtingen wordt verwacht. Aangeven dat niet alles in één keer in hout moet, maar dat het -op de schaal van de totale voorraad- prima is om een x aantal woningen in hout te bouwen.	RM	4
	Door overtuigende voorbeelden te geven van projecten die realiseerbaar zijn binnen de door de corporaties gestelde budgetten......En ook door ze "aan de hand te nemen" in het ontdekken van al het nieuwe.	TL	4
	Maatschappelijke betrokkenheid: het is goed voor de planeet en mensen worden gelukkiger in een biophilic design. Daarnaast kan door circulair ontwerpen (niet per se altijd met hout, maar vaak wel) meer flexibiliteit in de businesscase/eindwaarde gegenereerd worden.	JN	4
	Wat is er nodig om corporaties de eerste stap te laten zetten?		
	Meer inzetten op eindwaarde van de woningen. Minder kosten door schaal.	JN	6
	Voorbeeldgedrag, Financieel voordeel toelichten bij eerst tijdelijk en daarna permanent te exploiteren, wijzen op concurrenten die het al doen (dus het kan),	RM	6
	high level pitch aan bestuur / board (zie tomorrow's timber talks) > werkt vaak goed en daar aanspreken op verantwoordelijkheidsgevoel voorbeeld projecten laten zien / concurrenten laten zien die het WEL doen en hier publicitair mee scoren (bv fien wonen)	PL	6

	1. Overtuigingskracht vanuit het veld van leveranciers en ontwerpers (en andere disciplines) 2. Wetgeving die houtbouw meer stimuleert	TL	6
	Als hout meerdere keren duurder uitpakt dan verwacht, wat kun je dan nog doen om de corporatie te overtuigen toch met hout te bouwen?		
	De normale reflex als iets de eerste keer niet lukt is te stoppen. Leg de focus op 'leren'. De overstap van projectmatig denken naar procesmatig denken (industrieel) is prima te onderbouwen. Bij de bouw is ruim 40% arbeidskosten. In de maakindustrie ca 18%.	RM	8
	- Geduld hebben totdat hout de rest heeft ingehaald!... - Niet alleen naar de directe bouwkosten kijken maar het gehele plaatje (eerdere huuropbrengsten, minder rentelasten, restwaarde e.d.)	TL	8
	CO2 tax noemen gezondheidsvoordelen op maatsch verantwoordelijkheid aanspreken life cycle costing	PL	8
	Eindwaarde! het gaat niet alleen om initiele kosten	JN	8
2	Customization Mass Housing		
	Hoe kun je deze vooroordelen wegnemen?		
	succesvolle project cases / referenties tonen (bv referentieboek) van systemen waarin welk mate van customization mogelijk is, ook vanuit buitenland.	PL	11
	Door verbeeldingskracht: inzichtelijk maken dat systemen niet beperkend houven te zijn. In beton bouwen we overigens ook veel in 5400 of 7200 stramienen.....	TL	11
	Gevelvrijheid met name en flexibelere indeling.	JN	11
	Goede voorbeelden laten zien. Maatwerk leveren waar het gaat om architectuur en om stedenbouw.	RM	11
	Welke elementen van een gebouw kun je optimaal geindustrialiseerd produceren?		
	Vloeren, kolommen, balken. En door slim te ontwerpen alle inbouw. Inbouw scheiden van draagconstructie. Woningtypes ontwikkelen die iedereen sowieso altijd wel wil, met daaromheen specials zodat elke gebouw toch een deel dus volledig uniek is.	JN	13
	Eigenlijk alles!....En ook al wordt de gevel vaak een "maatpak" kan daar ook slim over worden nagedacht door efficient te ontwerpen.Als architect ben ik er niet bang voor.	TL	13
	zowel structure / shell als skin (layers of brand), wellicht lenen de grote casco elementen zich het beste hiervoor, maar bij een slim ontworpen gevel systeem kan de invulling nog steeds customizaiton mogelijk maken waarbij achterconstructie hele goed industrieel geproduceerd kan worden	PL	13
	De basis van industrialisatie is standaardisatie van het casco. gevels en stedenbouw blijven maatwerk. Vaak ook de snijpunten en vluchtwegen.	RM	13
	Customization Value proposition		
	Wat gaat hier mis, en hoe op welke manier kan dit problem overwonnen worden?		

	Ik weet niet zeker wat er mis gaat, want een "standaard" casco en een maatwerk gevel kan toch super efficient op eelkaar worden afgestemd?....Ik denk dat het komt omdat er met het ene been in de toekomst en het ander been in het verleden wordt gewerkt.	TL	16
	De meest geniale manier van industrialisatie is n=1. Er zijn ook voordelen te behalen bij unieke gevelontwerpen door deze te prefabriceren. Bijvoorbeeld RCpanels die unieke gevels geïndustrialiseerd produceren.	RM	16
	Gevel door een andere partij laten doen. Dus constructie altijd het zelfde door 1 partij. Een specialist of meerdere voor gevels.	JN	16
	Waarschijnlijk verkeerde beeldvorming, een goed ontwikkeld systeem zou dit moeten kunnen tackelen.	PL	16
3	Increased Risk - Knowledge		
	Is er een manier denkbaar waarop deze kennis zich verspreidt?		
	kennis is een groot hiaat. Dit maakt modules / cursussen / hoger onderwijs van groot belang. Denk aan een leerstoel houtbouw, een MOOC / ProfEd, en literatuur toegeend op NL praktijk (bv BENG en houtbouw).	PL	19
	Het gebrek aan kennis is relatief. Het is eerder een cultuurprobleem. De benodigde kennis is eenvoudig op andere plekken te vinden (bv Scandinavie, Oostenrijk en Duitsland).	RM	19
	Scholing (TU en HTS) en ik heb ook het gevoel dat de mensen met wie wij eraan werken meer uitgaan van kennis delen omdat de nood aan de man is.	TL	19
	Platform vanuit overheid, die door subsidie toch geld naar de belangrijkste adviseurs laat vloeien. Per gebouw dat het platform maakt.	JN	19
	Increased Risk - Proof of concept		
	Hoe kun je deze kennis effectiever gebruiken?		
	Moet op juiste bureau belanden, ook belangrijk om conservatieve afdelingen (financieel, onderhoud) te betrekken en vooroordelen weg te nemen	PL	21
	Transparant en open samenwerken met deskundige partners	TL	21
	Beschikbaar stellen van kennis & informatie.	RM	21
	platform	JN	21
4	Higher price - Risk Premium		
	Wat is ervoor nodig om een betaalbaar proof of concept te maken?		
	een goede plek in een binnenstedelijke locatie waarin dit zichtbaar is (positie vrijgeven door gemeente om niet). gestandaardiseerd en uitontwikkeld, slim systeem liefste waarin financieel model van circulair principe (take back / buy back)	PL	24
	heel veel gebouwen maken, voor die tijd heb je geen 'betaalbaar' proof of concept. OF: anders rekenen op eindwaarde is het wellicht al betaalbaar	JN	24
	Het onderzoek waar wij nu mee bezig zijn is daarvoor bedoeld.	TL	24
	Gewoon te doen. De proof of concept is er al.	RM	24
	Is het terecht dat de corporatie een 10% risico opslag rekent? Waarom wel of niet?		
	De kosten van materiaal ligt hoger. Dat verdien je terug met lagere faalkosten, lagere bouwplaatskosten en -bij voldoende schaal- lager aandeel arbeidskosten.	RM	27

	De premium kun je ook inzetten om verlengde garanties te vragen. Een leverancier van accoya biedt (bv) garantie van 50 jr. Nee, zo ingewikkeld is het nu ook weer niet. En ze zouden het eigenlijk moeten zien als een investering die ze moeten doen om e.e.a. te leren, waarmee ze in de toekomst verder kunnen.	TL	27
	Hoeft natuurlijk niet als je het goed doet, maar als de business case toch sluitend is zou je die 10% ook als investeringsbudget / bonus kunnen zien. Maar in principe is het niet nodig als je kijkt naar meer dan voldoende andere succesvolle mass timber project in buitenland, ook in meerlaagse woningbouw (zie TT boek)	PL	27
	Het is een middel om het dan wel te doen, maar met een marge. Dus goed idee. Daarmee krijg je de handen van institutioneel geld wel op elkaar (risk management).	JN	27
	Higher Price - Construction Costs		
	Hoe kun je de kosten van houtbouw verlagen?		
	Belasten van onduurzame materialen. Anders inkleden (duurzaamheidsfee) van de verhuurdersheffing of andere financiele regels voor duurzame corpo's.	JN	30
	Door niet de bouwkosten maar de stichtingskosten te vergelijken. De bijkomende kosten liggen lager. Daarnaast zijn de woningen sneller beschikbaar. Tevens is het mogelijk eerst tijdelijk en daarna permanent te exploiteren. Beleggers krijgen ook te maken met ' stranded assets'.	RM	30
	Ik denk dat dat vanzelf gebeurt als hout vaker toegepast wordt. Je kan dat niet afdwingen. Wellicht door het aanbod te vergroten (meer zagerijen en CLT fabrieken)	TL	30
	economy of scale. upfront engineering (skilled ontwerp en bouwteam)doorrekenen snellere bouwtijd in exploitatie (eerder inkomsten)Co2 tax meenemen	PL	30
5	Traditional Process - Tender for lowest Cost		
	Kan houtbouw concurreren in een traditionele aanbesteding? Zo ja, hoe doen? Zo niet, op welke manier kan houtbouw wel concurreren?		
	Is erg afhankelijk van de opgave....Ik denk dat hout niet alleen op de harde waardes van het geld moet kwalificeren maar ook juist op de sustainability. Een breder waardensysteem zal hier voedingsbodem voor bieden.	TL	33
	Houtbouw kan concurreren door te standaardiseren en industrieel te bouwen. Maar... Je weet pas achteraf wat de kostprijs was (vanwege de bezettingsgraad van de fabriek). Tegelijkertijd ligt de omzetsnelheid van vermogen hoger. Dus, ja, je kunt concurreren. Maar moeilijker op individueel projectniveau (met een focus op maatwerk).	RM	33
	MKI en CO2 meenemen (EMVI) in de kosten (maar dan wel met biogeen CO2 meegewogen in de NMD).	PL	33
	Nee, maar concurreren kan wel op basis van eindwaarde.	JN	33
	Traditional Process - Strategic Alliances with traditional Industry		
	Hoe kan het gebruik van vaste ketenpartners in het voordeel werken van houtbouwers?		

Actieve acquisitie van de nieuwkomers naar bouwers/ontwikkelaars (ketenintegratie) obv meerwaarde van het systeem / concept (vertical integration)		
Focus op ESG van investeerders / beleggers	PL	36
ketelpartner is autocorrect :-)	RM	36
Sneller en door vaak te doen goedkoper, dus dan gaan ze uiteindelijk overstag.	JN	36
Voor Finch geldt dat wij door VolkerWessels bedrijven worden gevraagd om mee te doen. Zij bieden toegang tot de longlist en soms kunnen we rechtstreeks omdat een dochter van VW een ketelpartners is.	RM	36
Zorgen dat je zelf een vaste ketenpartner wordt....	TL	36
Traditional Process - Different Program of Requirements		
Hoe kun je standaard plattegronden kwijt in een gebouw met een vrij-indeelbare gevel?		
Geen dragende gevel. Facade as a service. of een dubbele gevel zodat je niet afhankelijk bent van waar wanden uitkomen.	JN	39
Dat is met beton en kalkzandsteen nu ook al zo, dus wat dat betreft brengt hout of CLT in dit specifieke onderwerk geen verandering....	TL	39
Slim casco / skelet ontwerpen waarbij gevel niet dragend is en achterconstructie ruimte houdt voor flexibiliteit (ontwerptechnisch op te lossen)	PL	39
Door de gevel 'open source' te maken.	RM	39
Traditional Process - Changes in design phase		
De impact van onderhoud wordt nog niet altijd voorzien in de ontwerpfase. Hoe kan houtbouw hier op inspelen?		
Doordat houtbouw een 'droge' en demontabel bouw kan zijn. een voorbeeld is een zwevende dekvloer, uitgevoerd als computervloer om toekomstige flexibiliteit te behouden. Door voldoende ruimte te reserveren voor installaties, etc.	RM	42
Door systeemontwikkeling worden dingen eerder inzichtelijk.	JN	42
Daar heb ik eigenlijk (nog) geen goed antwoordt op.....Hout is wel een stuk flexibeler voor aanpassingen dan beton, steen en staal.	TL	42
Dit gaat om de schil niet om de casco, daar moet je high durable houtoplossingen kiezen (gemodificeerd hout). In casco kan een voordeel zijn dat hout bewerkbaarder is en daarmee makkelijker herstelbaar (bv infresingen, vullen, etc)	PL	42
Traditional Process - Unknown effect on maintenance		
Hoe los je het problem van een onbekende toekomstwaarde op?		
Proberen met elkaar lange termijn te denken en daar ook (hoe moeilijk ook) te kwantificeren	TL	45
Iedereen The Good Ancestor laten lezen: We krijgen het land niet van onze voorouders maar lenen het van onze kinderen....	TL	45
Studies naar gebruikerswaarde / productiviteit (biophilic design) wijzen op afbreukrisico als je fossiel blijft bouwen cases hogere waarde van goede houtbouw woningen vs betonnen buren (zie ijburg case in TT boek) residual value / circulaire business modellen introduceren	PL	45

Het probleem verminderen door alternatieve aanwendbaarheid van gebouw, maar ook de ma§terialen groot te maken.	JN	45
Door er op dit moment niet mee te rekenen, aar het wel als een 'future asset' te benoemen. Bij gelijkblijvende kosten zijn dit aantrekkelijke extra's.	RM	45
Hoe denk je dat de levensduurkosten van een houten gebouw zich verhouden tot dat van een traditioneel gebouw?		
Meer restwaarde en minder onderhoud	TL	47
Gelijk. Het hangt af van hoe je het in elkaar zet (droog of nat).	JN	47
Casco zou niets uit moeten maken, wellicht hogere investeringskosten / stichtingskosten, dat zou moeten worden verrekend met snellere bouw en evt hogere toekomstwaarde (zie antwoord vorige vraag)	PL	47
Mijn inschatting is vergelijkbaar. Behalve bij het einde van de exploitatie. Daar 'scoort' hout beter app meerdere manieren. Bij Finch bijvoorbeeld door het hergebruik van de complete modules/ casco's. En anders door het oogsten van de materialen (second best).	RM	47
Hoe kun je de corporatie hiermee helpen?		
Vanuit ontwikkeling en belegging allebei de boeken open en één casus proberen helemaal door te rekenen met verschillende scenario's	JN	49
Het onderhoud is niet erg afwijkend van traditioneel. Installaties (contractonderhoud + vervangen na ca 17 jr). Badkamers ca 30 jr. Keukens ca 20 jr. Schilderwerk, etc wijkt evenmin af. En het casco os flexibeler.	RM	49
voorbeelden / inhouse masterclass obv daadwerkelijke cases	PL	49
Ook hier weer aan de hand nemen en samen met hun (zij hebben ook veel kennis) nieuwe modellen opzetten.	TL	49