Exploring circular revenue models for temporary housing of housing associations

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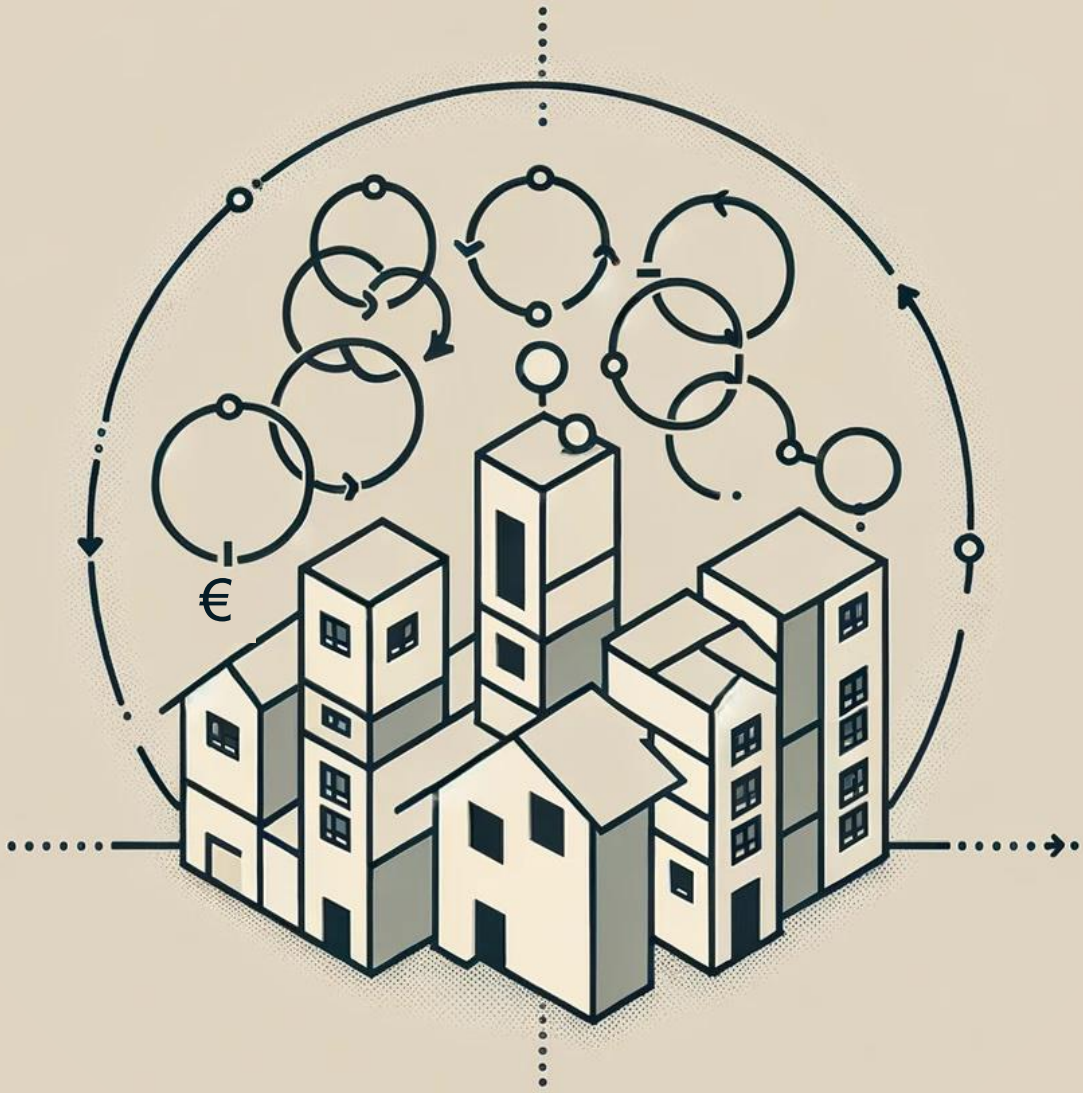

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Preface

It gives a great sense of satisfaction to finish this master's thesis. There is a lot of time dedicated in doing the exploration, research, interviewing and writing. The interest towards the research topic was sparked by the rise of modular construction methods in the Netherlands and the growing need to embrace the circular economy. These two topics came together in my thesis research called "Exploring Circular Revenue Models for Temporary Housing of Housing Associations". This thesis represents the final product of my master Urban System and Real Estate (USRE) at TU Eindhoven.

My academic journey began in University of Applied Sciences, where I completed my bachelor's degree and discovered a passion for the broader context, real estate and urban development. This led me to study a pre-master's degree, followed by my master's degree. During my master's degree I focussed particularly on the area of real estate development.

My appreciation goes to my supervisors for their advice, guidance and support during the research process, despite the challenges I encountered along the way. I would also like to thank the housing associations that cooperated in this study. Getting their cooperation was not an easy task and this was key to this study.
Furthermore, during my studies, I am thankful to have had the opportunity to work at project management company Qwinq. Where I carried out various projects that provided learning experiences.

I hope this thesis contributes to the ongoing research on the circular economy in (temporary) housing and inspires for further research and innovation in this important field.

Enjoy reading the thesis!

Mathijs Timmermans
Tilburg, April 2024

Abstract

This research explores circular revenue models for temporary housing of housing associations. It analyses the challenges, opportunities and feasibility of implementation. Temporary housing addresses housing shortages in the Netherlands with zoning exceptions that allow stay of 15 years. The construction sector has significant role in the worldwide emissions. Therefore, there is call for a circular economy. The research aims to identify changes needed in revenue models of housing associations to improve circularity and feasibility compared to current practices.

The literature review identifies circular strategies for temporary housing into three groups: smarter product use and production, lifetime extension and material application. Examples of the circular business models are service instead of products, shared use and reuse. Interviews with housing associations reveal unfamiliarity with but interest in adopting circular business models. Furthermore, challenges such as financial constraints and legal obstacles are found.

Findings highlight the varying financial feasibility and sensitivity of circular revenue models. Therefore, there is the need for project-based assessments. The recommendations call for overcoming financial and regulatory hurdles through policy adjustments and further empirical studies to refine circular revenue models and quantify their environmental impacts.

Summary

This research is on exploring circular revenue models for temporary housing of housing associations. The research analyses the challenges, opportunities and feasibility of implementing circular revenue models. In the Netherlands there is a shortage in housing. Temporary housing offers a short-term solution to contribute to housing in this context of the shortage. These temporary houses are allowed under zoning plan exceptions to stay in a specific location for up to 15 years without requiring complex amendments to zoning plans. The construction sector contributes significantly to global emissions and it relies mainly on non-renewable or virgin materials. Housing associations with their social housing in the Netherlands manage a large proportion of the total housing stock. The entire housing sector will have to move to a circular economy. Circular revenue models can contribute to this shift. A concern of the temporary housing is that they do not meet sustainable and circular agenda (of the Netherlands). This is the reason for exploring circular revenue models that can turn temporary housing into a (more) feasible and more circular solution compared to the current practice.

The research aims to identify changes required in the revenue models of housing associations to enhance circularity and enhance feasibility in the temporary housing projects. This study is done by analysing the current revenue model of housing associations and revenue models with integrated circular strategies and finally evaluating the feasibility of these models compared to current practices. The methodology includes a literature review, semi-structured interviews and variant analysis. This approach provides insight into feasibility and circularity and identifies the opportunities and challenges.

The relevance of the study consists of social, environmental and economic aspects. Societally, the research contributes to the literature which addresses the housing shortage. This could contribute to accelerate realisation of temporary housing solutions. Environmentally, it aligns with sustainability goals by encouraging circular economy. Economically, the study examines the feasibility of these models in comparison to the current practices of housing associations. The housing associations need to maintain financial stability; therefore this is of relevance.

The literature review explores three main elements: circular strategies for temporary housing, circular revenue models and the current revenue models of housing associations.
The review starts with the circular strategies for temporary housing by defining. The circular strategies for temporary housing outlines principles are categorized into three strategies "Use and produce the product smarter", "Extend the lifespan of the product and elements," and "Useful application of materials". The Building Circularity Index (BCI) is identified as the most comprehensive for decision-makers to make informed decisions about circular strategies. Modular temporary housing is aligned with circular strategies, but the extent of this alignment remains uncertain without BCI data.
The second part reviews the different general circular business models and real estate specific models. It identifies eleven models that focus on service instead of products, shared use and product reparability and assesses the models with the in the circular strategies.
Lastly the literature review evaluates how current revenue models of housing associations align with circular strategies. It explores the financial structures of housing associations, their approach to depreciation and the potential for integrating circular practices. The study identifies current revenue models and notes that these do not include the circular strategies. The modular temporary housing aligns with circular strategies. This offers potential for the adoption of circular revenue models by housing associations.

Based on the literature further empirical research is needed to bridge the research gap. For this empirical validation, insights into obstacles, and analysis of the financial feasibility of circular revenue models are needed. In the interviews four housing associations were examined and their experiences

with twelve temporary housing projects. The interviews focussed on understanding current practices (circularity and revenue models) and validating the circular revenue models found in the literature. Despite using 3d modular temporary housing systems that offer the potential for permanent placement, associations did not consider circularity in their housing choices. The revenue models of temporary housing is similar to regular housing with overhead costs, only potential lower maintenance costs. Lastly, while relocation strategies and the pursuit of agreements for free land varied, all associations agreed on the necessity of maintaining permanent quality in temporary housing to ensure financial feasibility.
The results of the interview on circular revenue models of the literature points to challenges including financial considerations, regulatory and legal factors and preferences. Interviews with housing associations reveal that housing associations are unfamiliar with circular revenue models but there is interest in integrating all except one circular revenue model. The model that all housing associations agreed did not fit their business is pay-per-use shared spaces.

The variant study gives a comparative analysis of the circular revenue models from the interviews. It concludes with categories based on financial feasibility and sensitivity of the revenue models tested on project. Firstly, there are models with enhanced feasibility and stability compared to current practice. These are the models Shared Pay-per-Use laundry and Shared space. Secondly, there are the enhanced feasibility but sensitive model Permanent quality. Thirdly there is the model of Co-living exhibit higher sensitivity, indicating potential risks under varying conditions. Lastly, some models lack financial data, requiring further research. These are the models of New ownership structure, Buy-back and Reusable products and materials.

To enhance feasibility and circularity in temporary housing projects compared to current practice, housing associations could integrate the circular revenue models found in the study. All models enhance circularity. The models Shared pay-per-use laundry and Shared spaces and enhance feasibility. Models like Permanent Quality offer feasibility but require thorough assessment for each project suitability. Models like Co-Living may not enhance economic feasibility. Housing associations should conduct project-specific assessments of the circular revenue models.

The study outlines several limitations related to methodological and empirical challenges. This includes low response rates in interviews and potential selection bias. It emphasizes the need for empirical validation of these theoretical revenue models. Further research is suggested to refine the explored revenue models, evaluate environmental impacts through Life Cycle Assessment (LCA), and analyse the long-term effects of circular choices on revenue model performance. Recommendations for future research include conducting case studies to validate circular revenue models empirically and addressing challenges like financial barriers and legal constraints.

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1. Introduction

There is a major shortage of housing in the Netherlands. Many houses must be built in the short term, and temporary homes offer the opportunity to meet this demand. These are not temporary emergency housing during major disaster, they are housing often of a modular nature that for example must comply strict BENG requirements (nearly energy neutral building regulations). For temporary housing, the predetermined duration for the structure's presence in a specific location is established in advance. As per the zoning plan exception, temporary housing is permitted to stay for a maximum of 15 years. This implies that, without undergoing complex zoning amendment procedures, a property can be utilized for an alternative purpose for a 15-year period. If the intention is to keep the building in place beyond this 15-year limit, the aforementioned complex zoning plan procedures become necessary. However, these temporary houses are unlikely to be sustainable. Brundtland's (1987) often used definition of sustainability is as follows: 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. Short-term thinking deprives future generations of the opportunity to fulfil their own needs. To prevent this, there are major developments taking place in residential direct sustainable energy consumption. Sustainable new construction is now enshrined in law to combat global warming. All residential new construction must meet strict energy performance requirements (BENG). This refers to the direct energy requirements of the building. Additionally, there are emissions generated during the construction phase, both of the materials and construction process. Significant gains can still be made in encouraging circular practices in material use and construction processes. Circular business models provide the opportunity to move towards a sustainable development on material level. Innovation is needed regarding the revenue models for companies to successfully switch to circular business models (Achterberg et al., 2016). This chapter will focus on describing the problem of temporary housing challenges in terms of circularity and the possible circular business models. It will then describe the research goal and the research questions, discuss the relevance of the study, and substantiate the research method.

1.1 Problem description

The production of materials for the construction sector accounts for 11% of global energy and process-related emissions (Zhong et al., 2021). The buildings consist of many non-renewable materials, such as bricks, concrete, metals and glass. Construction of houses is the largest source of business for the construction industry (Centraal Bureau voor de Statistiek, 2021b). Of these constructed houses, a large proportion is social housing. Currently, housing associations in the Netherlands own almost 2.3 million socially rented housing units, which is 30% of the total housing stock (Centraal Bureau voor de Statistiek, 2016). Social housing in the Netherlands is affordable housing intended for lower-income households; it is mostly managed by housing associations and subject to regulations to ensure affordability. The significant role of housing associations in providing housing thus contributes to challenges such as resource depletion, climate change, and pollution in the Netherlands.

Since the advent of global industrialisation, the global economy has adhered to the principle of a linear economy. The linear model is a resource consumption system that follows the 'take-make-dispose' pattern. This involves means manufacturing raw materials into goods, which are sold to the consumer, used, and lastly disposed (Ellen MacArthur Foundation, 2013). The linear system brings ecological and economical disadvantages with it. The ecological disadvantages are at the expense of global ecosystems. This endangers the supply of essential ecosystem services, such as soil, water and air (Michelini et al., 2017). Consequences include rising sea levels. Furthermore, there are the economic problems such as fluctuating raw material prices (Circle economy, 2018), geographical interdependence (European Commission et al., 2020), and critical raw materials and its growing demands (CBS, 2019; What Are the Disadvantages of the Current Linear Economy?, 2021). A turnaround is needed towards a circular economy. The aim of a circular economy is keeping

products, components and materials at their highest utility and value at all times (Ellen MacArthur Foundation, 2015). With this aim the construction sector is facing a significant transition. The Netherlands has already set the goal to become a fully circular economy by 2050, with the initial target (of 50% reduction) in 2030.

There is already substantial research on the circular economy and its related concepts (Geisendorf & Pietrulla, 2017; Lieder & Rashid, 2016). However, the literature moving towards the circular economy is still growing (Hart et al., 2019). The study of Hart et al. (2019) recognises the barriers and drivers moving towards the circular economy in construction. Among these barriers are the financial ones, which consist of high upfront investment costs, low virgin material prices, poor business case and unconvincing case studies, and limited funding. In addition, in the current linear economy, investments in real estate are prioritised by their short-term goals (Brouwer & Durmisevic, 2002).The research of Adams et al. (2017) suggests setting up a clear long term circular business model for commercial viability and overcoming the barriers of the circular economy in the built environment. Interest in these circular business model has grown. Business models are key and a requirement for the transition to the circular economy (Adems et al., 2017; Bocken et al., 2013). The term 'business model' is frequently referred to research. Alexander Osterwalder (2005; 2010) set up the well-known business model canvas, which consists of value proposition, target customer, distribution channel, relationship, value configuration, capability, partnership, cost structure and revenue stream.

For housing development, the cost structure and revenue steam are provided in the revenue model, and the discounted cash flow (DCF) method is often used. This research will focus on the revenue models, which are a part of the business model.

The driving force behind these revenue models is achieving financial growth with profits and sales (Jonkers, 2016). The traditional revenue models do not show the potential surplus of circularity. Fundamental change is needed. One contribution to this transition is changing the traditional linear business models to follow the take-make-dispose system (Ruiter et al., 2021). Research on the topic of the circular revenue model can contribute to the fulfilment of this circular business model.

Over the past decade, the supply and demand for housing has shown considerable dynamics, through prices and transactions on the Dutch housing market (CPB, 2020). But dwellings are characterised by their static nature. This means that most dwellings are not designed to adapt to the future demands of the market. In addition, construction periods for new housing are long. Further, there is a great shortage of housing in the Netherlands. As cited above, there is an opportunity in the regulations through an exemption in the zoning plan. This exemption, with the help of the industrialised temporary construction of housing, could contribute to solving the housing shortage in a shorter term. The advantages of the industrialised temporary housing construction are shorter construction periods and lower costs due to the industrialised factory work (Buijs et al., 2019).
Housing associations are increasingly offering temporary housing as a part of their social housing portfolio (Aedes vereniging van woningcorporaties, 2021). Housing associations refer to temporary housing as 'flex-housing.' Between 2017 and 2020, housing associations constructed about 7,000 temporary houses (Aedes vereniging van woningcorporaties, 2021). Temporary housing realised by investors other than housing associations is not the focus of this study.
Housing associations deal with revenue models differently. Some depreciate the temporary houses completely during the exploitation period of 15 years; others place them on a second location for another 15 years. Residual value after this period is a surplus but is not included in the model (Aedes vereniging van woningcorporaties, 2021). With this method, all modules, materials, products and elements are undervalued at the end of the exploitation period. These revenue models, in which the financing and depreciation periods are fixed, are determined by the housing association and are likely fixed to the traditional linear economy.

1.2 Research goal

The goal of the government-wide programme 'Nederland Circulair in 2050' is that by 2030, the Netherlands should use 50% less primary raw materials. Similar to the government's approach with minimum required energy labels in which housing associations had to be ahead, it is anticipated that housing associations will be obligated to contribute to achieving these circularity targets. Therefore, it is essential for housing associations to operate their temporary housing in accordance with to circular principles. Additionally, the position of housing associations was adopted because of their aim of providing affordable housing for low-income people. They do not handle housing speculatively but as a long-term investment. The housing associations seek both financial stability and the ability to invest in new housing projects. By leveraging circular revenue models, housing associations can create a more efficient and equitable system for providing temporary housing that is both financially feasible enhanced and environmentally sustainable.

Often, temporary developments projects are not feasible due to the revenue models that depreciate the houses in the short term. This research focuses on one of the downsides of this new way of construction of temporary housing with short-term depreciation. Circular thinking is needed to move the world towards a circular economy. This study aims to determine what changes are needed to transform the current revenue model for temporary housing by housing associations into a circular revenue model and whether this is feasible. This all connects to the larger goal of reducing the carbon footprint and contributing to solving the housing shortage in the Netherlands. The results of this study will be of interest to housing associations, which will gain insight into the changes needed for a circular revenue model.

The results will also be of interest to governments, municipalities, real estate investors and project developers. Developing and operating temporary houses in a circular way will give municipalities the opportunity to release more land for housing, because it is feasible and sustainable. In doing so, it can help solve the housing shortage in the Netherlands. The government also wants to create more temporary housing. Adding circularity to short-term housing can gain additional value for the government (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2022). Lastly, it will also be of interest to real estate investors and developers of temporary housing.

1.3 Research questions

The following main question (*m.q.*) was formulated based on the research goal.

M.q.: *What changes in the revenue models of housing associations are needed for enhanced feasible circularity in temporary housing projects compared to the current practices?*

To answer this main question, four sub-questions (*s.q.)* were posed.

S.q.: *What circular strategies should the revenue models of temporary housing be aligned with?*

S.q.: *What are the revenue models used by housing associations for providing temporary housing?*

S.q.: *Which circular revenue models have been identified as suitable for adoption in temporary housing?*

S.q.: *How do the financial results and feasibility of circular revenue models differ compared to the traditional revenue model?*

1.4 Relevance

1.4.1 Societal relevance

As previously noted, the Netherlands is facing a significant housing shortage, with an estimated one million new homes needed by 2031. The demand has increased since 2013. In the short term, industrialised temporary housing construction presents an opportunity to quickly build many homes; this construction is already underway. The government is also fully committed to temporary housing. For example, there is a parliamentary letter on the stimuulus approach to temporary housing

(Ministry of the Interior and Kingdom Relations Housing Market Directorate, Ollongren, 2019). With this, the government is taking measures to encourage the construction of more temporary housing. In addition, a housing programme 2022–2026 has been launched (Ministry of Housing and Spatial Planning et al., 2022). This programme aims to build a lot of housing. Additionally the parliamentary letter on 'decision-making refugee crisis' was added (Ministry of Justice and Security et al., 2022). This sets the target for the realisation of a total of 37,500 temporary homes in the period 2022–2024. Given this strong demand from governments to build more temporary housing, this research will also be of interest to them. The studies, memoranda and parliamentary letters of the government pay little attention to sustainability, in particular circularity aspects.
To maximise the environmental benefits, these homes should be operated according to a circular business model and constituent revenue model. To better care for our world as a closed system with two potential long-term destinations for materials (i.e., recycling and reuse), it is necessary to ensure that materials, products and elements are given appropriate value and kept in circulation rather than lost (Fischer et al., 2019; National Academy of Engineering et al., 1994). This will set the circular economy in motion, ultimately reducing the use of fossil fuels and the carbon (CO_2) footprint to zero. In summary, this circular housing research contributes to a solution for more sustainable housing that can be quickly constructed to address two current societal issues: global warming caused by CO_2 emissions and a shortage of housing.

1.4.2 Scientific relevance

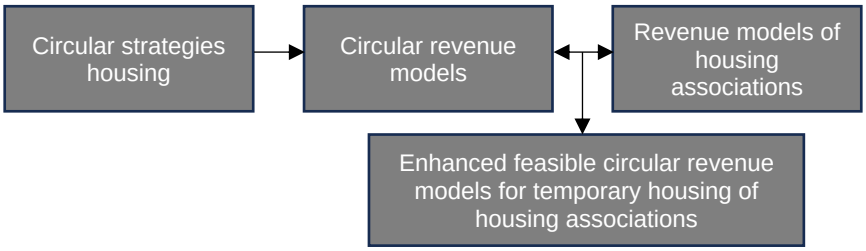
This research contributes to the ongoing research on the circular economy (Geisendorf & Pietrulla, 2017; Lieder & Rashid, 2016) and new housing concepts such as the off-site industrialised construction of modular and biobased housing (Oorschot & Asselbergs, 2021b; Ortega et al., 2020). The only studies on the topic of temporary housing available in the Netherlands are memoranda and studies conducted on behalf of the government. These only involve government-led densification initiatives, particularly through the use of flexible housing (temporary housing) (Groot et al., 2020). These documents merely address existing issues in the housing market. The primary objective of these studies and memoranda is to encourage the construction of temporary housing.
The study from Watkostdebouwvaneenhuurwoning & Expertisecentrum Flexwonen (2019) discusses the bottlenecks, feasibility and possible locations for construction of more government-commissioned temporary housing. The cooperative housing association Aedes (2020) conducted a similar study. The reports by the Arup Group and the Ellen MacArthur Foundation (2020) and Carra et al. (2017) present new circular business models implementation examples for real estate companies. The reports explain cases in which these circular business models have worked, such as a relocatable real estate or adaptable real estate. In doing so, these studies do not address the issue of a circular temporary housing. In addition, the reports of Arup Group and the Ellen MacArthur Foundation (2020) and Carra (20170; the reports conclude the relocatable real estate is a circular solution. There is therefore a lack of detailed discussion on the concept of temporary housing and the associated circular business models for temporary housing.
The reports illustrate examples of circular business models, including relocatable or adaptable housing. However, these studies fail to explore the concept of circular temporary housing. This omission is evident in reports by Arup Group and the Ellen MacArthur Foundation (2020) and Carra (2017), where they claim that relocatable real estate is a circular solution. The researchers did not choose to discuss the concept of temporary housing and associated circular business models for temporary housing.

Lewandowski (2016) mentions circular business models as a component of the transition towards the circular economy. Part of the business model is the revenue model. In a related context, Brekelman (2020) focused on creating a circular revenue model for office buildings and suggested extending the research to other real estate types. This research therefore focuses on integrating circular principles into circular revenue models for temporary housing.

1.5 Research method

The study consists of three main components: the circular strategies for temporary housing, the circular revenue models and the revenue models of housing associations. These three elements are integrated into circular revenue models for temporary housing of housing associations. The study first examines the circular strategies for temporary housing, which is the base of the circular revenue model. This circular model and the revenue model revenue model employed by housing associations are compared. Ultimately leading to the circular revenue model for temporary housing. This can provide an understanding of the models possible to adopt for housing associations.

Figure 1
Conceptual model



This research will be conducted following the design science research method (Johannesson & Perjons, 2014). Below it is shown that this research follows the design science research methodology which is shown in figure 2.

1. *Explicate the Problem*

The problem of creating temporary housing with the current revenue models in the context of a circular economy for housing associations needs further elaboration. In the present revenue models, there appears to be a limited integration of circular aspects. The current approach to these projects, the vision of the housing associations on temporary housing and circularity and revenue models for temporary housing will be further assessed through semi-structured interviews with experts (project managers for temporary housing). The findings from the interviews provide insight into the issues housing associations are facing regarding temporary housing, the status of implementing circularity in temporary housing and circular business models.

2. *Define Requirements*

Requirements, including financial requirements, must be identified for a circular revenue model for temporary housing of housing associations. This will be done through extensive research to analyse the circular strategies which the revenue model should align with, the circular revenue model and the revenue model of housing associations. The circular strategies will be determined by using the definition of circularity.
After, the possible circular revenue model will be determined by in literature found circular models; generic circular models and real estate specific circular business and revenue models. Information and insights related to circular temporary housing, the revenue model of housing associations, and the applicability of circular revenue models, which were not available through literature review, are gained through semi-structured interviews (SSIs). The SSIs are conducted with financial experts on temporary housing projects of housing associations.

3. *Design and Develop Artefact*

Circular revenue models are designed based on the findings of the literature review and SSIs.

4. *Demonstrate Artefact*

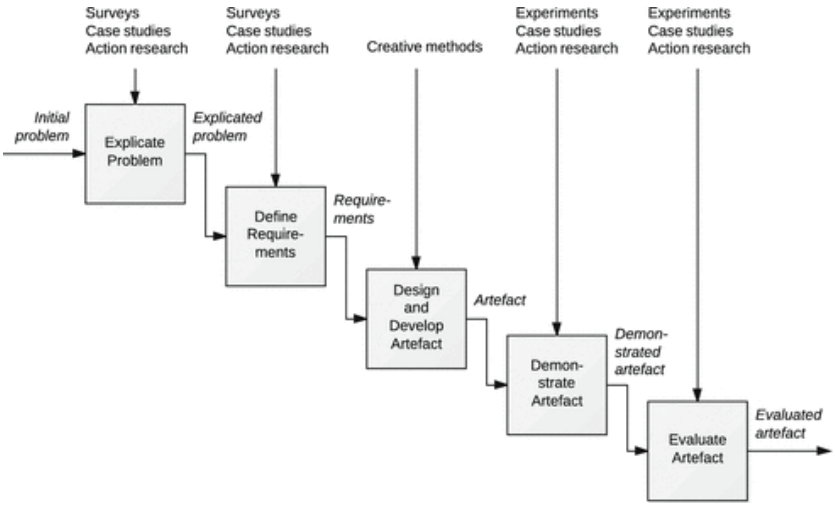
A project from the housing associations serves as the base model. This represents the existing revenue model employed by the housing associations. The base model and the circular revenue

models are tested and demonstrated with a variant study. This yields circular and financial results. These results models are compared with the revenue base model used by the housing associations to draw conclusions. The data collected for these variants are drawn from the previously mentioned interviews.

5. *Evaluate Artefact:*

These models are shared with housing association experts. The feedback is incorporated into the variant study. Appendix 5 describes the feedback received on the models and the adjustments. Following step 5 (evaluate artefact), step 4 (demonstrate artefact) is revisited. The variant study variant then includes the circular revenue models adapted according to feedback. Finally, in the variant study will be evaluated to determine whether it is currently feasible for housing associations or what needs to change to make it feasible.

Figure 2
Design research methodology



Note. From Johannesson and Perjons, 2014, pp. 75–89, Copyright 2014 by Springer International Publishing Switzerland

1.5.1 Semi-structured interviews

As discussed, this research includes of SSIs to analyse the problem and define the requirements for current temporary housing, the feasibility and the potential applicability of the circular revenue models for the housing associations. This is elaborated on in chapter 3 Research methods.

1.5.2 Variant study

The primary objective of this variant study is to design, develop, demonstrate and evaluate the feasibility of circular models for temporary housing projects. To select an appropriate research methodology for the study, Baxter and Jack's (2010) framework was used. This framework distinguishes seven different types of case studies, and two types were chosen that best suited the research objectives: the exploratory case study and the multiple case study.

The exploratory case study is most appropriate for this research because of its capacity to analyse an intervention or phenomenon and its context in the real world. This methodology offers the potential for an understanding of circular revenue models within temporary housing projects and how they compare to the revenue model of housing associations' models. In this respect it fulfils the main idea of an exploratory case study as articulated by Yin (2003).

Moreover, the inclusion of a multiple case study is necessary because it allows for an exploration of the differences between the different circular revenue models developed. This approach facilitates the comparison of the findings of these different cases (Yin, 2003).

This exploratory variant study involves analysing a circular revenue model for a temporary housing project. The exploratory case study was conducted by examining the financial results of circular models. In addition, sensitivity analyses are conducted to assess the sensitivity of the model to changes in input variables. This approach provides insight into the feasibility and potential outcomes of the circular revenue model.
To assess the financial performance a discounted cash flow (DCF) analysis was performed on the circular revenue models. This was done to compare the cash flows of each circular model with the base model currently used by housing associations.

1.5.2 Data collection

The method of data collection was different for each research method. This section explains the data collection method for each research method.

The information for the literature review was mainly obtained from online sources and books available in the library of Eindhoven University of Technology (TUE). The online data mainly includes studies found on Scopus. Searches included the following keywords: circular, business models, real estate, temporary housing. If the desired results could not be found on Scopus, Google Scholar was also used. Further, Google's search engine was used to search for news items and information about Dutch housing associations and Dutch government memos, explorations and studies.

The data for the empirical research (including interviews and case studies) was collected by engaging with experts from the housing associations and construction industry. A selection of experts was approached from housing associations with temporary housing in their portfolio. These housing associations were invited to participate in this study.

Finally, the data from both the explanatory and empirical research was applied to conduct the variant study on circular revenue models for temporary modular housing, which forms the basis for the research's conclusion and discussion.

1.5.3 Reading guide

This study's introduction defines the problem, explains the research goal, presents the research questions, highlights the relevance and the research methods.
In Chapter 2 the literature review starts with circularity for temporary housing, then reviews circular revenue models found in literature and lastly reviews the current revenue model of temporary housing of housing associations. Chapter 3 describes the research methods. It explains the details of the semi-structured interviews and explains their validity and reliability. Chapter 4 describes the results from the interview with the housing associations. On the one hand, it provides a detailed understanding of the current practices of associations housing on circularity, temporary housing and their revenue model. On the other hand, chapter 4 validates the feasibility and applicability on the in literature found circular revenue models for housing associations.
Chapter 5, the variant study, puts the theory into practice by using variant and sensitivity analyses for the different circular revenue models found in the literature and validated by the housing associations in the interviews. Each revenue model's financial feasibility is determined and compared with each other and the base model. Chapter 6, the conclusion, brings all the aspects together, including the circular temporary housing, circular revenue models and the revenue models of housing associations.

2. Literature review

This chapter of the research is an extensive analysis and review of the existing literature relevant to the core subjects of this study. The main purpose of this literature review is to present the available knowledge on circular strategies for temporary housing, circular revenue models and current revenue models of housing associations. In the first part (2.1), circular strategies for temporary housing are determined, against which the models in the second part (2.2), the circular revenue models, are compared. Finally, the third part (2.3) gathers the status of revenue models of housing associations to determine whether these already include circular revenue models.

This literature review serves as an essential basis for the interviews and variant study in chapters 4 and 5, respectively. Furthermore, as the research progresses, it will be necessary to formulate certain requirements and revenue models (for the variant study). In such cases the literature review plays a pivotal role by providing a robust theoretical foundation and the necessary underpinning and justification for any requirements introduced in the course of this research.

This chapter answers the first three sub-questions on circular strategies for temporary housing (2.1) 'what circular strategies should the circular revenue models of temporary housing be aligned with?', circular revenue models (2.2) 'What revenue models are identified for temporary housing in a circular economy?' and revenue models of housing associations (2.3) 'What are the current practices and revenue models used by housing associations for providing temporary housing?'.

2.1 Circular strategies for temporary housing

The circular strategy for temporary housing constitutes one of the three parts of the conceptual model explored in the literature review. The objective of this paragraph is to define the circular strategies that the circular temporary housing should be aligned with and to assess whether temporary housing can align with them.

This paragraph will begin by giving insights into circular strategies. Next, it will discuss how to measure these characteristics to ensure circular temporary housing solutions. Finally, it will assess whether temporary housing meets the requirements; can the temporary housing meet the requirements of the circular strategies.

2.1.1 Principles of circularity for housing

As mentioned earlier, the government aim is to make the Netherlands fully circular by 2050. However, there are many different definition of the circular economy used in research. Several studies about the definition of circular economy highlight a common set of strategies, which involve closing material cycles to conserve raw materials within products, components, and materials in the industrial system (Kirchherr et al., 2017; Zink & Geyer, 2017). Most of this is also covered by the definition used by European parliament (Circular Economy: Definition, Importance and Benefits | Topics | European Parliament, n.d.):

"The circular economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible."

This section first elaborates on the concept of circularity and which strategies are involved. Then this section explains and uses two strategies, to explain the application of circularity for buildings, its connecting concepts and the requirements it imposes. It discusses how these requirements can be met through circular principles. The objective of this section is to establish the strategies and principles of circularity for the measuring method.

The 10R framework (table 1) of Potting et al. (2016) helps shape circularity by describing 10 (R) strategies of circularity. The higher up the ladder, the higher the level of circularity. In the development process, the first three Rs must be considered. Academics and practitioners have been using this R framework for some time. This started with a 3R framework (King et al., 2005; Brennan

et al., 2015; Ghisellini et al., 2016), and then the 4R became the basis of the European Waste Framework Directive. Then studies arose using the 6R (Sihvonen & Ritola, 2015) and the 9R (van Buren et al., 2016; Potting et al., 2016). Several studies have since referenced this implementation of circularity. The 10R framework can be divided into three strategy groups: 'use and produce the product smarter', 'extend the lifespan of the product and elements', and 'useful application of materials'. In general, the higher the strategy on the ladder, the more circular the strategy is.

Table 1

Circularity strategies within the production chain, in order of priority.

Group strategy	10R's Strategy	Description
Smarter product use and manufacture	R-0 Refuse	Assess the potential for rendering a product obsolete by eliminating its core functionality or exploring the feasibility of substituting it with a significantly different product.
	R-1 Rethink	Enhance the utilisation of the product.
	R-2 Reduce	Improve the efficiency of production by minimising resource and material consumption, both in the manufacturing process and during product use.
Extend the lifespan of product and its elements	R-3 Reuse	Explore the possibility of reusing a discarded but still functional product for the same purpose by a different user.
	R-4 Repair	Engage in repair and maintenance activities to restore a broken product to its original functionality.
	R-5 Refurbish	Refurbish and modernise the original product to extend its lifespan and enhance its performance.
	R-6 Remanufacture	Utilise components from discarded products to create new products with the same intended function.
	R-7 Repurpose	Utilise discarded products or their components in the creation of new products with different intended functions.
Useful application of materials	R-8 Recycle	Process materials into products of equivalent or lesser quality.
	R-9 Recover	Employ incineration techniques with energy recovery for the disposal of materials.

Note. Adapted from *Circular Economy: Measuring innovation in the product chain (Issue 2544)*, Potting et al. (2017). In the public domain.

This section first addresses the strategy 'Use and produce the product smarter' and second the strategy 'Extend the lifespan of product and elements'. For each strategy the circular principles are defined. 'Useful application of materials' has been omitted from this study. First of all because it lacks environmental enhancement relative to prevailing construction practices. For instance, a significant portion of materials is recycled and recovered, such as using rubble for road foundations, and old wood is often utilized for incineration (CBS, 2020). In addition, R-8 Recycle and R-9 Recover are less directly relevant to housing associations. Recycling and recovery of materials are often more complex and require specialised facilities and processes that is outside the direct scope of housing

associations. These strategies focus on waste treatment and raw materials industries than on the initial construction and housing phase.

Strategy to use and produce the product smarter
The building sector is not yet at a point where all materials are reused, which is likely due to the increasing volume of new construction outpacing demolition volume, as well as the inability to detach elements, products and materials or even identify what is released. As such, raw materials must continue to be used in the construction sector; however, unnecessary use of materials should be avoided and those that are used should be employed more efficiently. This strategy group consists of the principels of refusing (R0), rethinking (R1) and reducing (R2).

Refusing (R0) involves both not designing entire unnecessary features and not using certain materials. Examples include not realising certain personal spaces, not using chemical compounds (Guy et al., 2006) or nut using artificial light but maximize natural light.

Rethinking (R1) consists of intensifying, sharing and extending the lifespan. Below, for this strategy, we will first discuss the location, the building and finally the layout. It is important to consider the environment and location of the project. For example, connecting to and making use of current (technical) infrastructure intensifies the use of external building site facilities such as sewers, roads, cycle paths and lighting. The environmental impact of a project goes beyond the building itself. Urban locations become better connected and residents can make joint use of existing facilities, for example if a bus line is already there. Van Broeck (2019) found that the social cost of infrastructure per building is 10 times higher for dispersed development than for inner-city developments.
Regarding the building itself, Habraken's research has indicated that the implementation of open floor plans and generous storey heights can extend the lifespan of a structure. This is because it has a positive effect on the flexibility and adaptability of buildings (Blok et al., 2018). However, the decision to opt for oversizing to enable future functions must be weighed against the associated carbon investment (Rijksdienst voor ondernemend nederland [RVO] et al., 2022). This creates a dilemma, as you have to decide whether it is more beneficial to oversize the structure to (potentially) extend its lifetime or to minimise material use.
For the space plan, the communal spaces and facilities should be incorporated, for example to promote car-free mobility and facilitate intensified shared spaces. When multiple users partake in the sharing of resources, their utilisation is more intensive. This leads to a decrease in individual space use. Renovation should be the starting point at the end of a lifetime. Prolonging the life can intensify the use of the existing layer of the structure.

The principle of reduce (R2) consists of minimising the impact of production and transport. The construction of houses has an impact on the environment. The extraction and processing of the required materials into products or elements contribute to this. For example, the production of cement and steel which are two of the most widely used materials in construction contribute significantly to greenhouse gas emissions. In addition, the transport of materials to the construction site and the use of equipment on site have a significant impact on (local) ecosystems.

Strategy to extend lifespan of products and elements
As aforementioned, the second group strategy is extending the lifespan of products and elements. It consists of the following principles: reuse (R3), repair (R4), refurbish (R5), remanufacture (R6) and repurpose (R7). These strategies have something in common: namely, prolonging life. Therefore, it is first necessary to determine what a lifespan is and what circular principles go with it. The requirements for principles of reuse (R3), repair (R4), refurbish (R5), remanufacture (R6) and repurpose (R7) are substantially equivalent andd therefore, unlike the previous section, they are discussed together.

The lifespan materials and elements in buildings is determined by several factors. Well-known factors are the quality of the materials used, the environment in which they are used and the maintenance of the materials and elements. Proper maintenance and upkeep can extend the lifespan of materials

and elements in buildings. These practices all fall under organizational management of the real estate. But the question is which circular principles are needed. Therefore, the end-of-life phase is critical in determining the lifespan.
The lifetime of buildings and their products and materials can be expressed in three ways (Hermans, 1999; IVSC, 2014; Grover and Grover, 2015; Mansfield and Pinder, 2008):

1. Technical or physical lifespan: this is the period the asset may be expected to last physically. Technical or physical lifespan refers to the period before a building gets demolished because the components of the building physically reach their lifespan and are no longer technically useable. This is used for life cycle assessment, which is explained in the next section.
2. Functional or social lifespan: this is the period over which humans desire or legal requirements dictate replacement. It is the period that a building loses its functional value due to societal or lifestyle changes and an alternative exists with lower or at least equal exploitation costs. For example, an old phone may still work but may not be able to run software applications due to outdated hardware components.
3. Economic lifespan: this is the period that no alternative exists with an equal or lower exploitation cost. The economic lifespan of a product or service is determined by factors such as cost of ownership and depreciation over time. Cost of ownership includes factors such as purchase price, repair costs, maintenance costs, etc., while depreciation refers to the decrease in value over time due to wear and tear or obsolescence.

All three lifespans (technical, functional and economic) are essential elements to consider when evaluating the lifetime of any product. Comprehending these lifespans assists in making informed decisions regarding investments. In the Netherlands, technical lifespan proved to be the least decisive reason for the end of the lifespan of both social housing and private dwellings (Thomsen and Andeweg-van Battum, 2005; Thomsen and van der Flier, 2007); instead, functional or economic motives are currently more significant.
Additionally, long term considerations are a key enabler of change due to economic, social or technical alterations. Consequently, perceiving buildings as dynamic systems that respond to emerging social, economic or technical needs (Schmidt et al., 2009) with long-term consideration of the sustainability of the built environment is essential in a circular economy.

When the technical lifespan is deemed the decisive factor, the lifespan of the building should be able to adapt to changing social, economic and technical needs and conditions over time. As technology advances and user needs change, buildings must be able to accommodate these changing factors. To extend a building's technical lifespan, a dynamic system that considers adaptability and detachability is necessary. Adaptability refers to the ability of a building to be modified or altered over time, while detachability refers to the ability of components or systems within a building to be removed or replaced without affecting the overall structure. Often utilised terms and strategies that are included in adaptability or detachability are 'flexibility, durability, transformability, upgradability, convertibility, accessibility (spaces for all life stages accessible), open plan, and performance-based building' (which describes the performance dimensions of a building concerning the functionality and preserving fit purpose over time) (Wilkinson, 2014).

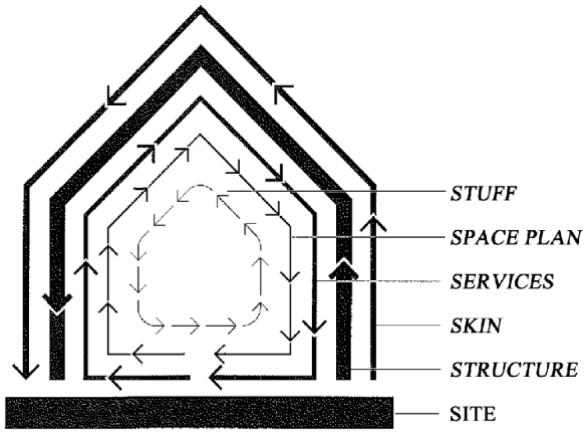
Adaptability is an important factor in extending the functional lifespan of a building because it allows for changes (Leaman et al., 1998). For example, if a building was originally designed as an office space but later needs to be converted into residential units, adaptable design can make this transition possible with less waste. The consideration of context enhances the ability to adapt and adjust to new conditions, which is a characteristic of adaptable buildings highlighted by Douglas (2001) and other authors.

If the technical lifespan is exceeded, adaptability and detachability makes it possible to reuse (R3), repair (R4), refurbish (R5), remanufacture (R6) and repurpose (R7). Detachability is therefore also an important factor in extending the lifespan of a building because it allows for components or systems within a building to be removed or replaced without affecting the overall structure, which is in line

with the R ladder. For example, if an outdated HVAC system needs to be replaced with a more efficient system, detachability allows for this change without having to demolish any part of the existing structure. This makes it easier and more cost-effective for owners to update their buildings over time, which also extends the economic lifespan. However, there are certain technological requirements that must be considered when designing an adaptable and detachable building. It can be concluded that detachability and adaptability can be defined as a design feature with a base in terms of time and absence of waste. Waste is a result of the building's inability to adapt to future conditions. Circular principles need to be established for adaptable and detachable buildings.

The perception of a building as a static entity is giving way to a more dynamic understanding that emphasises adaptability and detachability. This evolution in thought, supported by several studies including those by Duffy (1990), Brand (1994), Durmesivec and Brouwer (1999) and Van Vliet (2018), underscores the importance of considering buildings as dynamic systems with interconnected subsystems. Duffy (1990) defines these systems as the four layers of longevity (i.e. lifespan) of building components. Duffy called these the four layers and Brand elaborated on this concept in his book called *How Buildings Learn: What Happens After They're Built*. Brand (1997) expanded the layers to the six Ss (figure 3): skin, structure, space plan, stuff, services and site. Each of these hierarchal layers has its own life expectancy and impact. This framework shows that each different building layer should allow for replacement by adaptability or detachability. This is because some layers have a much shorter functional or technical lifetime and need more replacements than other layers. Therefore, it is important to construct the layers such that they do not depend on each other or interconnect. This means that there should be no or nearly no connections between the layers. The dependency on layers largely influences the building's adaptability and detachability.
Brand (1997) declared that all buildings are predictions, and all predictions are wrong. With this he pointed out that buildings that are not designed for change have a problem. He therefore called the six s's the 'shearing layers of change'. Understanding these layers enables an increase of the height on the R ladder for circularity.

Figure 3
6S shearing layers



Note. From *How buildings Learn: What happens after they're built,* Brand, S., 1997, Copyright 2017 by BERQ

Durmisevic and Brouwer (1999) have a different perspective. According to them there is hierarchy of four functional levels of building composition, which are building, system, component and element. Between these levels, flexible connections must exist to allow for change. Disassembly takes place at the building level to separate systems, at the system level to separate components and finally at the component level to separate elements and materials.
Understanding this technology enables getting high on the R ladder. The concepts of Steward, Durmisevic and Brewer can be used interchangeably. The layers of shearing are about the entire function of a part of the building: skin, structure, space plan, stuff, services and site. Within these layers, scaling can be applied to systems, components, elements and materials..

Van Vliet (2018) identified the technical requirements for building disassembly of systems, components, elements and material by identifying different types of independency, relational pattern, assembly sequence, assembly shape, method of fabrication, type of connection and accessibility to connection.

Conclusion
The core strategies of circularity (R0–R9) can be classified into three strategy groups: 'use and produce the product smarter', 'extend the lifespan of the product and elements', and 'useful application of materials'. In general, the higher the strategy on the ladder, the more circular it is.

The 'use and produce the product smarter' group consists of the following strategies: refuse (R0), rethink (R1) and reduce (R2). Refusing (R0) involves the circular principles of not designing entire features and not using materials. Rethinking (R1) involves the circular principles of sharing and prolonging life. Reducing (R2) involves the circular principles of minimising the impact of production and transport.

The 'extend the lifespan of the product and elements' group consists of the strategies: reuse (R3), repair (R4), refurbish (R5), remanufacture (R6) and repurpose (R7). The lifespan of the building should be able to adapt to changing social, economic and technical needs and conditions over time. This can be achieved through by an adaptable and detachable building. This can be achieved by a clear distinction between shearing layers and materials, components, products and elements.

Incorporating the found strategies into circularity measurement methods and revenue models is crucial for making informed decisions and achieving the strategies. It is therefore necessary to investigate how these principles can be incorporated into the measurement method and circular revenue models, which the following section addresses.

2.1.2 Measuring circularity
In the previous section, group strategies and various principles, including detachability, material non-use, sharing, prolonging life, and minimizing production and transportation impact, were defined. However, these represent distinct principles and does not offer a comprehensive metric for circular houses. This section first outlines how circularity at government level is defined in the Netherlands. Next, it examines the various methods for quantifying circularity, discussing their advantages and disadvantages. Finally, a measuring method is chosen through a multicriteria analysis to serve as the basis for determining whether the temporary housing matches circular strategy and thus the circular revenue models.

50% circular
The initial objective of the nationwide programme Netherlands Circular in 2050 is that by 2030, the Netherlands should reduce its usage of primary resources (minerals, metals and fossil fuels) by 50%. The government refers to Cb '23 for the circularity measurement method (Meetmethode Voor Circulariteit in De Bouw, 2022). However, a uniform circularity measurement method has not yet been established.
Three key indicators have been identified in the circular measuring guide. The first pertains to protecting material inventory, the second to protecting the environment through environmental impact scoring, and the third to protecting existing value. The last one refers to the extent to which components can be reused and retain their value. All three indicators align with the circularity strategies and principles as described in the previous section.
However, in the circular measuring guide, certain indicators remain open to a considerable degree of interpretation (Platform CB'23, 2020). It was therefore chosen to look for a comprehensive measurement method.

Comprehensive measuring methods

This section explains commonly used circularity measurement methods, indicating why they do or do not align with the strategy groups named in the previous section. The methods that are analysed are Life Cycle Assessment, MPG (dutch: Milieu prestatie gebouwen), Material Circularity Index and Building Circularity Index. The conclusion will discuss which method is most appropriate for measuring circularity.

Life Cycle Assessment

The Life Cycle Assessment (LCA) is a method that encompasses the environmental impact of the building. This environmental impact of buildings is wider than the only energy use in the use phase because it also includes the embodied energy and environmental impact related to resource extraction, manufacturing, construction activities, dismantling and construction waste disposal at the end-of-life phase (Sesana & Salvalai, 2013). LCA ISO 14 040 is a method to determine the total environmental impact of a product throughout its life cycle. It provides insight into the effects of different products and their processes. The effects of the life cycle are highly interdependent. It may be the case that a lot of embodied energy is put into the first phase, which is easily 'recouped' later in the use phase. Think of a windmill. Its construction uses large amounts of steel, which has a high embodied energy. But in the use phase, this is earned back (Sesana & Salvalai, 2013).
The outcome of an LCA is an environmental profile with different measures environmental impacts. This is difficult to interpret. Additionally, these do not include the components for protecting material inventory and protecting existing value. This method also does not include detachability. This method thus only includes 'reduce' by measuring the environmental impact of the product, element or system over the lifetime.

MPG

The results of the LCA can be translated into shadow costs (Quist, 2021). This is done in the MPG tool which is mandatory in the Netherlands. 11 Impact categories are weighted and linked to a monetary value such as euros. These 11 monetary values are combined into one score: the total shadow costs of a product or material. These shadow costs are calculated over all materials of a building. The costs are then divided over the floor area of the building concerned. As a result, the MPG is expressed in euros/m^2/year (Quist, 2021). However, the MPG does not yet include all factors in the determination method. For instance, it does not consider the effect of CO_2 retention in wood. TNO states, 'Calculations show that if biogenic CO_2 is included, the net contribution to climate change related to the production of the wooden houses is half'.
The outcome of an MPG is one variable of the impact of the building, which is easier to interpret than the LCA. However, this method does not include the other strategies.

Material circularity index

The Ellen MacArthur Foundation has developed the Material Circularity Index (MCI) (Material Circularity Index [MCI], n.d.) to evaluate circularity within supply chains and products. The MCI measures the extent to which materials and products incorporate recycled and renewable resources, as well as their recyclability and reusability at the end of their life cycle. By considering these aspects, the MCI offers a comprehensive evaluation of circularity on material level. However, this method does not consider the levels of building, system, component and element.

Building circularity index

The Building Circularity Index (BCI) score represents a composite measure of circularity derived from the calculation of various metrics including the Material Circularity Index (MCI), the Disassembly Index (DI), the Product Circularity Index (PCI), the Element Circularity Index (ECI), and the environmental impact (as measured by the MKI) of each individual product or element within a building. The detachability of the layers and the whole building are determined according to the following characteristics: type of connection, accessibility of the connection, shape enclosure and intersections (Whitepaper Building Circularity Index V1.0, 2022). These metrics are weighted and

combined to generate a single score, the BCI. However, the strategies of refusing or rethinking are not measured.

In table 2 below the different measuring methods are test on the strategies found in the previous section

Table 2

Inclusion of circular strategies in measuring methods

	Use and produce the product smarter		*Extend the lifespan of the product and elements*
	R0 Refuse / R1 Rethink	R2 Reduce Impact production and transportation	R3 – R7 Detachability and adaptability on different levels
LCA	No	Yes	No
MPG	No	Yes	No
MCI	No	Yes	No
BCI	No	Yes	Yes

Conclusion

In conclusion, after evaluating several circularity measurement methods, the Building Circularity Index (BCI) appears to be the most appropriate for further elaboration in this study, because the BCI aligns the best with the indicators in table 2. The BCI is the most comprehensive a tool for decision-makers to make informed decisions that take circular strategies into account. However circular strategies rethink (R0) and reduce (R1) are not considered within this tool.

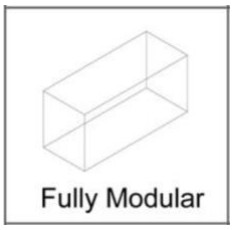
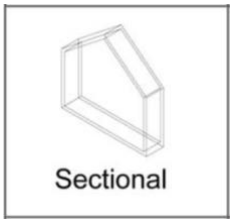
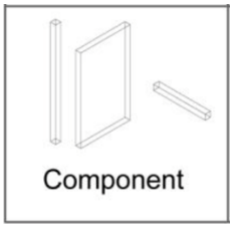
2.1.3 Circular temporary housing

Circular strategies were defined in the previous chapter. The extent to which these strategies fit temporary housing is analysed in this chapter. What is needed is to determine whether housing is suitable for all circular strategies and thus circular revenue models. Therefore, this subsection discusses temporary housing and its relationship to circularity.

This research focuses on the use of modular temporary housing, as most temporary housing solutions are modular in nature. A growing number of companies are interested in industrial building systems based on modularity (Barbosa et al., 2017; Bertram et al., 2019; Hofman et al., 2019). Rutten conducts annual market research on providers of modular industrial construction with more than 75 homes in the development. The 2022 results show a clear increase from 21 market players in 2018 to 130 in 2022.

Modular construction is a building technique in which modules are coupled or stacked to create the desired shape of the building. The module represents the standardised segment which is spatially dimensionally unified (Hoínková, 2021).
Broadly speaking, there are three different types of modular construction: fully modular, sectional modular and component modular (Huang, 2007).

Table 3
Type of modular construction

Fully modular • 3-dimensional modules like boxes • Simple connections for installation on the foundation and service conducts • Size restrictions for transport	
Sectional modules • 2-dimensional walls and floors • Smaller and easier to transport • More labour at the construction site	
Component • Factory made components such as facade components • Allowing more flexibility in the design process • Easy transport • Most labour at the construction site	

Note. Figures in table from *A Choice Model of Mass Customized Modular Housing by Internet Aided Design, Huang,* J., 2007.

Modular housing in relation to circularity

The current literature does not provide information on the results of BCI scores (2.1.2) for temporary housing or modular housing. Hence, the decision has been made to explore the relationship with the strategies outlined in the first section of the paragraph, being 'extend the lifespan of product and elements,' and the group strategy of 'using and producing the product smarter.' As a starting point for the transition towards the circular economy, modular construction has potential. This is because of its industrial character and its predestined character for disassembly, reuse and circular resource flows, as already showcased in various other industries. Multiple studies have already shown that modularity facilitates detachability and offer opportunities for the R3–R7 strategies at end-of-life (Ellen MacArthur Foundation, 2015a, b; Van den Berg, 2019; Minunno et al., 2018b; Mackenbach et al., 2020; Chung et al., 2014; Kimura et al., 2001; Ma and Kremer, 2016; Okudan Kremer et al., 2013). This is in line with the circular strategy ‘extend the lifespan of product and elements’.
Potemans' (2017) case study examined different systems of modular housing. The study's findings were as follows: all modular housing systems were detachable, with some able to be disassembled down to the elemental level due to the use of dry joints; others could be broken down to the component level when elements were chemically joined together. Within the modular housing system, these components could be reused, but their reusability outside this system was not investigated further. Furthermore, all modular building systems, were adaptable at the end of functional life. These opportunities are consistent with the adaptable and detachable approach to circularity described in the literature. The constraint is the systems potential for deconstruction. Adaptability and detachability align with the circular strategy of ‘extending the lifespan of products and elements’.

One of the construction companies, Daiwa House Modular Europe, conducted a carbon footprint analysis for modular construction in comparison to traditional construction (Nikerk, 2023). This

analysis was confirmed by EcoReview, a specialist in LCAs. The modular construction method resulted in over 50% less CO_2 emissions compared to traditional construction methods. It is reasonable to assume that this was due to efficient production processes in the factory and the minimal number of transport movements. However, no further research has been conducted on this topic. The reduction in CO_2 is in line with R2 ('Reduce'), which is part of the circular strategy 'use and produce the product smarter'.

2.1.4 Conclusion

Modular temporary housing aligns with the strategies 'extend the lifespan of products and elements' and 'Use and produce the product smarter' as outlined in the first part of the literature review. Therefore, the housing is suitable for the circular strategies and thus circular revenue models. However, the extent of this alignment cannot be determined due to the lack of data from the BCI on temporary housing.
The current literature does not provide information on the results of BCI scores for temporary housing. Therefore, interviews will be conducted to ascertain if a deliberate selection of modularity type was made in advance and whether the consideration of circularity (using BCI) played a role in this decision.

2.2 Circular revenue models

Circular revenue models constitute one of the three parts of the conceptual model explored in the literature review. The aim of this paragraph is to identify and review circular business models for temporary housing. However, there is little knowledge about specific circular revenue models for temporary housing as circular revenue models are a relatively new sector with still-developing literature. Therefore, this section first discusses circular business models that are gaining traction in various sectors, including real estate (2.2.1). This is achieved by comparing three publications of general circular business models found in the literature. These are compared to the circular business models specific to real estate. This section then presents an overview of the current state of these circular business models and then analyses potential applications of the circular business models (2.2.2). After, this section analyses the key aspects of the cost and revenue components (revenue model) in the business model.

2.2.1 The business models of circularity

The biggest barrier to adopting circular economy in the built environment is the unclear revenue model (Adams et al., 2017b). Circular business models can be defined as the way an organisation creates value within closed material loops (Geissdoerfer M, Moroka S N, de Carvalho M M and Evans S 2018 J. Clean Prod. 190 712–721). Circular business models typically align commercial value creation with resource efficiency strategies by putting the value of the environment and economics in the products. In traditional models, this value is mostly depreciated to zero and the value is lost. The added value of these circular business models becomes evident in a total cost of ownership (TCO) analysis, as this approach considers not only the acquisition costs but also the costs incurred during usage and end-of-life (Copper8, 2020).

First, this section explains the difference between a business model and a revenue model. The various archetypes of circular business models are then described below. In addition, it explains through a timeline which of these models are of interest to housing associations. Next, real estate specific models are discussed and compared. The conclusion assesses which elements of the different models are relevant.

Business models and revenue models

A business model consists of several components. A business models can be divided into four questions (Eschberger-Friedl, n.d.).

1. "Who are the target customers (segments and relationships)?"

2. “What is the benefit a company provides to its customers and key partners in the value chain (value promise or value proposition)?”
3. “How does the company deliver this benefit (partners, activities, resources)?”
4. “How does the company make money?”

The last question focusing on how a company makes money is the revenue model. This research mainly focuses on the revenue model. This research also delves into identifying the customer involved, the housing associations or the social tenant. The revenue model is part of the wider business model and refers to the methods and strategies a company uses to generate revenue.

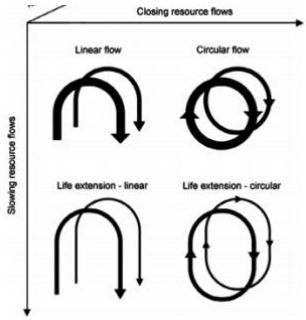
In the context of this study, the focus is on understanding and analysing the circular revenue model. This involves delving into how revenue is generated within the scope of housing associations and the circular revenue models. However, little information is available on the circular revenue models separately. Therefore, it is chosen to analyse circular business models in the litarature.

Archetypes of circular business models

Three studies repeatedly referred to when discussing circular business models are Bocken et al. (2016), Moreno et al. (2016) and Bakker et al. (2014) (as shown in table 4). Below, the archetypes of circular business models are sorted. The primary aim of business models for slowing loops is to decelerate or prolong the life cycle of products and materials, minimizing their environmental impact. Business models for closing loops aim to create a closed-loop system, wherein products and materials are reused and recycled, and their components are reintroduced into the production cycle (Bocken, et al 2016). This is shown in figure 4.

Figure 4

Framework of closing, slowing and narrowing resource loops.



Note. *Product design and business model strategies for a circular economy*, Bocken, et al, 2016.

Table 4

Types of business models found in the publications of Bocken et al. (2016), Moreno et al. (2016) and Bakker et al. (2014).

Publication	Business models for slowing loops or closing loops	Archetypes of circular business models
Bocken et al. (2016)	Slowing loops:	Access and performance, classic long life, encourage sufficiency
	Closing loops:	Industrial symbiosis, extending resource value, extending product value
Moreno et al. (2016)	Slowing loops:	Product life extension, sharing platforms
	Closing loops:	Circular supplies, resource value, extending product value.

Bakker et al. (2014)	Slowing loops:	Access model, performance model, hybrid model, classic long-life model
	Closing loops:	Gap exploiter model

Next, these archetypes are compared with each other to define a research-supported list of circular business models. In addition, these models are compared with the phases of life and the 10R model for circularity. The aim is to organise the archetypal business models to produce an overview of the circular business models.

Model 1 - Performance and access models
This model focuses on delivering a service instead of a product. The user pays for the service. An example is Philips with their pay-per-lux service. Philips sells the service of light instead of selling a light bulb. The aim is for the manufacturer to develop a product with a long lifespan that easily can be extended by R3 to R7 (reuse, repair, refurbish, remanufacture and, repurpose). Bocken et al. (2016) refer to this model as an 'access and performance' model. Bakker et al. (2014) refer to this model as a 'performance model' and 'access model'. The access model differs from the performance by renting out, for example car rental which is not based on performance but based on the product. Both studies do not differ much in describing the models. This model is in line with the strategy "Extend the lifespan of the product and elements" and therefore the BCI can be used to determine the applicability of the model to the building.

Model 2 - Sharing platforms
This model focuses on increasing utilisation by shared use, access or ownership. It is based on the principles of the sharing economy. This model works by connecting producers, consumers and third-party organisations through a platform, allowing them to share and trade resources, materials and services. Moreno et al. (2016) refer to this model as 'sharing platforms'. The other studies by Bocken et al. and Bakker et al. do not describe an equivalent model specifically focused on increased utilisation. This model is in line with the strategy "Extend the lifespan of the product and elements". This model is in line with the strategy "R0 Refuse and R1 Rethink" and therefore the BCI cannot be used to determine the applicability of the model to the building.

Model 3 - Classic long-life model
This model focuses on delivering a product with a long lifespan. It focuses on product durability, reuse, and remanufacturing in order to extend the product's life cycle. Bocken et al. (2016) refer to this model as a 'classic long life'. Moreno et al. (2016) refer to this model as a 'product life extension'. Bakker et al. (2014) refer to this model as 'Classic long life model' and 'hybrid model'. The models 'Classic long life', 'Product life extension' and 'Classic long life model' are in line with each other. The hybrid model differs and refers to a model that relies on a combination of a long-lasting product with consumables (often disposables) to fulfil a certain function. This model is in line with the strategy "Extend the lifespan of the product and elements" and therefore the BCI can be used to determine the applicability of the model to the building.

Model 4 - Encourage sufficiency
This model focuses on enabling extended product and resource value through solutions that actively seek to reduce end-user consumption through adaptability, repairability, upgradability, etc. Bocken et al. (2016) refer to this model as 'encourage sufficiency'. The other studies do not refer to this model. This model is in line with the strategy "Extend the lifespan of the product and elements" and therefore the BCI can be used to determine the applicability of the model to the building.

Model 5 - Extending product value
This model focuses on retaining ownership and by doing so benefitting circular resource productivity. This is done by extracting residual value in the 'after life phase'. Bocken et al. (2016) refer to this model as 'extend product value', Moreno et al. (2016) refer same to this model as 'extending product

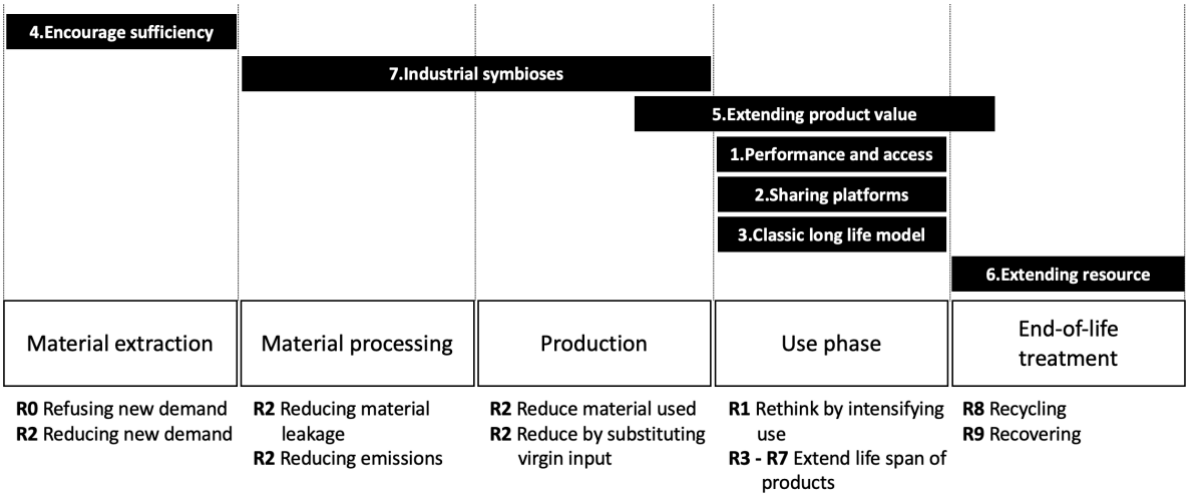
value' and Bakker et al. (2014) refer to this model as a 'gap exploiter model'. The difference of the model of Bakker et al. and the other researches is that it combines the models of the lost value of industrial symbiosis during production and at the 'end' of the life of the product and resource. This model is in line with the strategy "Extend the lifespan of the product and elements" and therefore the BCI can be used to determine the applicability of the model to the building.

Model 6 - Extending resource value
This model focuses on recovering the value of materials and resources so that the resource can be used in a new product. Bocken et al. (2016) refer to this model as 'extend resource value'. Moreno et al. (2016) refer to this model as a 'resource value'. Bakker et al. (2014) refer to this model as a 'gap exploiter model'. This difference of gap exploiter model with the other researches is that it combines it with products and industrial symbioses. This model is in line with the strategy "Extend the lifespan of the product and elements" and therefore the BCI can be used to determine the applicability of the model to the building.

Model 7 - Industrial symbioses
This model focuses on using residual outputs from an industrial process as a resource for another process. Bocken et al. (2016) refer to this model as 'industrial symbioses'. Moreno et al. (2016) refer to this model as 'circular supplies'. Bakker et al. (2014) refer to this model as a 'gap exploiter model'. This model is in line with the strategy "Extend the lifespan of the product and elements" and therefore the BCI can be used to determine the applicability of the model to the building.

These archetypes of circular business models are related to circularity. To demonstrate this, these archetypes of circular business models are compared with the, in previous part found, 10R strategy in 'time' from material extraction to end-of-life in figure 5 below. This model is based on the model of Nußholz (2017), an overview of existing categorisations of resource efficiency strategies. Horizontally in the black bars with white text are the seven business models mentioned above. These models are mapped over time in the life cycle from material extraction to end-of-life. This life cycle can be linked to circular strategies R0–R9.

Figure 5
Business models in lifetime of material



Note. Adapted from *Circular Business Models: Defining a Concept and Framing an Emerging Research Field,* Nußholz, J., 2017.

These concepts thus belong to the circular strategies defined in the first part of the literature review. However, for temporary housing of housing associations, the main focus is the use phase of the product. Therefore, circular business models that fall entirely within the use phase are of interest of this study, which are model 5 (extending product value), model 1 (performance and access), model 2 (sharing platforms) and model 3 (classic long-life model). The other models are not of interest to this

study. Some of the models have a relation to the BCI scoring (R2-R7) and others do not have a relation the BCI scoring (R0 and R1).

Real estate specific circular business models
The archetypes business models, which are of interest, are applicable across all products and thus not specific for real estate. Therefore, it is chosen to explore specific models for the real estate, from now on real estate specific circular business models. Two studies on real estate specific circular business models were found and have been further elaborated from two different viewpoints. One study focuses on the potential market in which (new) companies can nest (Carra et al., 2017). The other focuses on projects of real estate development companies (Arup Group & Ellen MacArthur Foundation, 2020). The study proposes alternative real estate specific circular business models for the construction projects. Both studies have much in common as their strategies are aligned. The aim for this study is to define a list of possible real estate specific business models.

Comparing the models of Carra et al with Arup Group & Ellen MacArthur Foundation reveal many similarities. Similar business models are merged into one. Unique models are included separately. From this, the subsequent business models are then derived. A detailed description of the business models is included in appendix 1. Below each model is discussed with the first name in the title of Carra et al and the second part between brackets of Arup Group & Ellen MacArthur Foundation. The subsequent business models are referred to as sub real estate circular business models in this study.

Model A - Flexible spaces (sharing platforms)
This model is based on a higher utilisation of existing stock through its shared use. Earnings can be made on shared-use transactions (Carra et al., 2017). A specific application of this model is flexible spaces (Arup Group & Ellen MacArthur Foundation, 2020). The lost value of underutilised space is captured with this model. A platform can list actual data from a building to make all unused space available to tenants.

Model B - Shift in ownership of materials and products (Product as a service (PAAS) / sell and buy back)
This model captures the lost value of underperforming components. This encourages service providers to create long-lasting, high-performance systems. The model is mainly compelling for the shearing layers skin and services as they determine the energy performance of a building; this allows the model to generate a return. By offering products as a service, products are often extended in life through reuse, repair, refurbishing, remanufacturing or repurposing.
Another ownership business model that is included is sell and buyback. This model provides a product that is sold with an upfront commitment that it will be repurchased after a certain period of time.

Model C - Adaptable assets (lifetime extension)
This model captures the lost value of prematurely demolished buildings. Real estate use can be changed at lower market costs, often by retrofitting through disassembly, reassembly, repair and maintenance, rather than demolition. This approach offers flexibility in adapting and repurposing property structures, contributing to cost-effectiveness and sustainability. This model can be based on a different investment partnership because of the different lifespans of the shearing building layers. The proposal of Ellen MacArthur's (2020) study is a long-term investment for the skin and structure. Short-term investors rent the skin and structure for a specific space plan for particular use.

Model D - Relocatable buildings (lifetime extension)
This model captures the lost value of a piece of vacant land. In cities where land is scarce, this model can provide affordable space to users. It can also enable operators and landowners to recover lost values. The building will then be operated in multiple locations. The lifetime of the building is prolonged by reusing the whole building.

Model E – Residual value
This model captures the lost value of depreciated building materials. The introduction of commodity futures contracts for buildings is inherent in this model. These contracts can be traded on a central exchange. The value is linked to the estimated future value at dismantling. The contract contains all information on the materials released on dismantling. The forward contract is tradable. The holder of the term contract upon decommissioning is the owner of the materials. The building must be designed for the deconstruction of retrieving materials. However, the market for this type of contract has not yet developed enough to use this business model.

Model F – Support life cycle
This model captures the lost value of prematurely demolished materials. This business model makes revenues off sales from consumables to support the life cycle of long-lasting products.

Comparing the circular business models
When comparing the archetypes of circular business models with the real estate specific circular business models, the following links can be logically established. **Performance and Access Model (Model 1)** aligns with **Model B (Shift in Ownership)**, as both provide a service rather than a product. **Encourage Sufficiency (Model 4**) and **Classic Long-Life Model (Model 3)** connect with **Model C (Adaptable Assets)** because all three supporting the idea of adaptable and long-lasting use of buildings. **Extending Product Value (Model 5)** connects with **Model D (Relocatable Buildings)** and **Model E (Residual Value)**, because they both seek to extend the lifecycle of the physical building and its materials. **Industrial Symbioses (Model 7)** and **Extending Resource Value (Model 6)** find practical applications in real estate through **Model F (Support Life Cycle)**, which enhances material reuse and recycling in building operations. **Sharing Platforms (Model 2)** connects to **Model A (Flexible Spaces)**, utilizing the sharing platforms for space efficiency. These connections represent the most logical connections between the various models, which also link with the other models.

In conclusion, the circular business models of extending product value (3), performance and access (1), sharing platforms (2) and classic long life model (5) are relevant to the development of a circular revenue model. These circular business models align with the circular strategies. Real estate-related studies elaborate on these models. Models that could potentially be integrated are shift in ownership of materials and products (A), adaptable assets (B), relocatable buildings (C), residual value (D), flexible spaces (E) and support life cycle (F).
By using the circular business models presented, the loops of buildings, structures, elements, materials and products are slowed and closed. It should be mentioned that these models do not consist only of revenues and costs (revenue models), but also of the other subcomponents such as customer segments, value proposition and partners.

2.2.2 Application of circular business models and identifying the circular revenue models
This paragraph aims to identify the applications of the circular business models, align them with the strategies and provide insight into the revenue model. This section first presents business models, including their application to temporary housing for housing associations. This is followed by the models' customer segment, which includes both external and internal circular business models. Next, it elaborates and give insight into the key aspects of the revenue models of the business models. This consists of the key aspects for external revenue models and is followed by an analysis of the key aspects for internal revenue models.

The application of the models
Table 5 organises the circular business models into four columns for clear analysis of the found circular business models. The archetypes of circular business models are derived from the aforementioned literature and placed in the first column of the table. The second column outlines circular business models specific to real estate, referred to as real estate specific models. The relationship as indicated in the previous section, the real estate specific models are arranged under

the archetypes of business models. The third column outlines the applications and examples of the circular business models in the first and second column found in literature. These are numbered from 1– 13. Some applications have multiple applications under different archetype of real estate business models and real estate specific business models. These can be recognised by the number in front of the application (see 8 and 4). The fourth column identifies the primary customer for each business model application:

- external if revenues go to an external party, such as investors, manufacturer or developers and
- internal if the service and/or products' revenues are collected from tenants by the housing association.

This classification helps demarcate for who the circular business model is and provides a comprehensive overview for further analysis and insights into the revenue models in the section below the table.

Table 5
Applications of the circular business models

Archetypes of circular business model	*Real estate specific circular business model*	*Applications of circular business model found in literature*	*External / Internal*
Model 1 - Performance and access model	*Model A - Shift in ownership of materials and products*	1. Creating smaller personal spaces and more shared pay-per-use spaces 2. Pay-per-use laundry machine (Bocken et al., 2018). 3. Signify has a pay per lux business model (Case Study: Signify Light-as-a-Service, n.d.).	*Internal* *External/ internal, External*
	Model A - Shift in ownership of materials and products	4. Procure products kitchens, facades (Circle Economy et al., 2020) or mechanical installations with technical performance as a product as a service, guaranteeing performance (Trevor, 2021). 5. In the circular building catalogues of the Netherlands there are companies which procure kitchens, elevators, facades and lighting (De Circulaire Bouwcatalogus - Circulaire Diensten, n.d.).	*External*
Model 6- Sharing platform	*Model E - Flexible spaces*	6. Sharing underutilised by others; parking, offices, fitness, childcare, training (Aalto-Yliopisto, 2019; Arup Group & Ellen MacArthur Foundation, 2020). 7. Co-living concepts (Arup Group & Ellen MacArthur Foundation, 2020).	*Internal* *Internal*
Model 7 - Classic long life model	*Model B - Adaptable assets* *Model D - Residual value*	8. Set building requirements that allow for materials and products to be easily reused (Arup Group & Ellen MacArthur Foundation, 2020).	*Internal*
	Model C – Relocatable housing	9. Reuse the entire building in another location (Arup Group & Ellen MacArthur Foundation, 2020).	*Internal*
Model 2 – Encourage sufficiency	*Model B – Adaptable assets*	8. Set building requirements that allow for materials and products to be easily reused (Arup Group & Ellen MacArthur Foundation, 2020).	*Internal*

	Model D – Residual value		
	Model B – Adaptable assets *Model D – Residual value*	10. New ownership structure in which the housing association is not the owner of all shearing layers (Arup Group & Ellen MacArthur Foundation, 2020).	*External*
Model 3 - Extending product value	*Model A - Shift in ownership of materials and products*	4. Procure products (facades or mechanical installations) with technical performance as a product as a service, guaranteeing performance (Arup Group & Ellen MacArthur Foundation, 2020).	*External*
	Model A - Shift in ownership of materials and products	11. Buy products with a guarantee of sell back to producer, such as kitchen, furniture and carpet tiles (Arup Group & Ellen MacArthur Foundation, 2020; KPMG Advisory N.V. et al., 2019).	*External*
Model 4 - Extending resource value	*Model B - Adaptable assets* *Model D - Residual value*	8. Set building requirements that allow for building and for recovering resources (captured by the measuring method) (Arup Group & Ellen MacArthur Foundation, 2020).	*Internal*

As described in the third column, the literature contains several opportunities and examples of applications of circular business models. However, this list of potential applications is not exhaustive. Within this list the models where the tenants are customers of the housing association are identified as 'internal'. The models where the housing associations are the customers of external business models are identified as 'external'. This addresses the first question as articulated for business models: 'Who are the target customers?'. The other business model questions, 'What is the benefit a company provides to its customers and key partners in the value chain?' and 'How does the company deliver this benefit?', are not relevant to answer in this study, as this research only explores the revenue models. The question of how the company makes money is addressed below and is referred to as revenue model within the internal and external business models. The analysis of revenue models within business models was done on the basis of whether it is an internal or external model.

Key aspects for <u>external</u> revenue models in the business models

The new external circular business models in the third column of the table are 2, 3, 4, 5, 10 and 11. This part delves into the revenue stream of the business models. Therefore, as defined in 'the application of the models' subsection of 2.2.2, the models are hereafter referred to as revenue models.

In these models the producer is responsible for the product during and/or after the use phase. The houses association repeatedly has to pay an amount to the external producer. The applicability of these six ownership models depends on four key aspects (Copper8, 2020).

Key aspect 1 - Operational expenses

Circular products have the potential to reduce operational expenses (OpEx), leading to better justification of investment expenditure (CapEx) (Copper8, 2020). The implementation of circular revenue models offers significant opportunities, especially in building layers with higher operational expenses. In Smeets' research (2019), finance and residual value experts emphasized a higher potential for implementing circular revenue models in the skin and service layers.

Holding producers responsible for operational costs through circular business models incentivises them to incorporate new, efficient technologies with long lifetimes and thereby lower expenses. This creates an appealing business case both for building owners and users and for producers.

Key aspect 2 - Short lifespan
Several researchers (van Renswoude et al., 2015; van Oppen et al., 2018) have highlighted that the lifespan of a product plays a significant role in the adoption of a circular revenue model. Specifically, products with longer life cycles are considered less suitable for circular revenue models.

Key aspect 3 - High degree of innovation
Product categories characterised by a high degree of technical innovation, which enhances product functionality, are generally more suitable for a circular business model. Implementing a circular business model creates an incentive for producers to provide adaptable products that can evolve alongside market innovations. As a result, it is conceivable that the building shearing layers (as found in 2.1.1) of skin and services are particularly suitable for a circular business model.

Key aspect 4 - Complexity
Circular revenue models are more suitable to adopt to technical complex products. This is because the real estate owners lack the knowledge to maintain and repair, while producers have this knowledge and can optimise. Due to this knowledge gap, it is easier to achieve both circular and financial gains when producers retain responsibility for the products. As a result, it is conceivable that circular revenue models are most applicable to the layers where most knowledge is needed; service layer within buildings.

In conclusion, there are opportunities for applying circular ownership models externally. This is particularly evident in the skin and service layer, which is influenced by all four aspects, and the space plan layer, influenced by its short lifespan. However, Copper8's study considered buildings with long lifetimes and did not consider buildings with short functional lifespan like temporary housing. With temporary housing, even the shearing layer of structure can have a short lifespan. Therefore, in contrast to the conclusions drawn by these studies, it is decided to incorporate all levels of shearing layers. Thus, all proposed external circular revenue models meet the key aspects.
The applicability of the external circular business models for temporary housing for housing associations remains unknown. This cannot be determined solely from the literature.

Key aspects for <u>internal</u> revenue models in the business models
From the internal business models, two types can be identified. The first type comprises models that incorporate new revenue streams, such as product as a service, underutilised space and flexible space. The second type includes models that aim for higher residual reuse value, such as relocatable houses, adaptability and easy reusability. The revenue models of the two types of business models are discussed below. The discussion below relates to the revenue stream derived from business models and will henceforth be referred to as revenue models.

Revenue streams
To gain insights into the revenue streams, it is necessary to first determine the application. Subsequently, an estimation needs to be made regarding the potential additional income and the corresponding extra associated costs. The same principle applies to the technical requirements. To illustrate using the example of a flexible share space, certain requirements must be fulfilled: namely, the space should be easy to find, and it should be easy to make a reservation, make a payment, and access the space. There is also the operation and management of the spaces. These include services such as maintenance and upkeep, cleaning, security and insurance; as well as services to meet the needs of the users, such as furniture, audio-visual equipment and other basic equipment, depending on the function of the space that is offered (Aalto-Yliopisto, 2019).

Residual value
Copper8 conducted research into the valuation of circular buildings within the construction industry (Copper8 et al., 2021). The purpose of the study was to gather knowledge and insights on the valuation of circular objects. The research paper discusses the significance of valuing circularity and examines the key factors involved in determining residual value. The findings indicate that the valuation process is highly intricate, and substantial progress is still needed. This complexity stems from the diverse aspects associated with valuing circular objects, including their functional, multicycle technical and economic value, as well as their lifespan. Additionally, there are also considerations of ecological and social value, collectively known as societal value. Furthermore, the focus extends beyond the present value and encompasses the long-term value, which is inherently challenging to forecast. Integrating all these dimensions, both quantitatively and qualitatively, into a single numerical representation poses a considerable challenge. Consequently, it is not possible to determine the extent of the influence of housing detachability and adaptability on the residual value. Therefore, assumptions will need to be made when developing the revenue model. However, it can be determined that detachability positively influences the residual value of construction products and materials.
In addition to the residual value of the real estate object on the site, modular construction also allows the possibility of reusing the entire building through relocation. Here, as with residential properties, the comparative method of valuation can be used. However, this does not determine the future value, so assumptions must be made for this as well.

2.2.3 Conclusion
From the literature on circular business models, 12 circular business models were found with possible applications for the housing associations and it's temporary housing. These models are in line with the circular strategies as concluded in 2.1. The key aspects of the cost and revenue components (revenue models) in the business model are distinguished for two types of customers: internal models where the customers are tenants of the housing association and external models involving other stakeholders like investors, developers and manufacturers. This segmentation is crucial for understanding the flow of the revenue models.
The external revenue models are suitable for layers with the key aspects: reduction of OpEx, short lifespans, high innovation levels, or complexity. This resulted in the external models becoming particularly intriguing for the service, skin, and construction space plan layers. This aligns with the suggested circular revenue models.
Regarding the internal models, a distinction was made between models aimed at generating a larger revenue and those focused on higher residual value. The first type involves new revenue streams such as 'product as a service', 'underutilised space', and 'flexible space'. The second type focuses on achieving higher residual reuse value through models like 'relocatable houses', 'adaptability', and 'easy reusability'. The first type of revenue streams involves gaining insights into revenue streams' potential for additional income along with corresponding extra costs, involving operational and management aspects for maintenance. It requires specific technical requirements, such as reservation, payment and access for flexible shared spaces. The second type involves calculating the residual value. However, housing adaptability's influence on residual value is challenging to determine.

This chapter showed that while circular revenue models are promising, their integration faces significant hurdles due to financial structures, regulations and market acceptance issues. Moreover, the applicability of these models for temporary housing for housing associations cannot be determined from the literature alone.

2.3 Revenue model of temporary housing
The revenue model of temporary housing constitutes one of the three parts of the conceptual model explored in the literature review. The aim of this paragraph is to identify current practices and

revenue models used by housing associations for temporary housing, which consist of income, cost and structure. Furthermore, it aims to investigate the potential implementation of circular models within housing associations and their relevance to temporary housing.

This section explores the revenue model utilised by housing associations for temporary housing by examining the revenue model of housing associations, explaining their cost, income and structure. For this section, the Association of Housing Corporations (Aedes) (2018; 2021) is used as the main source. This is the overarching organisation above all housing associations.

2.3.1 Revenue model housing associations

The main purpose of Dutch housing associations is to rent to low-income households at affordable prices. These rents are lower than those of commercial landlords. The source of income for housing associations are the rental payments made by residents, with additional income from the sale of dwellings. While housing associations do not receive specific subsidies, they have the ability to secure loans at a low interest rate, supported by government guarantees.
A significant cost for housing associations is the payment of interest, although it is relatively low compared to current interest rates. The majority of expenditures are directed towards investments in the construction of new social housing. Substantial investments are also allocated to the renovation of existing housing units, incorporating energy-saving measures. Financial costs include taxes, encompassing standard levies such as property tax, VAT, and corporation tax, along with the landlord levy ('*verhuurdersheffing*' in Dutch). Considerable financial resources are dedicated to the maintenance of existing properties, as well as general operational costs.

2.3.2 Revenue model temporary housing

This section explores the current operational methods of temporary houses, as determined from a report by Aedes. As indicated earlier, the revenue model consists of how the company makes money. It consists of costs, income and the structure. Construction and land costs, maintenance and operation cost and income, as well as valuation, are therefore discussed as specified by Aedes.

Construction and land costs
Different approaches are possible. Many municipalities make sites available free of charge for relocatable housing. Another form is land rental by the municipality. The level of that rent is then often driven by the financial capacity in the business case. This is called the residual method. Housing associations apply different assumptions when land is owned. When considering land costs, the extent to which infrastructure should be included is also important. Access, sewerage and utilities that are already in place and/or can be utilised for a subsequent use will weigh much less on project costs than if they are not.

Maintenance and operation costs
The usual distinction between mutation, repairs and planned maintenance can also be used with relocatable housing. The facade material used in the most prevalent relocatable concepts is wood, which incurs slightly higher planned maintenance costs. However, the installation costs for new installations are comparable to those in traditional new-build dwellings.

Income
Currently, socially rented housing is subject to a maximum rent points system (Ministerie van Algemene Zaken, 2023b). Housing falling within the point maximum is capped at the liberalisation limit. Points are used to determine the maximum rent. Points are allocated to an independent dwelling, the surface area of the dwelling, the energy performance and the WOZ value of the house (the value of the house according to municipal taxes, in dutch: Waardering Onroerende Zaken), among other things.

The cost and income structure
There are several methods to calculate the value of a building. For the gross initial yield (GIY), future rent and investment costs are used to determine feasibility. The GIY expresses the ratio between the

gross market rent in the first year and the total investment. Another method is the net present value (NPV) and internal rate of return (IRR), which also includes future costs and returns. In the latter model, it is possible to assign an economic residual value to the property and the house.
The GIY calculation is simple compared to other methods. A high yield means a high rental income relative to the investment. This is often seen with properties and investments that carry a high risk of vacancy, for example. With housing associations have a very low yield because of the low social rents and non-profit motives. The risk of this method is that future changes in rent, vacancy or interest are not included.

$$GIY = \frac{Gross\ rent\ income\ (year = 1)}{Total\ investement\ costs}$$

The NPV is the difference between the discounted present value of cash inflows and the discounted present value of cash outflows over the exploitation period. This provides a better understanding of profitability. To calculate NPV, the future cash flows of the investment must be discounted to present amounts using a discount rate. This is done in a discount cash flow table with yearly cash flows of expenses and incomes. The sum of the cash flows is converted into the present value. The NPV is the sum of the cash flows. With a positive NPV, the project is profitable. However, the profit has to outweigh the risks. For example a higher profit is often demanded for retail properties because they are more likely to be vacant than residential properties. With a negative NPV, the project is unprofitable. The feasibility of the project can be achieved by reducing costs, increasing revenues or changing the period.

$$NPV = \Sigma \frac{Net\ cash\ flow_t}{(1+r)^t}$$

The financial performance benchmark of the project is calculated with the IRR. This benchmark is equivalent to the discount rate at an NPV of zero. This rate also allows the performance to be compared with other (housing)projects.
Differences in the revenue model between temporary and permanent dwellings mainly stem from costs side and the potential loss of rental income in the event of relocation. When valuing residential properties, experience figures such as transaction prices of comparable properties and maintenance standards are normally used. These are not yet widely available for relocatable properties. The expected lifespan is a significant unknown. Values of dwellings are often based on location, which in the case of these houses is therefore not fixed. This makes valuation difficult.

2.3.3 Circular revenue models

Limited information is available in the literature on specifically circular revenue models of housing associations. Namely, the integration of circular revenue models into the revenue model of housing associations is not observed in the literature. The revenue model of housing associations primarily focuses on costs, income, and structure, incorporating elements such as construction and land costs, maintenance and operational expenses and income generation. Circular revenue models offer an alternative aimed at optimizing resource use such as extending product value and emphasizing performance and access. This could potentially influence the cost and income structure of temporary housing projects. However, there is currently limited empirical evidence to prove there are circular revenue models within the revenue model of housing associations.

2.3.4 Conclusion

This section identifies the current revenue models used by housing associations for temporary housing. The revenue model of housing associations primarily rely on rent payments and dwelling sales for income. They benefit from low-interest government-backed loans and face costs that include (new) construction, renovation, taxes and operational expenses.

Nonetheless, the literature lacks the necessary information to ascertain how the revenue models are used for temporary housing. This includes valuation of properties over time, cost of relocation and

the lifetime. Furthermore, there is a lack of specific information regarding the construction, the land acquisition and the IRR. Moreover, there are no observations or information available regarding the integration of circular models. Consequently, there is a need for additional information on the precise revenue models utilised.

2.4 Resumé

The literature study is comprised out of the three main sections of theoretical model; circular strategies for temporary housing, circular revenue models and the revenue model of temporary housing.

The circular strategies for temporary housing outlines principles (R0-R9) are categorized into three strategy groups "Use and produce the product smarter," "Extend the lifespan of the product and elements," and "Useful application of materials". This study omits discussing the "Useful Application of Materials" due to perceived limitations. Circularity measurement methods are explored. The Building Circularity Index (BCI) is identified as the most comprehensive for decision-makers to make informed desicions about circular strategies. Modular temporary housing is aligned with circular strategies, but the extent of this alignment remains uncertain without BCI data. Furthermore, the literature review did not uncover any information regarding whether a deliberate selection of modularity type for the temporary housing. In addition, it is unknown whether the consideration of circularity played a role in this decision-making process.

In the literature no circular revenue models specifically targeting temporary housing were found. It was therefore decided to analyse the circular business models found in the literature. Several possible circular business models applicable to temporary housing for housing associations were found and aligned with the circular strategies found in the first section. These models are divided into internal and external models, each of which has its own characteristics and requirements. However, information is still missing in this section. First, there is a need for further empirical validation of the proposed circular business models for housing associations. Second, there is a need to understand the possible obstacles and challenges in implementing circular revenue models in the context of temporary housing for housing associations. This may include insight into legal, financial and operational barriers. Third, the literature lacks concrete examples or case studies that can confirm the feasibility of these models.

The third part of the literature explores the current practice of revenue models of housing associations and also models specific to temporary housing. The section highlights the principles of the association’s revenue models. However, the literature lacks detailed information on how these models are applied to temporary housing. Gaps in information includes aspects such as valuation over time, moving costs and lifetime considerations, specific data on construction, land acquisition and Internal Rate of Return (IRR). The circular revenue models identified do not seem to be integrated into the revenue models used by housing associations. Empirical evidence supporting this assumption is lacking.

While each section provides valuable insights, further empirical research is needed to bridge the research gap. For this empirical validation, insights into obstacles, and analysis of the financial feasibility of circular revenue models are needed.

3. Research methods

As stipulated in the literature study, there is a need for supplementary on all three sections. Starting with 2.1 on circular temporary housing, the literature lacks information on whether a thoughtful choice of modularity type was made beforehand and to what extent the degree of circularity was included in this decision. The subsequent section, 2.2, focuses on the circular revenue model. This section identifies relevant revenue models and discusses the extent to which these models meet the requirements, focusing on the elaboration of revenue streams. Nevertheless, solely form the literature the feasibility and applicability including barriers and challenges of these circular revenue models for temporary housing cannot be derived. Chapter 2.3 discusses the revenue model of temporary housing, highlighting the limited information in the literature regarding the specific revenue models that have been used for temporary housing. There is a gap in understanding the valuation, the relocations and the lifespan of temporary housing. Additionally, specific details regarding construction, land acquisition and IRR are lacking.

Semi-structured interviews provide insights to bridge the gap between literature and practice. These interviews serve a dual purpose. First, to enrich the literature and identify the gap between literature and practice. Second, to validate the feasibility and applicability of implementing the circular business models from the literature. For the circular revenue models this is the gap between theoretical model applicability and practical feasibility.

This section includes an extensive motivation of the chosen methodology, the method and the validity and reliability of the data.

3.1 Comparison of research methods

Qualitative research methodology is regarded appropriate when exploring new fields of study or aiming to understand and theorize significant issues as in this study (Corbin & Strauss, 2008; Creswell & Poth, 2017). Various qualitative methods have been developed to gain an in-depth understanding of issues. Interviewing and observation are the most used (Creswell & Poth, 2017). For the complex of decision-making processes, financial analyses, and theoretical frameworks explored in this study observation seems to be enough. Additionally, key aspects under investigation, such as modularity type selection and specific valuation models, are not observable in real-time settings. Therefore, interviews, are preferred for addressing the research questions and objectives.

According to Mathers et al (1998), interviews can be divided into three main types: structured, semi-structured and unstructured interviews. Structured interviews consist of asking the same set of questions in the same way to each respondent. This can be done through a fixed questionnaire. Semi-structured interviews consist of open-ended questions related to the research topic. This allows for more flexibility and in-depth discussion between the interviewer and the respondent. Unstructured or in-depth interviews start with a few topics and let the conversation unfold based on the interviewee's answers. Semi-structured interviews were chosen for this study to encourage open and flexible responses from the participants. Semi-structured interviews are thus most likely to provide good insight into the perspectives of housing associations.

3.2 Semi-structured interviews

Semi-structured interviews (SSIs) are a widely accepted approach for conducting exploratory research, as indicated by Yin (2014). SSIs provide an interactive dialogue with participants with open-ended questions. In this way, it is possible to delve deeper into the 'what', 'why' and 'how' behind specific processes (Adams, 2015). These interviews are designed to transcend the limitations of a fully structured one. This allows the experts to share their perspectives and explore key topics. This approach improves the objectivity of the research by allowing experts to express their views. also allows them to provide in-depth answers in areas of interest (Latour, 2000).

McCracken's (1988) research emphasises the importance of carefully selecting interviewees who share substantial similarities in order to effectively answer the research question. Therefore, this study chose to interview property developers and project managers engaged in the development of housing associations' temporary housing projectn. This choice corresponds to the need to ensure homogeneity among our interviewees to ensure consistent data collection, facilitate comparative analysis and draw reliable conclusions across cases.

The interview questions were (mostly) open-ended and not sent to participants in advance. The interviews were conducted both in real-life settings and online via the platforms Teams, and each lasted approximately 1.5 hours. The interview guide can be found in Appendix 2.

The interview consisted of two parts. Part one consisted of the housing associations' current practices in terms of life span, relocation, IRR, residual value calculation and the DCF model used, construction, maintenance, land acquisition and the integration of the temporary home and circularity. Part two aimed to determine whether the models found in chapter two are feasible for application to temporary housing for housing associations and what challenges and issues then arise.

The section below details the interview design and the questions derived from the literature.

3.2.1 Interview guide

The interview invitation included details such as an overview of the study, a question about the expert's willingness to participate in the interview and specific information about the temporary housing projects the housing association was participating in for this study (Appendix 3).

After the expert agreed to participate, an appointment was scheduled via e-mail. The e-mail provided information on the location, date and time of the interview, along with a brief explanation of the purpose of the interview. However, no details were given to avoid influencing answers. The mail also described the maximum duration of the interview of 1.5 hours. It also included information about anonymously coding the expert's name in the study. The e-mail also explained to the expert that the interview would be recorded for research purposes only.

During the interview, participants were encouraged to answer freely. Statements were coded to ensure anonymity. The interview began with a casual dialogue. Discussions were conducted impartially, ensuring that participants were not steered towards specific answers. Participants were explicitly informed of their right to end the conversation at any time.

3.2.2 Current practice of housing associations

The first part of the interview consists of 18 questions (table 6) about the current practice for temporary housing projects and circularity in the projects. It starts with the introduction with questions about the experts role, then about the construction and land costs, maintenance and overhead and valuation of the temporary housing. Lastly question on the vision on circularity will be asked. These questions have been formulated based on the missing information in the literature review.

Table 6
Questions interview current practice

Introduction	
1	What is your function and responsibility within the housing association?
2	What was your role within the temporary housing project?
3	Which temporary housing projects did the housing association do? Which were you involved in?
Construction and land costs	

4	Does the financial model employed for temporary housing resemble the same which is utilised for conventional housing projects? If not, what are the differences?
5	What type of temporary housing is employed?
6	What do the land charges entail? Are these land expenses borne by the housing association or by the municipality?
7	How are the infrastructure expenses covered? Is it through municipal funding? Does this encompass utility connection costs (gas, water and electricity)?
Maintenance and overhead	
8	What costs are distinct in temporary housing as compared to conventional housing? If so, which specific costs are involved?
9	Do maintenance cost differ compared to a regular housing project? Are there variations in the maintenance costs between temporary housing and a standard housing project? If so, why?
10	Are there disparities in the overhead expenses when compared to a regular housing project? What are these expenses comprised of?
Cost and income structure	
11	What financial model valuing method is used?
12	What lifespan is assumed for the temporary housing?
13	How is the financial return assessed? Is the internal rate of return (IRR) used? What is the intended target return?
14	Has a residual value been computed? If so, how is the residual value determined?
15	What assumption is made regarding the frequency of house relocations?
Circular strategies	
16	What is your housing association's approach to and vision of circularity?
17	How does your housing association incorporate circularity strategies or principles into its temporary housing projects?
18	What challenges have you faced in implementing circularity in your temporary housing projects?

3.2.3 Feasibility of circular revenue models

For each of the circular revenue models identified in chapter 2.2, the question has been posed as to whether they are integrable, why the model is integrable or why it is not. These are given in table 7 below. In cases where the expert answered that it was not integrable, they were asked about the barriers they identified.

Table 7
Circular revenue models for interview

1.	Creating smaller personal spaces and more shared pay-per-use spaces
2.	Pay-per-use laundry machine (Bocken et al., 2018).
3.	Signify has a pay per lux business model (Case Study: Signify Light-as-a-Service, n.d.).
4.	Procure products, kitchens, facades (Circle Economy et al., 2020) or mechanical installations with technical performance as a product as a service, guaranteeing performance (Trevor, 2021).

5.	In the circular building catalogues of the Netherlands, there are companies that procure kitchens, elevators, facades and lighting (De Circulaire Bouwcatalogus - Circulaire Diensten, n.d.).
6.	Sharing underutilised with others; parking, offices, fitness, childcare, training (Aalto-Yliopisto, 2019; Arup Group & Ellen MacArthur Foundation, 2020)
7.	Co-living concepts (Arup Group & Ellen MacArthur Foundation, 2020).
8.	Set building requirements that allow for materials and products to be easily reused (Arup Group & Ellen MacArthur Foundation, 2020).
9.	Reuse the entire building in another location (Arup Group & Ellen MacArthur Foundation, 2020).
10.	New ownership structure in which the housing association is not the owner of all shearing layers (Arup Group & Ellen MacArthur Foundation, 2020).
11.	Buy products with a guarantee of sell back to producer, example are kitchen, furniture and carpet tiles (Arup Group & Ellen MacArthur Foundation, 2020; KPMG Advisory N.V. et al., 2019).

3.2.4 Analysis of results

The interviews were transcribed. The semi-structured interview data were compromised in in two tables; part one contains current practices and part two contains circular revenue models (appendix 4). The thematic analysis is an easily accessible and theoretically adaptable method for interpreting qualitative data, which allows identifying and exploring patterns or themes within a data set (Braun and Clarke 2012). As pointed out by Braun and Clarke, coding and analysis involves both deductive and inductive approaches, which also applies to this study.

The transcription has been translated and written down descriptively. Each response is organized in a table format, with questions listed in rows and interviewees in columns. A thematic analysis was conducted using an inductive approach. This approach involved collecting and analysing data without preconceived categories or theory. After, a thematic analysis was conducted by coding the answers to identify recurring themes. The themes were compared across the different housing associations to highlight key similarities and differences. The table (8) below shows an example of how the answers analysed from a question. This is for housing association A with the themes in the right-hand column. The analysis was supported with quotations from the interviews, providing evidence of key findings derived from participants' perspectives.

Table 8

Example of analysis of the given answer

Housing Association A	Themes
Housing Association A has adopted this approach. They repurposed ground-floor units into communal spaces, effectively creating communal living rooms. These areas allowed residents to socialize, relax, and enjoy shared amenities, all without sacrificing the size of their individual homes. Cleaning and utilities for these shared spaces were covered within the service fees, with a small monthly contribution from each resident to ensure proper maintenance. In cases where extensive upkeep was required, Housing Association A appointed a part-time manager to oversee the space and encourage residents to maintain its cleanliness. Housing Association A is about introducing additional charges for shared spaces such as pay per use, as it might deter residents who are already on tight budgets. However, for commercial entities and organizations with specific needs, Housing Association A offered flexible arrangements. These organisations often need access to (shared) spaces for different purposes, such as meetings, events or services. Housing Association A accommodated these spaces in a shared way and ensured that residents could access these spaces.	- Realizing communal spaces - Cleaning in service fee component - Residents on tight budget not pay per use - Sharing with commercial company - The rent is capped

3.3 Data validity and reliability

The interviews consisted of semi-structured questions, which allowed respondents to provide detailed answers. This provided the option to give more explanation if needed. This minimised the risk of misinterpretation. The website 'flexwonen.nl' was utilized to identify housing associations with temporary housing projects. This site contains a map of practical examples of temporary housing. The filter 'housing associations' was used. Using this list, a list of potential housing associations was developed for the interviews. Twenty-five housing associations were approached. Out of the housing associations, only AREA wonen (renting out 8,600 dwellings), Cazas wonen (renting out 16,600 dwellings), Heuvelrug (renting out 3,500 dwellings) and Portaal (renting out 58,800 dwellings) were interested. This is a response rate of 16%. Several housing associations did not respond and several unfortunately did not want to take time for the interview. There is no unequivocal reasoning for this. It can be expected that this is because it involves sensitive information.

At Cazas Wonen, an interview was conducted with a project developer. At Heuvelrug, the real estate manager was interviewed, who is responsible for both planned maintenance and the development of new properties. At Portaal, a combined interview was done with two project managers, who oversee responsibilities from project initiation to completion, and with a real estate advisor, who focuses on sustainable developments, including circular construction.

An interview guide with predefined questions was established which enhanced the data's reliability by ensuring a structured approach where the most important topics were consistently addressed in all interviews, reducing the likelihood of overlooking vital information.
However, the interviews were not all conducted in the same environment. Three of the interviews were conducted online, while one interview took place in person. As a result, variation in external factors may influence the results. Unintentional bias may exist on both the respondents' and the interviewer's side. Respondents may provide answers they believe the interviewer wants to hear, rather than their genuine responses. Structuring the questions in a specific sequence where circularity is addressed as the final topic was an attempt to prevent this bias as much as possible.

3.4 Resumé

This chapter has provided an overview of the SSI's questions, the setup and preparation, the method of analysis and the primary objectives within this research. The next chapter delves into the interview results, drawing conclusions about the current practice and the feasibility of the circular revenue models.

4. Results interview

This chapter presents the outcomes of the two parts of the SSIs. The first part outlines the current practices of the housing associations. This consist of an introduction of the expert, the current practice of the financial model (construction and land, maintenance and overhead, and valuation) and the current practice on circularity. The aim is to retrieve this information to set up the case study in the following section. The second part offers an in-depth exploration of the feasibility, preferences, barriers, and potential risks of the circular revenue models for the housing associations. The aim here is to determine whether these circular models can be integrated into the financial models of the housing associations.

4.1 Results current practice

The results of the first part, the current practices are presented here. This paragraph aligns with the sub-topics outlined in the literature. These data were analysed using thematic analysis as described in the methodology.

4.1.1 Introduction

All experts interviewed were engaged with temporary housing projects from initiative through realisation. They were also involved in permanent construction projects. Two of the experts also had post project responsibilities.
All four housing associations were engaged in temporary housing projects and were working on or had already realised a total of 12 projects across three provinces: Gelderland, Noord-Brabant and Utrecht.

4.1.2 Construction and land

All housing associations follow a revenue model found in literature for normal construction, but there are differences compared to the traditional housing model. Temporary housing models must account for the costs associated with relocations, which are not present in permanent construction. Additionally, the cost assumptions for land vary. Housing association A also had a different assumption for the lifespan. This is further elaborated below.

All housing associations opted for a modular system, emphasising the construction of permanent quality (in accordance with permanent building degree dutch Bouwbesluit). This choice was made to allow the possibility of eventually placing the temporary housing in a permanent location. Housing associations A, C, and D chose a modular system composed of multiple modules. Housing association A selected a row house comprising a three-story module. Two housing associations used a cross laminated timer (CLT) construction system, with one of them also incorporating a steel construction project. Housing association C conducted research on 2D modules, but this was deemed unfeasible for temporary housing due to relocation costs. None of the associations indicated that circularity factored into the choice of type of temporary housing.

All housing associations received the land for their respective projects on municipal sites free of charge. However, there were differences in how the land was provided. In the case of three out of the four housing associations, the land was delivered as 'construction-ready' and 'residential-ready' (Dutch: bouw- en woonrijp), including infrastructure and utilities. The other housing association had to undertake the groundworks themselves and later restore the site to its original condition. One housing association developed a temporary project on its own land. They were also responsible for the groundworks. Financial viability was significantly influenced by the terms of land provision and agreements with municipalities.

4.1.3 Maintenance and overhead

All housing associations noted that the costs of temporary housing were not substantially different from those of regular housing.
Housing associations A, B and D expected lower maintenance costs in temporary housing due to specific design choices and selected materials. Two housing associations used a TCO approach to evaluate costs for these projects. Housing association C did not elaborate on this topic.

4.1.4 Valuation

All housing associations indicated that they use the DCF model, and they assess financial returns using the IRR. All housing associations indicated that the internal rate of return IRR was under pressure, making the project financially unprofitable.
There were various approaches regarding the number of relocations for the temporary housing. All housing associations had agreements with the municipality for new locations (three of the four had made agreements with the municipality to eventually place the homes on a permanent location. Below are the different approaches of the housing associations:

housing association A: First location for 15 years, then second location for 21 years.
housing association B: First location for 25 years, then permanent.
housing association C: First location for 15 years, then permanent.
housing association D: First location for 10 years, then second location for temporary use, and third location for permanent placement.

Housing association A estimated a minimum value of temporary house for relocation costs at year 36, while Housing associations B, C, and D used a straightforward depreciation of the houses to zero over 50 years. Housing association A pointed out that the homes do not increase in value because they are not permanently placed in one location.

4.1.5 Circularity

Two of the housing associations had set circularity goals. Housing association A had a vision for circularity. Housing association D utilised minimum MPG and BCI scores, supplemented with an additional budget for circular objectives. In contrast, housing associations B and C lacked a specific vision regarding circularity. Housing association A had implemented the circularity principles into their core strategy. Housing associations B and C had not implemented one of the strategies. Housing association D has just started integrated it into their minimum scores by using the BCI and MPG. None of the associations had BCI data available on temporary housing projects.

Challenges faced by the housing associations in implementing circularity included financial, regulatory, adaptation and internal alignment. These challenges vary in exact subject but share common themes.

The housing associations' responses revealed a diverse approaches and challenges in temporary housing, with distinct project-specific strategies and challenges. Their experiences provide insights into the complexities and opportunities within the temporary housing projects.

All housing associations encountered barriers in the integration of circularity. Some of these barriers were common and some were unique.

Common barriers

- Financial hurdles: All housing associations ran into financial challenges. These included challenges in terms of revenue stagnation and rising costs as they committed to circular principles. Financing circular projects was a consistent obstacle across all housing associations.
- Regulatory constraints: Housing associations B and C highlighted the impact of additional local statutory requirements from municipalities. Also, problems with the (unexpected) constant updates of building regulations. These regulations can hinder circular investments and make

projects complex. Housing association C experienced financial hurdles in the form of tax burden on housing associations. This left little money available to renew. Housing association A faced legal and certification issues of building products, especially in the context of historical building elements.

- Adaptation and internal alignment: Housing associations C and D expressed the need for adaptation to align practices with sustainability and circularity goals. The lack of a proactive sustainability focus within the associations was attributed to financial constraints and also internal discussions on direction.

Unique barriers

- Market perception: Housing association A was concerned about the market's perception of their rapid circularity goals. It noted the contrast between the market's lobbying for circularity initiatives and the perceived speed in the market.
- Supply and demolition challenges: Housing association A faced challenges regarding the mismatch of circular demolition supply and demand.

All housing associations were unfamiliar with the circular revenue models.

4.2 Results review circular revenue models

This second part of this chapter consists of the reaction and review of the housing associations on the practical feasibility and applicability of the circular revenue models found in the literature (2.2.2).

1. Shared pay-per-use space

Housing associations A, B and D had all implemented communal spaces. Housing association A had incorporated the cleaning costs into the service fees for rental properties. Housing association B mentioned that these costs could be easily included in the service fees. The housing associations unanimously agreed that individuals with a limited budget should not be charged for the use of shared spaces: 'Pay-per-use for shared spaces does not feel right, as we are there for the people with a small budget'.

2. Pay-per-use laundry

All four housing associations had experience with this model. Three of them were satisfied with the operation of this model, while one was dissatisfied with the provider. Two of the housing associations primarily used this model for a younger target audience, who often appreciated not having to purchase a separate washing machine.

3. Pay-per-lux / 4. Procure kitchens / 5. Procurement facades and mechanical installations / 10. New ownership

Due to the similarities between the pay-per-use model, performance procurement and new ownership structure, the housing associations provided equivalent responses, and therefore, these items will be discussed together.

Two housing associations were sceptical about the pay-per-lux model, while housing association D was open to adopting a pay-per-lux model. They have already successfully integrated a heating system with this approach. The sceptical housing associations also noted that, from a financial standpoint, it was currently less appealing than ownership: 'Owning is often still more attractive than renting or paying for the service, financially speaking'.

They also expressed a desire for ownership to retain control over the technical condition of their housing. One housing association mentioned that the market was not yet ready, and the supply for such models was insufficient. Three out of the four housing associations discussed legal and regulatory considerations, including contract complexity and regulations that prohibit the leasing and subleasing of residential properties.

Furthermore, housing association A specifically mentioned as a risk related to the new ownership structure model that the layers of shearing may not align precisely, potentially leading to disputes

over responsibilities. This could give rise to complex legal responsibilities and accountabilities for the project.

6. Shared spaces
Both housing associations A and B indicated that shared spaces were not their core business, and they would prefer to not facilitate in shared spaces 'We try to stay out of those shared spaces or facilities as much as possible, because there are things we are good at and there are things we are worse at. And managing a nursery or a gym. It turns out every time we are not good at that'.Housing association A, however, had a positive experience with a commercial user of the shared space.

7. Co-living concept
Housing association A was highly satisfied with the concept of co-living apartments, particularly in combination with a younger target audience that often prefers not to live alone in an apartment. Housing association D indicated that they serve an older target group with more traditional preferences, making this concept less suitable for them. Housing association B was less enthusiastic and had recently demolished several apartments. Housing association C expressed interest but currently only applied the concept situationally or occasionally.

8. Reusable products and materials
None of the housing associations attributed higher residual value to the property due to increased repairability and/or detachability. Housing association A, however, incorporated this factor into its TCO calculation. The easier the repairability, the lower the maintenance costs. This housing association mentioned that they often consider designs that involve interchangeable supplier systems from the outset. The other housing associations primarily cited regulations (e.g., WSW (Social Housing Guarantee Fund) regulations specifying that assets cannot be movable) and the continuously evolving building regulations as the key factors of not reusing products and materials.

11. Buy-back
Housing associations expressed their preference not to rely on another party. Additionally, housing association C indicated a preference for suppliers not to be involved in financing, as they believed it could potentially jeopardise financial stability. Housing association C also noted that a buyback kitchen is more expensive than a regular kitchen without a buyback option.

12. Permanent quality
This model was added to the existing models after the interviews. All housing associations had requirements for a permanent construction quality in accordance with the permanent building regulations. This allowed the housing to remain in one location for longer than 15 years and potentially be permanently placed elsewhere in the future.
The only risk the housing associations faces is a changing building code. Housing associations B and D mitigated this by making agreements with the municipality that the building, after relocation, may comply with the legally acquired standards. Housing association B specifically pointed out that in this context, the NTA8800 (energy performance) calculation still poses a risk because the orientation of a building can change, which has a influence on the calculation.

4.3 Conclusion

This study examined four housing associations and their experiences with twelve temporary housing projects. The aim is to understand the current practice of revenue models. It also validates the feasibility and applicability of circular business models found in the literature for housing associations.
Findings are that the associations use 3d modular systems with permanent quality. This offers the possibility of being able to place the houses permanently on the follow-up site. None of the associations indicated that circularity (with BCI) had been factored into the choice of the type of temporary housing. Overhead costs of temporary housing were found to be similar to those of traditional housing. Housing associations expect lower maintenance costs in temporary housing due

to specific design choices and selected materials. It is unknown if this is because the temporary housing is in line with circularity.
Relocation strategies varied between housing associations, with different numbers for relocations. All housing associations were seeking agreements with municipalities to obtain free land and secure follow-on sites.
All housing associations stressed that the temporary housing should not be of temporary quality but of permanent quality because of financial feasibility. Valuation methods involved the DCF model and IRR. However, the IRR in temporary housing projects was often under pressure. This indicates the overall profitability and feasibility of the project is under pressure.
Circularity goals differed between housing associations. Some have specific targets and others do not. Challenges in integrating circularity include financial constraints, regulations, adaptation needs and internal alignment. Not all used measurement methods for circularity. Only one had just started using the BCI. None of the associations had Building Circularity Index (BCI) data available for their temporary housing projects. As a result, this study cannot assess the degree of alignment of temporary housing with circular revenue models. All housing associations were unfamiliar with circular revenue models.

Overall, the projects of these housing associations provided insight into their revenue model and the conditions for the operation of temporary housing on the topics of construction, land, maintenance, overhead and valuation. These conditions and requirements were used in establishing the variant study.

The second part of this chapter has examined circular revenue models from the perspective of housing associations and has provided insights into their feasibility, preferences and potential risks. The key findings from the assessment of each model are summarised below.

- Shared Pay-Per-Use space (1): Housing associations A, B and D have introduced communal spaces, but they shared a common stance against implementing pay-per-use for shared spaces because of the limited budgets of the tenants. Thus, this model is not applicable for housing associations and therefore not further elaborated upon in the variant study.
- Shared Pay-Per-Use Laundry (2): All four housing associations had experience with this model. Three of them were satisfied with its operation, especially for younger target groups. This model can therefore be included in further analysis in the variant study.
- Pay-per-lux (3) Procure kitchens (4) Procurement facades and mechanical installations (5) New ownership (10): Housing associations were sceptical about these models for reasons including financial considerations, preference for ownership and control over technical condition, disputes over responsibilities and complex legal responsibilities. There are no significant constraints to investigate this model further; therefore, these models will be addressed in more detail in the variant study.
- Shared flexible space (6): Housing associations said they were reluctant to engage in managing shared spaces or facilities outside their core expertise. However, housing association A had a positive experience with a commercial user of a shared space. This model is further elaborated in the variant study.
- Co-Living (7): Housing associations held diverse perspectives on the co-living model. One housing association expressed a high level of satisfaction with co-living apartments, while another, due to its older target group, considered this model less suitable. Housing association B, in contrast, demonstrated less enthusiasm, having recently demolished several apartments. Lastly, one housing association showed interest in the co-living concept. This model is further elaborated in the variant study.
- Reusable Products and Materials (8): None of the housing associations attributed higher property value to increased repairability or detachability. The primary obstacles for the housing associations were regulations and evolving building standards. Housing association A, however,

incorporated these factors into its TCO calculations, emphasising lower maintenance costs through interchangeable supplier systems. This model is further elaborated in the case study.

- Buy-Back (11): Housing associations preferred not to rely on external parties and expressed concerns about supplier involvement in financing, which could affect financial stability. Housing association C noted that buyback kitchens tend to be more expensive than regular ones without buyback options. This model is further elaborated in the variant study.
- Permanent Quality (12): This new model emphasises permanent construction quality in accordance with building code. It allows housing to remain in one location for an extended period or potentially be relocated permanently. Risks primarily involve changing building codes, but agreements with municipalities are used to mitigate these risks. All housing associations used this model. This model is further elaborated in the variant study.

In conclusion, the research on circular revenue models for housing associations points to a number of complex financial considerations, regulatory and legal factors and preferences.
Housing associations showed reluctance in areas that could jeopardise their core mission. The model that all housing associations unanimously agreed did not fit their business is pay-per-use shared spaces. The other models are elaborated further financially in the variants analysis.

5. Variant analysis of circular revenue models

The previous chapters identified circular revenue models in the literature and examined them through the interviews. The aim of this chapter is to define the effect of the circular revenue models on the revenue models of the housing associations in comparison to the current practice, as articulated in the last sub-question. Determining the financial impact and the uncertainty of the models contributes to the main goal of analysing the feasibility of the circular revenue models of in temporary housing projects. This involves assessing the feasibility of each individual circular revenue model and comparing it to the feasible current revenue model of the housing association and the other circular revenue models.

The circular revenue models are drafted with the financial inputs of the housing associations in the last chapter. Each circular revenue model is introduced as a separate variant, and its financial performance is assessed. This is done by comparing the circular revenue models found in the literature and verified in the interviews with the associations with a base variant. This provides integral insight into which models are most likely to be feasible for housing associations. This chapter starts by describing the methodology for the variant analysis of the circular revenue models. It then discusses the individual variants (revenue models) on their financial performance and sensitivity. Lastly, this chapter finishes with a mutual comparison of the base model with the variants and draws conclusions.

5.1. Methodology

The methodology includes a test (5.2.1) of housing associations to uncover insights and form understanding of these models and input variables. Also included is a sensitivity analysis (5.2.2) to test the resilience of the models to variations in key parameters. This is in line with the exploratory nature of the study.

According to the findings of Borgonovo and Peccati (2006), decision-makers consider three main uses of the sensitivity method when assessing investment opportunities. First, to assess the inherent robustness of the financial model. Second, to analyse how the model's output responds to variations in input parameters. Third, to understand the impact of each assumption within the model on the overall valuation of the investment. For this study, robustness and financial output were important. The exact impact of the model's parameter is not important for this study. However, the differences between the models are. Therefore, this chapter concludes with a comparison between the models.

This approach provides insights into the financial outcomes and robustness of the circular revenue model in the context of temporary housing. Based on these considerations, it can be deduced which models are the most financially feasible for housing associations to adopt and which are the infeasible ones.

5.2.1. Check model and input variables with experts

The financial models were shared with the same housing association experts. Unfortunately, there has been no feedback on the models.

5.2.2. Sensitivity analyses

The constructed revenue model is used for conducting sensitivity analyses, exploring various scenarios that reflect variations in variables. This analysis provides a nuanced understanding of how different revenue models impact financial outcomes (Borgonovo & Peccati, 2004). The sensitivity analysis is conducted in the following way. The formula of the net present value is:

$$NPV = \sum_{t}^{n} \frac{f(x)t}{(1 + IRR)^t}$$

where the future net cash flow is defined as $f(x)t$. This is the future net cash flow expected for the period t, with $x = (x_1, x_2 \ldots . x_n)$ representing the model's input variables.

The sensitivity analysis is conducted on the IRR. This is where the net present value reaches zero:

$$0 = NPV = \sum_{t}^{n} \frac{f(x)t}{(1 + IRR)^t}$$

The sensitivity analysis is obtained when the input variables are changed from the base case. The formula of the base case is as follows:

$$0 = NPV^0 = \sum_{t}^{n} \frac{f(x^0)t}{(1 + IRR^0)^t}$$

where x^0 denotes the base case value of the input variables. This sensitivity analysis is tested by changing the input x, registering the change in IRR^0, $\Delta IRR = IRR - IRR^0$.
From the sensitivity analysis, the consistency and correctness of the revenue model and its influence on IRR^0 can be observed from the tornado diagram (Clemen, 1998).

For this research a parametric sensitivity analysis is chosen with a 20% increase or decrease of input variables is used as the sensitivity analysis. This methodology is also seen in other study on NPV model analysis with assumptions (Durham et al., 2015). It is mostly used when there is uncerntain conditions and no statistical information is available on the input variables (Van Groenendaal, 1998). It also identifies input variables on which managers' attention should be focused during model implementation (Borgonovo & Peccati, 2004b). With this type of sensitivity analysis, a wider range between outcome means greater uncertainty. If results vary significantly within this range, it indicates that small changes in inputs can have a large impact on the outcome. If the results of the model remain relatively stable within the range of variation, this suggests a lower level of uncertainty. The model is more robust against fluctuations in the input variables. This sensitivity analysis can be used to determine which outcomes of the models are most and least certain.

To meet the above purpose, the following steps according to Nwanekezie (2009) are followed:

i. Identify key variables to which the project decision may be sensitive.
ii. Calculate the effect of likely changes in these variables on the base – case IRR or NPV, and calculate a sensitivity indicator or switching value.

5.2.3. Comparison of the revenue models' financial performance

The financial performance of each circular revenue model was assessed using a standardised comparative methodology using each time the same project with circular revenue model specific parameters. The methodology used several key financial measures as identified in the interviews. The main financial measures used were net present value (NPV) and internal rate of return (IRR). NPV provided a measure of the net value created over the life of the project, converted back to its present value. IRR gave insight into the profitability of projects and reflected the discount rate where the NPV of all cash flows (both incoming and outgoing) of a project equalled zero.

5.3 Circular revenue models

Besides the data on how the housing associations use the models as retrieved in the interviews, financial data input is also retrieved from one of the interviewed housing associations, including the investment amounts, residual value, rental income, discount rate, indexation and lifespan. This empirical basis allows the translation of theoretical circular revenue models into practical models. The models were structured in accordance with the DCF method, as derived from the insights gathered during the interviews. As explained, some new input variables are introduced for the circular model. For these variables assumptions based on sources were made. However as found in literature preferably the analysis is a complete TCO analysis including overhead and energy costs.

However, this was not possible due to limited data. This is expected to have no further impact on the results of the comparison as all models miss the part.

This study begins by introducing a real-life case of a housing association that developed 99 housing units of about 30 square metres. Then, the revenue models from the interviews are applied to this case.

5.3.1 Base model

The baseline is derived from an existing project within one of the housing associations. This project comprised a block of studio apartments, each with an approximate area of 30 square meters (figure 6). The total floor area of the building is 5017 square meters. The modular construction is full 3d modular. The modular system main construction is steel with wooden floor, roof and facade construction. No data was available on the circularity index of this project. The land was delivered as 'construction-ready' and 'residential-ready'. The apartments in this project were in operation for two periods of 15 years each. The depreciation of the real estate is over a span of 30 years to zero, with any potential residual value considered as an upside at a later point and consequently not factored into the calculations. This observation aligns with the results on the temporary housing and revenue models of housing associations outlined in Chapter 4. Nonetheless, the current analysis introduces a variation in the total lifespan compared to the lifespan found in that chapter. An extended lifespan has been incorporated as an alternative variant circular model revenue model (5.3.2).

This project with small studios is used because three of the four housing associations also operated this type of housing as temporary housing. Additionally, all circular models are applicable to these studio apartments. As an example, implementing the revenue model for co-living is more challenging for an individual row house compared to a block of studio flats.

Figure 6
Fragment of façade and floorplan base model of the housing associations' project

Modelling the case

As mentioned above, the base case formula is

$$0 = NPV^0 = \sum_{t=30}^{n} \frac{f(x^0)t}{(1 + IRR^0)^t}$$

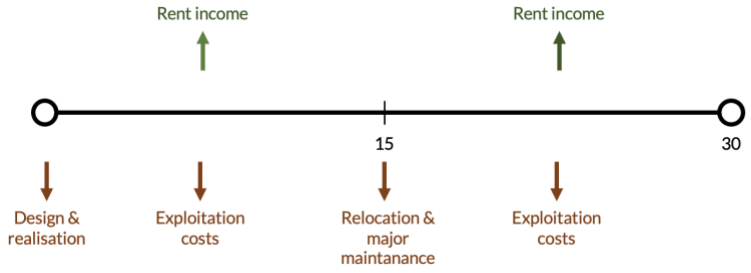
The variables (x^0) used for modelling the revenue model can be found in appendix 5.

Table 9
Outcome base model

	Base model	
IRR^0		1,8%
NPV^0 (discount rate 2,3%)	€	- 625.000
NPV^0 per house (discount rate 2,3%)	€	- 6.300

Figure 7 presents the cashflow, and table 9 presents the net present value and the IRR. Costs include the design and realisation, the exploitation costs for the first location and for the second location and the relocation and maintenance costs. The only income is the rent of the housing. As already mentioned in Chapter 4, the realization of a temporary project with a lifespan of 30 years is an unfeasible revenue model for housing associations. It becomes feasible only if contributions come from municipalities or subsidies are provided. Here, the unprofitable top is financed by the respective municipality.

Figure 7
Cashflow base model



5.3.2 Model 1 Shared Pay-Per-Use space

As stated in the interview, this model is not applicable for housing associations and therefore not further elaborated upon in the variant study.

5.3.2 Model 2 Shared Pay-Per-Use laundry

The model comprises two circular models. There is the underutilised space model, designed to optimise space by enabling the sharing of laundry facilities, and there is the pay-per-use model, which charges users a modest fee for each session.
This model eliminates a certain area in the flats and reduces the number of laundry machines (the 'refuse' strategy) and significantly optimises the use of available square metres and the use of the laundry machines (the 'rethink' strategy). Moreover, the model extends the lifespan of the laundry machines, as the manufacturer is responsible for their maintenance (reuse, repair, refurbish, remanufacture and repurpose).

Modelling the revenue model

In the base model, a separate laundry room is designed for each flat. This washroom is approximately 1.5 m^2. In the created model, the assumption was that these personal laundry rooms are dropped and that on each floor consisting of 20 apartments, about 10m^2 of shared washroom is realised. Therefore, less area of building is ultimately realised and maintained. This is different than the base model. In line with the rent points system, the rent remains the same because the room is less than 2 m^2.
The premise is that washing machines will be placed by a supplier in a pay-per-use model. The housing association does not have any costs related to this.

$$0 = NPV = \sum_{t}^{n} \frac{f(x)t}{(1+IRR)^t}$$

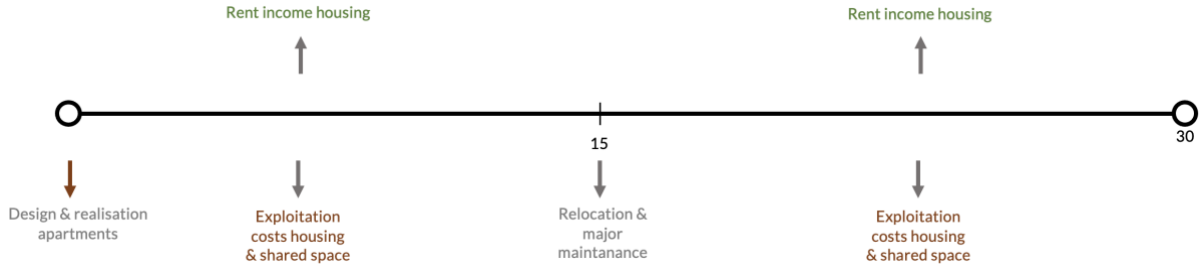
The following changes of x are made in comparison with $f(x^0)$:

- $x_{personal\ laundry} = -1.5\ m^2$

- $x_{total\ shared\ laundry} = 50\ m^2$

Figure 12 presents the cashflow with the new variables in colour in comparison to the base model.

Figure 8
Cashflow shared laundry room model



Financial results
When the financial outcomes of this model are compared with the base case, it becomes clear that the performance of the model exceeds that of the base case. The IRR is 0.2% higher than in the base case and the NPV is significantly improved.

Table 10
Financial outcome shared laundry room

	Results base model[0]	Results co-living model
IRR	1,8%	2,0%
NPV (discount rate 2,3%)	€ - 625.000	€ - 407.000
NPV per house (discount rate 2,3%)	€ - 6.300	€ - 4.100

Sensitivity analysis
It can be argued that the space saved does not benefit fewer area to be built when using a fixed measurement modular system. It could also be argued that the living room is 1.5 m^2 larger, but this is too little of an area to affect the rent. A sensitivity analysis of the IRR is carried out to assess the model's responsiveness to variations in shared and personal area. The robustness of the financial model is high with a delta of 0.07% in the IRR.

The sensitivity analysis, it can be concluded that the business case is positive. The model is not highly sensitive to changes.

Sensitivity analysis revenue model shared space on FTE

Table 11
Sensitivity analysis revenue model shared laundry on shared area

Sensitivity area shared	Results Sensitivity IRR
Input -20%	2,0%
Input baseline	2,0%
Input +20%	2,0%
Delta IRR	Δ 0,0%

Table 12
Sensitivity analysis revenue model shared laundry on personal area saving

Sensitivity area personal	Results Sensitivity IRR
Input -20%	2,0%

Input baseline	2,0%
Input +20%	2,0%
Delta IRR	Δ 0,0%

5.3.3 Model 3, 4 and 5 Performance procurement

Due to the similarities between the pay-per-use model, procurement façade model and procurement mechanical and installations, they are discussed together. As concluded in the previous chapter, housing associations were interested in this model. This model finds its link with the performance procurement model.

As found in the literature, this model is particularly interesting for layers that require high maintenance with a relatively short depreciation period that also have a measurable performance. Therefore, it is chosen to cover the shearing layers skin (façade) and service (mechanical installations) here.

This model significantly optimises the use of the skin and service. Moreover, the model extends the lifespan of both layers, as the manufacturer is responsible for its own maintenance and when it is harvested (reuse, repair, refurbish, remanufacture and repurpose).

Modelling the revenue model

Because the performance is quantifiable, it is to establish performance agreements. However, it is important to note that there is no available data regarding these models. The assumption made here illustrate of how it could potentially benefit the housing association. Arup Group & Ellen MacArthur Foundation (2020) suggest that the technical performance of these layers is improved because the producer is responsible for maintenance. There is a 20% efficiency improvement in maintenance (Arup Group & Ellen MacArthur Foundation, 2020), and it is essential to add that the assumed interest rate for this analysis is 0%. The model takes on the following form under these considerations:

$$0 = NPV = \sum_{t}^{n} \frac{f(x)t}{(1+IRR)^t}$$

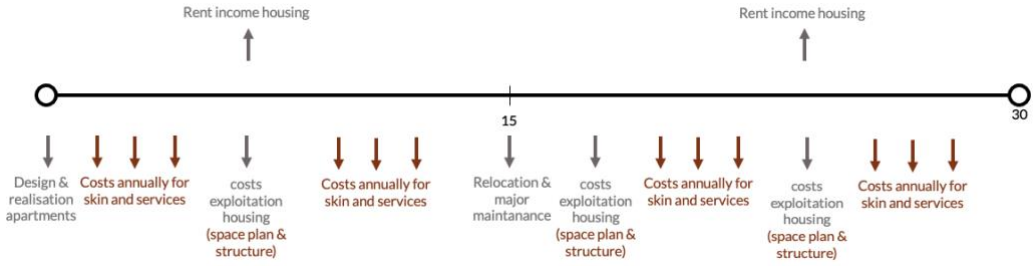
The following changes of x are made in comparison with $f(x^0)$:

- $x_{technical\ lifespan\ skin\ \&\ service} = 30\ yr$
- $x_{maintenance\ skin\ \&\ service\ efficiency} = 20\%$
- $x_{interest\ rate} = 0\%$

Figure 9 presents the cashflow with new variables in colour in comparison to the base model.

Figure 9

Cashflow performance procurement



Financial results

With these assumptions, the results provide a negative business case for the housing associations. Earlier research for a facade-as-a-service at TU Delft showed similar results (Azcárate-Aguerre et al., 2023). However, at TU Delft the facade-as-a-service is closer in financial performance to the

traditional model because the user also benefitted from the extra performance of the facade with reduced utility costs. Due to regulations, the housing association is unable to benefit from these reduced utility costs. As a result, this is not yet an interesting model for the housing associations.

Table 13
Financial outcome performance procurement model

	Results base model^0	Results performance procurement model
IRR	1,8%	1,5%
NPV (discount rate 2,3%)	€ - 625.000	€ - 283.100
NPV per house (discount rate 2,3%)	€ - 6.300	€ - 7.600

Sensitivity analysis
A sensitivity analysis of the IRR is carried out to assess the model's responsiveness to variations in maintenance skin & service efficiency. When the input variables are changed, the model's output responds to variations. The robustness of the financial model is high with a delta of 0.24% in the IRR.

Table 14
Sensitivity analysis revenue model performance procurement

Sensitivity maintenance	Results Sensitivity IRR
Input -20%	1,4%
Input baseline	1,5%
Input +20%	1,6%
Delta IRR	Δ 0,2%

5.3.4 Model 6 Shared space
As concluded in the preceding section, housing associations showed limited interest in the shared space model. It is challenging to fully demonstrate the potential of this model as it requires many assumptions. In this context, it is important to carry out a robust sensitivity analysis.
This model integrates the sharing model. This significantly optimises the use of available square metres (the strategy of 'rethinking').

Modelling the revenue model
The base model consists of 99 apartments with a shared living area of 142 m^2. This living room has the potential to be shared with co-residents. Further, because most people work or study between 9am and 5pm on weekdays, this room would be underused between those times. Therefore, it is already assumed that 50% of the living room (71 m^2) could be rented out between these times. It could be rented as a space for offices, meetings and gatherings or training and fitness.
If the room is rented out 30 times a month for two hours, the room would have an occupancy rate of about 30%. The assumption is that the space would be rented out for 50 euros (excl. taxes) per time. However, besides the income, something would also change on the cost side. Namely, there would have to be more supervision. The assumption is 0.1 FTE for supervision. Furthermore, additional investments would need to be made in furniture, an extra wall and possibly a booking system.

$$0 = NPV = \sum_{t}^{n} \frac{f(x)t}{(1+IRR)^t}$$

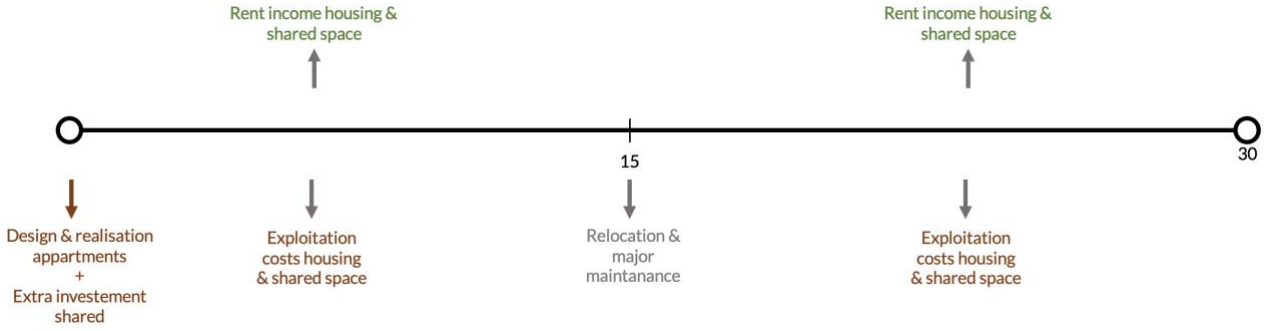
The following changes of x are made in comparison with $f(x^0)$:

- $x_{additional\ investment} = € 30.000$
- $x_{amount\ of\ rents} = 30$
- $x_{cost\ rent\ per\ time} = €50$
- $x_{fte\ supervisione} = 0.1$

- $x_{wage\ for\ 1\ fte} = €4{,}000$

Figure 10 presents the cashflow with the new variables in colour in comparison to the base model.

Figure 10
Cashflow shared spece model



Financial results

When the financial outcomes of this model are compared with the base case, it becomes clear that the performance of the model exceeds that of the base case. The IRR is higher than in the base case and the NPV is significantly improved.

Table 15
Financial outcome Shared space model

	Results base model[0]	Results co-living model
IRR	1,8%	2,1%
NPV (discount rate 2,3%)	€ - 625.000	€ - 225.100
NPV per house (discount rate 2,3%)	€ - 6.300	€ - 2.200

Sensitivity analysis

A sensitivity analysis of the IRR is carried out to assess the model's responsiveness to variations in operating costs and number of rentals. When the input variables are changed, the model's output responds to variations. The robustness of the financial model is high with a delta of 0.2% in the IRR.

Table 16
Sensitivity analysis revenue model shared space on FTE

Sensitivity FTE	Results Sensitivity IRR
Input -20%	2,1%
Input baseline	2,1%
Input +20%	2,1%
Delta IRR	Δ 0,0%

Table 17
Sensitivity analysis revenue model shared space on amount of rentals

Sensitivity amount of rentals	Results Sensitivity IRR
Input -20%	2,0%
Input baseline	2,1%
Input +20%	2,2%
Delta IRR	Δ 0,2%

As concluded in the previous chapter, housing associations are already integrating this model into housing more frequently. This model finds its link with pay-per-use model and underutilised space model.

5.3.5 Model 7 Co-living

As the previous section concluded, most housing associations are interested in the co-living model. Some have also already applied this model in permanent construction. This model connects to the sharing model. The model eliminates a certain area in the buildings being built (the 'refuse' strategy) and significantly optimises the use of available square metres (the 'rethink' strategy).

Modelling the revenue model

The base model is changed in several aspects for the co-living revenue model. The building area has been reduced, along with a reduction in incoming rent in line with the rent points system. This is shown in the formula and the timeline.

For the redesign of the co-living concept, the floorplan of two studios from the base model is changed. In this rearrangement, the partition wall within these two studios is removed, and a quarter of the combined living space is removed. This modification effectively reduced the total square metres to be built.

In addition, the rent is recalculated according to the central government's regulated rent points system. This means that the apartment changed from a rent of €525 per person for the base model to €420 per person (-20%) for the co-living model. The current rent point system penalises not having your own facilities and therefore the rent is reduced. The rent is a fixed variable with no uncertainty.

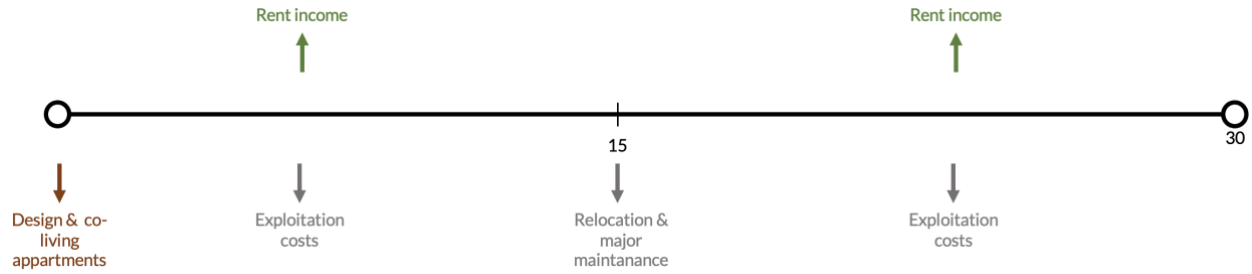
$$0 = NPV = \sum_{t}^{n} \frac{f(x)t}{(1+IRR)^t}$$

The following changes of x are made in comparison with $f(x^0)$:

- $x_{area\ total\ building} = -17\%$
- $x_{rent\ per\ month} = €420$

Figure x presents the cashflow with the new variables in colour in comparison to the base model.

Figure 11
Cashflow co-living model



Financial results

When the financial outcomes of this model are compared to the base case, it becomes evident that the model's performance does not surpass that of the baseline scenario. The IRR is lower than in the base case, and the NPV has significant decreased. This is due to a 20% lower rent and an area saving of 17% of the entire building.

Table 18
Financial outcome revenue model co-living

	Results base model^0	Results co-living model
IRR	1,8%	1,1%
NPV (discount rate 2,3%)	€ - 625.000	€ - 1.337.000
NPV per house (discount rate 2,3%)	€ - 6.300	€ - 13.500

Sensitivity analysis
A sensitivity analysis of the IRR is carried out to measure the extent to which the model responds to variations in realised square metre savings (17%) in practice. The only variations were with the variable of area of the total building. The rent is given and has no uncertainty. When the input variables are changed, the model's output responds to variations. The robustness of the financial model is low with a delta of 1.1% in the IRR.

Table 19
Sensitivity analysis revenue model co-living

Sensitivity area building	Results Sensitivity IRR
Input -20%	0,5%
Input baseline	1,1%
Input +20%	1,6%
Delta IRR	Δ 1,1%

5.3.6 Model 8 Reusable products and materials
As explained in the literature review, determining the residual value of these buildings is a complex and challenging task. Combining all these factors into one numerical representation is complex, making assessing the impact of building adaptability on residual value a difficult task. Nevertheless, it appears that the detachability has a positive impact on the residual value of building products and materials. Follow-up research on residual value is essential for feasibility.
As found in the literature, a TCO can show that demountable shearing layers or products already offer financial benefits. Here, the trade-offs are important, which are also included in the BCI score.

5.3.7 Model 9 Reuse the entire building
As stated in the literature this model is not other than the base model of the housing associations because of the modular construction, eliminating the need for a separate analysis.

5.3.8 Model 10 New ownership structure
This model is financially equivalent to the aforementioned performance model. There was also no financial data available for this. Financial analysis is therefore also omitted. This model is not expected to be financially viable because when leasing, the landlord most likely sets a yield requirement higher than an IRR of 1.8%.
This model extends the lifespan of the layers, as the layer owner is responsible for its maintenance (reuse, repair, refurbish, remanufacture and repurpose).

5.2.9 Model 11 Buyback
As indicated in the interviews, the housing associations have no direct objections to the buyback model.
Limited financial reference data is available for this buyback model. This model will extend the lifespan of the buyback product, as the producer will guarantee a buy back and residual value. This allows the producer to reuse, repair, refurbish, remanufacture and repurpose the product for a new project at the end of the product's life.

5.3.10 Model 12 Permanent quality
As concluded in chapter 4, housing associations agreed that the temporary housing should be built with a permanent quality. Additionally, it is concluded that the houses should have a lifespan of 50 years to ensure financial feasibility. This model finds its connection to the classic long-life model and

the circular strategies of ‘extend lifespan of products and elements’ by reusing the product for a third ‘life’ as found in the literature.

Modelling the revenue model

The base model is changed in several aspects. First, operation is extended for 20 years, which means both longer rental income than the base model and longer operating costs than the base model. Assuming the last location is a permanent site, the temporary house can be situated there for 20 years. In addition, an additional investment (+10%) is included for the permanent quality (according to permanent building specifications) and €15,000 for each dwelling for the permanent location.

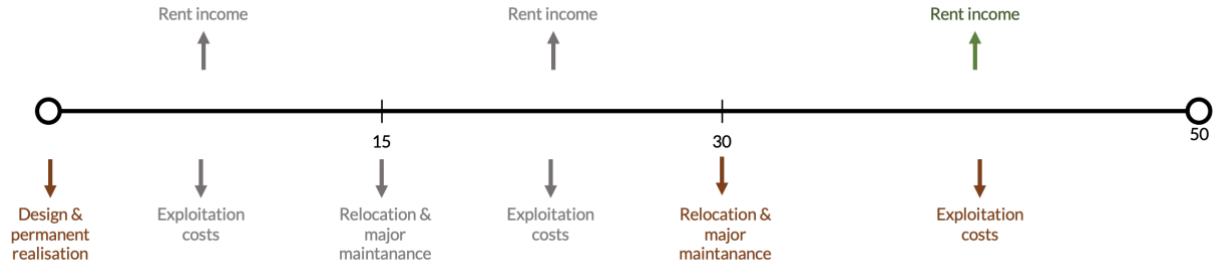
$$0 = NPV = \sum_{t}^{n} \frac{f(x)t}{(1 + IRR)^t}$$

With the following changes of x in comparison with $f(x^0)$ and t:

- $t = 50\ years$
- $x_{relocations} = 3$
- $x_{extra\ quality} = 10\%\ extra\ investment$
- $x_{investment\ permenant\ location} = €15{,}000\ reference\ year\ 2023$

Figure 12 displays the cash flow, highlighting the new variables in comparison to the base model using color. New or changed variables compared to the base case are the design and permanent realisation, relocation cost in year 30, rent income and exploitation costs and rent income after year 30.

Figure 12
Cashflow permanent quality



Financial results

When the financial outcomes of this model are compared to the base case (table 12), it becomes clear that the output of the model's performance surpasses that of the baseline scenario. The IRR is higher than in the base case, and the NPV has significant improvement.

Table 20
Financial outcome permanent quality model

	Base model^0	Permanent model
IRR	1,8%	2,2%
NPV (discount rate 2,3%)	€ - 625.000	€ - 390.000
NPV per house (discount rate 2,3%)	€ - 6.300	€ - 3.900

Sensitivity analysis

When the input variables are changed, the model's output responds to variations in the IRR (table 21). The biggest variations were with the variable of permanent quality. However, the housing associations indicated that this variable is certain because it has identified from reference projects.

Therefore, the uncertainty on this value is very low. This sensitivity is in 5.4 compared to the other models.

Table 21
Sensitivity analysis revenue model permanent quality

Sensitivity investment permanent location	Results Sensitivity IRR
Input -20%	2,0%
Input baseline	2,2%
Input +20%	2,3%
Delta IRR	Δ 0,3%

Sensitivity perm quality investment	Results Sensitivity IRR
Input -20%	1,5%
Input baseline	2,2%
Input +20%	3,0%
Delta IRR	Δ 1,5%

5.4 Comparative variant analysis

The results of the comparative analysis of circular revenue models provides insight and understanding of financial performance and robustness. The analysis consists of financial metrics to measure the financial feasibility of the model through internal rate of return (IRR) and net present value (NPV) . As already argued in the interviews, IRR is under pressure. This is also seen in the base model with an IRR of 1.8% and NPV of -€625,000. This is the benchmark for the variants.

Two models appear to be an improvement and on view of the basic model due to both improved financial performance and stability in the sensitivity analysis. These are shared laundry (model 2) and shared unused space (model 6). The sensitivity analysis shows that they have low sensitivity to variable fluctuations.
In contrast, the Permanent Quality (model 12) and Co-living (model 7) models show higher levels of financial uncertainty. The larger deltas of these models reflect significant sensitivity to input variables.

The Performance Procurement model (a combination of models 3, 4 and 5) shows lower sensitivity. This suggests predictability of the model. Financial performance is less favourable compared to the base model. This performance will be associated with a cautious approach to integration. Therefore, there is also a need for a more in-depth study of the potential of the model under different market conditions or regulatory environments.

The lack of financial that for the new ownership structure (model 10), buy-back (model 11) and reusable products and materials (model 8) precludes a direct financial comparison. However, their conceptual contribution to circular economy principles warrants further investigation. This would become interesting as market conditions change and the models become more common and more data becomes available.

Table 22 below summarises the data from this chapter. Each column represents a different revenue model and indicates its performance based on the financial indicators in the rows. The green colour represents that the variable is improved over the base model.

Table 22
Comparison of revenue model financial and sensitivity outcomes

	Base model[0]	**Model 2** Shared pay-per-use laundry	**Model 3/4/5** performance procurement	**Model 6** Shared space	**Model 7** Co-living	**Model 12** Permanent quality

IRR^0	1,8%	2,0%	1,5%	2,1%	1,1%	2,2%
NPV^0 (discount rate 2.3%)	€ - 625.000	€ - 407.000	€ - 283.100	€ - 225.100	€ -1.337.000	€ - 390.000
NPV^0 per house (discount rate 2,3%)	€ - 6.300	€ - 4.100	€ - 7.600	€ - 2.200	€ - 13.500	€ - 3.900
Variable with biggest impact (-20%)	Base 1,8%	2,0%	1,4%	2,0%	-0.5%	1.5%
Variable with biggest impact (+20%)	Base 1,8%	2,0%	1,6%	2,1%	1.6%	3.0%
Δ IRR(-/+ 20%)		Δ 0,0%	Δ 0,2%	Δ 0,1%	Δ 1.1%	Δ 1.5%

5.5 Conclusion

This chapter provided an insight into which models are most likely to be financially viable for housing associations and where further research is needed. This chapter did this by comparing the financial impact of circular revenue models with the revenue model of housing associations. Through an evaluation, a comparison of different models was presented on IRR and NPV. From the comparative analysis of circular revenue models, four main categories of circular earning models can be formulated.

The models with enhanced financial feasibility and stability

This includes the models that show better financial performance and stability compared to the base model. This are the models of Shared pay-per-use laundry (2) and Shared space (6). They seem to have a better financial performance better with IRR performance. The reduced sensitivity with the delta indicates a higher degree of financial resilience and predictability.

The models with enhanced financial feasibility but sensitive

This includes the model of Permanent quality (12). It shows better financial performance but also shows financial uncertainty in the sensitivity analysis.

The models with financial uncertainty

This category includes models characterised by higher financial uncertainty. The Co-Living (7) model belong to this category with their higher sensitivity deltas. An in-depth study of the model's potential under different market conditions or regulatory environments is recommended.

The models with theoretical enhanced feasibility but limited financial data
These include models such as the New ownership structure model (10), Buy-back (11), and Reusable products and materials (8). For these models the financial comparisons were not possible due to the lack of financial data. Due to the lack of data, further research into these models is recommended.

Circular revenue models show potential for improved financial performance. This is especially the case for the models in the category of improved financial performance and stability. The models offer opportunities for housing associations to increase their financial robustness while contributing to environmental goals. However, there is financial uncertainty and the need for further research for some models. This highlights the need for housing associations to carefully consider and adapt circular revenue models to their specific context and objectives. Where in the decision making they need to take into account both financial and circularity factors.

6. Conclusion and recommendations

This chapter starts with the conclusions and recommendations on the circular revenue models for temporary housing projects of housing associations. It answers the main question in the conclusion and provides the limitations of this research. Next, recommendations to the housing associations are discussed. Lastly, the recommendations for further research are discussed

6.1 Conclusion

To answer this main question, four sub-questions (*s.q.)* were posed. These are answered first below. After the main question (m.q.) is answered.

S.q.: What circular strategies should the revenue models of temporary housing be aligned with?

For circularity, in general, there are three circular strategies that can be fulfilled; "Use and produce the product smarter," "Extend the lifespan of the product and elements," and "Useful application of materials". This study omits discussing the "Useful Application of Materials" due to perceived limitations. The higher up the strategies R ladder the more circular the material, product, element or building is. To improve circularity to goal is therefore to get higher up the R ladder. These strategies need to be fulfilled in the revenue models for achieving the circularity in temporary housing projects. For measuring these circular strategies the BCI is the most comprehensive for informed decisions. Based on the findings it is concluded that temporary housing which is constructed modularly aligns with the with the strategies 'extend the lifespan of products and elements' and 'Use and produce the product smarter'. In the interviews it is found all housing associations use 3d modular construction. However, no data was available (with BCI) for the extent of which the modular construction is in line with the circular strategies.

S.q.: What are the revenue models used by housing associations for providing temporary housing?

Literature and the interviews conclude that the revenue models of housing associations are formed in DCF with a Net Present Value and an IRR financial feasibility measurement. This includes future rental income and investment for construction and land acquisition, maintenance, and operating costs. Housing associations operate on a non-profit basis and focus on providing affordable housing to low-income households. They are supported by low-interest loans with government guarantees. Importantly in the interviews is found that all housing associations received land for the projects free of charge including infrastructure and utilities and is therefore not part of the revenue model of the housing association. The maintenance costs of the temporary housing are expected lower because of design choices and selected materials. There assumption is that this is due to integrated circular strategies in the modular temporary housing, but cannot be deduced from the information from the interviews. Further research is needed. The housing associations have a minimum of two locations for planned as starting point for the revenue model.

S.q.: Which circular revenue models have been identified as suitable for adoption in temporary housing?

The housing associations face different challenges implementing circularity. Financial hurdles persist with stagnant revenues and rising costs. Regulations is complicating factor, for example unexpected updates to building codes and tax burdens. Adaptation and internal alignment within associations is also a challenge. The sustainability goals often constrained by financial and internal challenges. Lastly, market perception and the mismatch between supply and demand is an obstacle.

The identified circular revenue models for adoption in temporary housing present the circular strategies found in the first sub question. The housing associations exhibit varying levels of familiarity and readiness to integrate these models into their revenue models due to the challenges.

First, models such as shared pay-per-use space (1) and pay-per-use laundry (2) align well with circular strategies of smarter product use and extending product life. Yet housing associations have expressed reservations about charging residents for shared space due to financial constraints. In contrast, housing association see the shared laundry facility as an opportunity.

Pay-per-lux (3), procurement (4 / 5) and new ownership models (10), where users pay for performance rather than ownership, also received mixed reactions. While some housing associations are open to these innovative approaches, most prefer ownership-based models for financial reasons and to have control over ownership conditions.
The model of utilising shared spaces (6) for rental income resonates with circular strategy of optimising resource use, but is generally considered not to be the core strengths of housing associations.
Co living model (7) aimed at extend the lifespan of product and elements received varied responses and were considered more suitable for younger residents. The idea of a revenue model with reusable products and materials (8), despite recognising its impact on overall costs and maintenance, faces regulatory hurdles that prevent implementation. Furthermore, a model has been identified for reusing the entire building (9) in another location. However, this is no different from the basic revenue model of the temporary house. Buy-back model (11), where products are sold with a guaranteed buy-back, raise concerns among housing associations about third-party dependency and financial implications. Finally, the model for permanent building (12) is in line with the strategy "Extend the lifespan of product and elements". The requirement for permanent construction quality is heard across the housing associations, emphasizing the need for durability and the risk of compliance with building regulations.

S.q.: How do the financial results and feasibility of circular revenue models differ compared to the traditional revenue model?

In conclusion, the variant analyses of circular revenue models compared to the current revenue model of housing associations show several outcomes.
First, models such as pay-per-use laundry (2) and shared space (6) show better financial performance and sensitivity. These models offer opportunities for adoption, because they enhance financial feasibility. On the other hand, the Permanent Quality (12) model show feasibility but greater sensitivity. This model requires project-based analyses to understand their feasibility. The model of Co-living (7) is compared to the base model less feasible. Finally, there are models with theoretical added value but limited financial data. This models of procurement and new ownership structures (3 / 4 / 5 / 10), buy-back (11) and reusable products and materials (8). These models require further research to quantify their financial impact.

Overall, circular revenue models offer opportunities to enhance the feasibility of temporary housing projects of housing associations. However, the existence of financial uncertainty highlights the need for project and context-based testing.

M.q.: What changes in the revenue models of housing associations are needed for enhanced feasible circularity in temporary housing projects compared to the current practices?

To conclude, to enhance feasible circularity in temporary housing, housing associations should consider integrating each of the circular revenue models identified in the study. Housing associations can improve feasibility by revenue streams as shown in model pay-per-use laundry (2) and shared spaces (6) while advancing circularity compared to current practices. The revenue models of permanent quality (12) exhibit greater feasibility but also more uncertainty. This reflects possible enhanced feasible models analysed project, but a project-specific evaluation is needed to determine whether this is the case. The here fore named models are also seen as suitable for housing associations. However, for the other models either feasibility is not enhanced with Co-living (7), no

data was available (3/5/10/11) or the market is not ready (3 /4). This shows that the financial challenge can be eliminated for the named circular revenue models. However, no research is done to overcome the other challenges faced by housing associations.

6.2 Discussion

This research began by exploring to understand the integration of circular strategies into temporary housing projects of housing associations. It was expected that the concept of temporary housing was not in line with the transition to a circular economy. However, the research shows that modular temporary housing does align with the principles of circularity. Nevertheless, this research lacks data to measure the extent to which this is the case, for example through a BCI. In addition, it was unknown how the houses were depreciated. It appears that most housing associations assume a similar lifespan as a regular home. With that, the applicability of the circular revenue models found appears to be also to regular houses.

Secondly this research focussed on the circular revenue. Which required an analyses of circular business models. Studies have been done on circular business models. However, in-depth research on these models and the relation to circular strategies has been lacking. The results of circular business models in the different studies are similar and often the same categorised business models are used. This research therefore provides a complete view of archetypes of circular business models for follow-up research.

Thirdly, the research gap was analysed of the state of integration of the circular revenue models in the projects and the willingness of housing associations. The interview results indicate that housing associations have scarcely implemented any circular revenue models. However, contrary to expectations, the temporary housing is already often operated in two locations. Furthermore, there is a varying degree of willingness and enthusiasm among housing associations to adopt circular revenue models. These differences were partially assigned to a combination of factors, including financial risks, the lack of established market standards for circularity and regulatory constraints. In particular, the reliance on external parties for the success of certain circular models, such as buy-back, raised concerns about financial autonomy. These findings are relevant to the government for setting circularity goals and to business developers seeking to understand circular revenue models.

After the research analyzed the feasibility of the models and compared it with the regular revenue models. This had not been researched before. Introducing the financial results and comparison of the circular revenue models offers housing associations a sight into integrating the revenue models. However, there are several circular revenue models where further research, legislation or market change is needed before integration at the houses associations is possible.

6.3 Limitations

The limitation of the study consists of some methodological and empirical challenges that there were in the research. The literature may not cover all aspects or perspectives of a topic due to limitations in found research because of its scope. This limits the general applicability of the results to other projects than the project of the variant study.
Modular temporary housing appears to align with circular strategies and principles as substantiated in the literature study. However, the extent of this alignment is uncertain without empirical data, such as the Building Circularity Index (BCI).

The representativeness of the interview sample is very low, only 16% responded to the invitation. This limits the reliability and generalizability of the findings to the broader population of housing associations. In addition, the interviews were conducted in different environments, online and in person. Differences in the environment may affect participants' comfort. This potentially affects the consistency of responses in the study. This can lead to variability in respondents' behaviour and responses.

The identified housing associations with temporary housing were found through only one website. The reliance on one website may limit the generalizability of the sample and introduce selection bias. For example, housing associations that were not on this website may not have been used for that reason. It is unknown whether this website covers all temporary housing projects.
The goal of the SSI methodology is to obtain detailed answers. This is achieved through the flexibility of the interviewer to ask more in-depth questions. However, this approach can therefore also lead to variability in detail and quality of answers. This can be influenced, for example, by the skill of the interviewer, relationship with the participants and phrasing. Therefore, this can affect the validity of the results.

The financial assumptions have been drawn from sources but these may lag behind actual numbers. Also, none of the housing associations provided more feedback on the revenue models and assumptions. So, no validation of the revenue models is done. Ideally the revenue models are tested in practice.

For the sensitivity analysis, as in other studies, +/- 20% variations were chosen. However, if real world conditions do not reflect these variates but larger deviations these conclusions can be misleading. This method of varying by the fixed percentage +/- 20% provides clarity. However, this can oversimplify complex interdependencies between variables in the real world.

The study conclude that the circular revenue models identified are not currently integrated into the revenue models used by housing associations. With the SSI's with the experts of the housing associations the research tried to argue the challenges of implementing. However, there is a lack of empirical evidence supporting how these circular models can be incorporated into existing revenue structures of housing associations.

6.4 Recommendations

The research reveals a gap between theoretical frameworks (circular business models) and their practical implementation on (temporary) housing. Future research should focus on empirical validation through, for example, a case study of the proposed circular revenue models.

The study concludes with several challenges to implementing circular business models, such as financial hurdles and legal constraints. Further research should explore to overcome these barriers, possibly through policy adjustment recommendations, financial incentives e.g. through a carbon tax or subsidies and frameworks and standardised contracts for the involvement of external stakeholders in the revenue models. In addition, specifically for the buy-back model, how to reduce the risk for housing associations should be investigated.

The study concludes that modular temporary housing aligns with the circular strategies found in the literature. However, the degree of alignment, e.g. through a BCI, is not known. Follow-up research could focus on this empirical metric. Through the BCI, a study could be conducted on applying circular strategies and quantifying the benefits in temporary housing projects.

The study conducts variant analysis to determine the feasibility of circular revenue models. As already indicated in the discussion, there is a risk of oversimplification of complex interdependencies between input variables. Future research could refine these revenue models taking interdependencies into account. In this way, there will be a better understanding of circular revenue models.

The research has focused on the financial feasibility of revenue models. However, this did not calculate the exact environmental effects of the circular models. Through an LCA, these effects could be calculated and evaluated per model. In addition, research could be done on the full business models. So, this would also highlight target customers (segments and relationships, the benefit a company provides to its customers and key partners in the value chain and how does the company deliver this benefit to partners, activities and resource.

Also, little is still known about the long-term effects of circular choices. Through a case study, it is possible to analyse what impact circular choices have on the performance and outcomes of revenue models in the long term.

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8. Appendices

Appendix 1 Circular business models

Currently, you can already see several circular business models emerging in the construction sector and real estate market. Below are Carra et al's (2017) models for real estate companies.

Circular Supplies
The development of new circular materials is central in this business model, such as bio-based, co2 reducing or fully reuseable materials. This fits the reduce strategy, because less recourses are used.

Tracking Facility
A business model which provides tracking of elements, materials, products or parts so that the value is known and can be traded when dismantled. These are tracked the strategies from R3 to R9 are all included in this model.

Lifetime extension
The use of technical solutions that facilitate, for example, disassembly, reassembly, repair and maintenance (R3 to R9). This extends the life of materials or adjacent materials.

Sell and Buy-Back
This business model provides a product which is sold with upfront commitment that it will be repurchased after a certain period of time. The goal is to get as high as possible up the ladder with a maximum of R3, reuse (R3 to R9) .

Product As A Service (PAAS)
Delivering a performance rather than delivering a product. This means that kpi's are agreed in advance and maintenance is also included in the performance. The business model runs on revenue from the provided performance. By offering products as a service, they are often extended in life through reuse, repair, refurbishing, remanufacturing or repurose (R3 to R7).

Sharing Platforms
This model is based on higher utilisation of existing stock through shared use of it. Earnings can be made on shared-use transactions. (R1)

Recapture material suppliers
Materials released from the disarticulation of a demolition are sold instead of new materials. This reduces resources used (R2) by strategies R3 to R9.

Recycling Facility
The business model is based on transforming waste into raw materials through recycling (R8) technologies.

Support Life cycle
This business model makes revenues of sales from consumables to support the life cycle of long-lasting products by reducing (R2).

Refurbish and Maintain
This business model makes revenue by refurbishing (R5) used to subsequently sell it.

The real estate development company
These circular business models can also be translated on the real estate assets. Arup Group & Ellen MacArthur Foundation (2020) proposes five new business models that capture each source of lost value and respond to market trends with similar to the above circular economy business models. A large part of the models are based on the model of shearing layers.

Flexible Spaces (sharing platforms)
The lost value of underutilised space is captured with this model. A platform can list actual data from a building (which are smart) to make all unused space available to tenants. This has similarities to the

business model of sharing platforms because this model also aims optimising utilisation of the existing stock.

Adaptable Assets (Lifetime Extension)
This model captures the lost value of prematurely demolished buildings. The use of real estate can be changed at a lower market cost, more likely through retrofitting than demolition. This model is based on a different investment partnership because of the different lifespans of the shearing building layers. Ellen MacArthur's study proposes a long-term investor for the skin and structure. Short-term investors can rent the chassis for matching the specific use, for example office use.
Important design parameters to include are floor-to-floor height, floor plate depth, core positions and entrances, riser sizing, plant-room sizing and positioning. This model is similar to the lifetime extension business model because it facilitates changes in the building for a longer life cycle.

Relocatable Buildings (Lifetime Extension)
This model captures the lost value of vacant land In cities where land is scarce, it can be utilised to provide affordable space to users. It can also enable operators and landowners to recover the lost value of vacant land. The building will then have to be operated in multiple locations. This model has also similarities to the lifetime extension business model because it facilitates changes of the building's location for a longer life cycle.

Residual Value (Recapture Material Suppliers / Refurbish and Maintain)
The lost value of depreciated building materials is captured with this model. The introduction of commodity futures contracts for buildings is inherent in this model. These contracts can be traded on a central exchange. The value is linked to the estimated future value at dismantling. The contract contains all information on the materials released on dismantling. The forward contract is tradable. The holder of the term contract at decommissioning is the owner of the materials. However, the building will have to be designed for deconstruction for materials. This has parallels with the recovery stage and the business models of recapture materials and refurbish and maintain.

Performance Procurement (Product as a Service)
This model captures the lost value of underperforming components. This encourages service providers to create high performance, long-lasting systems . This model is mainly compelling for the skin and services as they determine the energy performance of a building; this allows the model to generate a return.

The table below shows the similarities between the two researches. Three models bear no direct resemblance to the business models of the other study. 'Circular supplies' from the design phase and 'support lifecycle' in the recovery phase have no similarity. These models must be added to the research as separate models. The sell and buy back business model is not included in the other study. This model also brings a shift in ownership in the life cycle the same as the performance procurement model.

Phase		*Flexible Spaces*	*Adaptable Assets*	*Relocatable Buildings*	*Residual Value*	*Performance Procurement*
Design	*Circular Supplies*					
Use	*Tracking Facility*				x	
	Lifetime Extension		x	x		
	Sell and Buy-Back					
	Product as a Service					x

	Sharing Platforms	x				
Recovery	*Recapture Material Suppliers*				x	
	Recycling Facility				x	
	Support Lifecycle					
	Refurbish and Maintain				x	

Appendix 2 Invite interview housing associations

Geachte heer / mevrouw, Beste voornaam,

De overheid stuurt aan op 50% circulariteit in 2030 en in 2050 zelfs een circulariteit van 100%.

Mijn naam is Mathijs Timmermans. Ik ben master student bouwkunde aan de TU/e en ben geïnteresseerd in dit onderwerp dat een aanzienlijke impact heeft op het bouwen en exploiteren van (tijdelijk) vastgoed.

Naam verwees mij door naar u en gaf aan dat woning corporatie ervaring en kennis heeft in de ontwikkelingen van tijdelijk vastgoed.

In het kader van mijn Masterthesis voor de TU/e onderzoek ik verdien modellen van tijdelijke woningen die oplossingen en inzichten geven in de circulaire economie van (tijdelijk) vastgoed. Ik volg de masterstudie USRE (Urban Systems & Real Estate) waarbij de thesis wordt begeleid door Ir. Stephan Maussen van die faculteit. Graag vraag ik u om medewerking in dit onderzoek. Ik licht dit toe.

In het (literatuur)onderzoek stelde ik vast dat woningcorporaties de investeringskosten van de tijdelijke woningen afschrijven in een relatief korte periode tot 0%- 20%. Verwacht wordt dat de overheid de woningcorporaties een leidende rol geeft in de circulaire transitie, net zoals bij de transitie m.b.t het energielabel. Het optimaliseren van de (circulaire) verdienmodellen kan bijdragen aan het op andere wijze investeren (lees: het vergemakkelijken van investeringen) in tijdelijke woningen.

Op de website van woning corporatie ik dat jullie al het project hebben afgerond. Ik zou graag een interview willen afnemen bij de projectverantwoordelijken van deze tijdelijke woning projecten.

Tijdens het interview heb ik vaste lijst van vragen waar ik op doorvraag. Op deze wijze kan op basis van meerdere expert interviews (met woning corporaties) conclusies getrokken worden over de huidige verdien modellen, circulariteit en de haalbaarheid van de circulaire verdien modellen. Voor het interview heb ik 1,5 uur nodig. Uw gegevens worden volledig geanonimiseerd in het onderzoek.

Ik zou uw medewerking bijzonder op prijs stellen. Ik ben ervan overtuigd dat dit wetenschappelijk onderzoek woning corporatie een stap verder brengt in de mogelijkheden m.b.t het ontwikkelen en vermarkten van circulaire tijdelijke woningen.
Indien u meer informatie wilt over mijn onderzoek, de onderzoeksmethoden of een (online) afspraak wil inplannen hoor ik dat graag.

Alvast hartelijk dank,

Met vriendelijke groet,

Mathijs Timmermans

Student USRE TU/e
Tel: 06-40256009

Appendix 3 SSI guide

General information

Invite

The following information will be given in the invite of the interview

- Information about the research
- The question if the expert is willing to conduct an interview of 1,5 hours
- The temporary housing projects on where the housing assocation is selected to take part in this study

Appointment interview

When the expert agreed on taking part in the interview. An appointment is scheduled. This is done via mail. The mail consists the following information:

- Location, date and time
- Small explantion of the aim of the interviews. It is chosen not to expand to much on the subject because this may influence the answers.
- Maximum time of 1,5 hours of the interview
- An explantion of the coding of the name anonymously in the study.
- That the interview will be recorded. The recordings will only be used for this research and listened by the researcher Mathijs Timmermans.
- An explanation that the interview questions will nog be send before the interview.
- Receive the 'informed consent formulier'.

Conducting the interview

- Participants are encouraged to respond freely, and their statements will undergo coding to ensure anonymity.
- The dialogue will start with casual conversation.
- The discussions will be conducted unbiased and participants will therefore not be steered towards responses.
- Participants are explicitly informed of their right to stop the conversation at any point.

Questions

Start

0.1 What is your function and responsibility within the housing assocation?
0.2 What was your role within the temporary housing project?
0.3 Which temporary housing projects did the housing assocation do? Which were you involved in?

R1 Financial model

Construction and land costs

1.1 Does the financial model employed for temporary housing resemble the same which is utilized for conventional housing projects? If not what are the differences?
1.2 What type of temporary housing is employed (modular)? and what are the associated construction costs and building expenses?
1.3 How are the infrastructure expenses covered? Is it trough municipal funding? Does this encompass utility connection costs (gas, water, and electricity)? What are the costs?
1.4 What do the land charges entail? Are these land expenses borne by the housing association or by the municipality?

Maintenance and overhead

1.5 What costs are distinct in temporary housing as compared to conventional housing? If so, which specific costs are involved? Consider aspects such as cleaning, overhead, etc.
1.6 Do maintenance cost fundamentals differ compared to a regular housing project?* Are there variations in the maintenance costs between temporary housing and a standard housing project? If so, why and how much?
1.7 Are there disparities in the overhead expenses when compared to a regular housing project? What are these expenses comprised of? *

Valuation

1.8 What financial model valuing method is used?
1.9 What lifespan is assumed for the temporary houing ?
1.10 How is the financial return assessed? Is the Internal Rate of Return (IRR) used? What is the intended target return? What has been the realized return?

1.11 Has a residual value been computed? If so, how is the residual value determined?
1.12 What assumption is made regarding the frequency of house relocations?

R2 Circular temporary housing

2.1 What is your housing associations' approach and vision to circularity?*
2.2 How does your housing association incorporate circularity principles into its temporary housing projects?*
2.3 What challenges have you faced in implementing circularity in your temporary housing projects?*
2.4 Do you measure circularity? If so, how do you measure it in the projects? Do you have BCI scores?
2.5 Can you explain how circularity is incorporated into its financial/revenue models?
2.7 Based on my study, the following circularity principles have emerged. Do you concur with these principles, and do you perceive any additional circular principles that may be absent from this list?

Designing following the R ladder and therefore
Designing detachable and adaptable
Low invironmental impact
Clear distinction of shearing layers
Clear distinction of materials in products and products in elements

R3 Circular business models (validatie dmv barriers?)

3.1 From my research, it has been shown that there are opportunities through the application of circular revenue models. Do you know circular revenue models? If not a brief explanation is given.
3.2 Did the housing assocation ever use these circular revenue models? If yes can u explain how?
Why have you applied / not applied the circular models? What are the barriers?
3.4 Do you recognise the drivers and barriers found in the litarture?
3.5 I show the in literature found models. Do you share this view? why? Do you miss circular revenue models?
I will ask per model if they see barriers by asking aout every barrier found in literature?
3.5 What changes are needed? In laws? In the market?
3.6 In the remainder of this study, the effects of these models are depicted. Are there any specific concerns that need to be taken into account?

End

0.3 Do you have anything extra to add ?
0.4 Do you have any tipps for my next interviews?

Appendix 4 Thematic analysis

Current practices

		A. Cazas Wonen	B. Heuvelrug	C. Portaal	D. Area	Themes
R1 Financial						
0.1	What is your function and responsibility within the housing assocation?	*An interview was conducted with a project developer from the housing association engaged in the development of both temporary and non-temporary housing.*	*An interview was conducted with a manager real estate which is engaged in the development of both temporary and non-temporary housing and planned maintenance.*	*The two of the three interviewees are interim project managers at the housing association. They are tasked with projects throughout, from their initial conceptualization through execution and post-project care for temporary and non temporary. One interviewee is a real estate advisor with the housing association. His primary focus revolves around issues related to climate adaptation and the promotion of circular construction practices*	*An interview was conducted with a r eal estate developer which is engaged in differtent housing projects, temporary and non-temporary.*	- Project managment function with responsibility form begin to end of project - Post project responsiblity - Temporary housing projects - Non- temporary housing projects
0.2	What was your role within the temporary housing project?	*The interviewee is actively involved in projects from initiative to completion.*	*The interviewee is managing three flexible housing projects from i nitiative to completion.*	*The project managers are involved from initiatieve to completion.*	*The real estate developer is involved from i nitiatieve to completion.*	- Initiatieve to completion
0.3	Which temporary housing projects did the housing assocation do? Which were you involved in?	*The housing association is in the initiative phase of three flexible housing projects, with the developer's direct involvement in two of them: 150 flexible housing units in Utrecht and 100 flexible housing units in Ijsselstein.*	*The housing assocation is in three projects: 52 flexhousing in Utrechts Heuvelrug, 52 flex housing in Duurstede and Zeist in an initiative phase which will be bigger project the exact amount is unknown.*	*The housing association is managing three flexible housing projects: 48 flexhousing in Bunnik, 500 flexhousing Nijmegen together with two other housing assocations and 140 flexhousing in Arnhem*	*Already two projects are accomplished in Uden en Erp. They just started with a flex housing project in Veghel.*	- Amount of projects - Project in province Utrecht - Projects in province Gelderland - Projects in province Noord-Brabant
Construction and land costs						
1.1	Does the financial model employed for temporary housing resemble the same which is utilized for conventional housing projects? If not what are the differences?	*The regular model was used with different assumptions about relocations and the lifespan. The assumption of the lifespan of the temporary house is 36 years.*	*The regular model was used with different assumptions about relocations.*	*The regular model was used with different assumptions about relocations.*	*The regular model was used with different assumptions about relocations and residential preparation of the land..*	- Regular model - Relocation - Land preparation - The lifespan
1.2	What type of temporary housing is employed (modular)?	*Housing association A has not yest selected contractors for both projects. It is likely that Housing Association A will use the Aedes procedure to choose the contractor for these projects. They need fullfill permanent regulation for the second location.*	*Housing Association B articulated their preference for a distinct type of housing design, emphasizing efficiency and practicality. Housing Association B encountered housing units consisting of two separate blocks transported on trucks, necessitating subsequent disassembly and reassembly. They expressed a clear preference to avoid such complexities. Consequently, they have explored an alternative housing solution, ultimately leading them to the "Startblock" dwelling. The Startblock is a three-story storey house configuration with units arranged back-to-back. The ground floor is equipped with a kitchen-living area, the first floor accommodates a living room and a restroom, while the second floor houses the bedroom and a shower. This system is constructed using cross-laminated timber and is internally finished with a durable lacquer coating.* *From a cost perspective, Housing Association B indicated that the approximate cost per unit stands at €225,000 for a 60-square-meter dwelling. This housing concept aligns with their desire for a simplified and cost-effective approach to housing development.* *The depreciation period for these housing units is set at 50 years, with a strict requirement that these units adhere to permanent construction standards.*	*Housing association C aims for permanent construction through building systems with extremely short construction times. In the case of the Nijmegen project with 500 housing units, Housing association C chose the c onstruction system of "De Meeuw". This system is characterised by steel frame frames, modular building units, hallow walls and steel cladding.* *On the other hand, the Arnhem project uses wooden Cross-Laminated Timber (CLT) modules. These CLT modules offer specific advantages in terms of durability and aesthetics.* *Regarding the flexible housing units in Bunnik, which come from the National Real Estate Company (Rijksvastgoed bedrijf), housing association C sees this as a unique venture. It serves as a valuable opportunity for them to gather essential insights and lessons which they can apply to larger-scale projects, like the one in Utrecht, so that they can be successfully implemented.* *Housing Association C has also explored the concept of remountable 2D modular construction. However, the feasibility of this approach is limited by high relocation costs.* *The design phase, including engineering, is aimed at achieving a permanent building quality.*	*Housing assocation D emphasises on that difference is not in modular or anything like that but particularly in, the difference building regulations make between temporary construction, permanent construction. They opt for a long lifespan. So that it can be built at several locations one after the other.* *They chose one builder from the challenge of so you think you can build? which is MOOS.*	- Modular concept - Permanent construction - One module - Steel frame construction - CLT - Feasibility 2D modularity - Selecting contractor
1.3	What do the land charges entail? Are these land expenses borne by the housing association or by the municipality?	*The municipality will provide the l and free of charge in with construction and residential preparation.* *The duration of the land use is stipulated in the agreement with the municipality, which, in these cases, is consistently set at 15 years, as a 10-year period does not allow for financial viability.* *One project is situated on privately owned land. During the period, Housing Association A will not have any lease income, which they currently receive. Projects on the housing assocation owned land present additional challenges in terms of financial viability, as the association has to take responsibility for the preparation of the land for construction and housing.*	*Housing Association B has established an agreement with the municipality where both the construction and residential preparation of the land are the responsibility of the municipality. Additionally, it's noteworthy that Housing Association B operates under a framework in which they benefit from a subsidy provided by the central government. Importantly, this subsidy is directed entirely to the municipality.*	*Housing association C received the land at no cost from the municipality of Bunnik. Moreover, the municipality provides f ully developed and ready to build land, including the necessary infrastructure for residential use.*	*The municipality provide the land for free for a period of 15 years. Housing assocaiton D gets a right of superficies from the municipality.*	- Free ready to build land from muncipality - Privatly owned land - Right of superficies form municipality
1.4	How are the infrastructure expenses covered? Is it trough municipal funding? Does this encompass utility connection costs (gas, water, and electricity)?	*The infrastructure are covered by the municipality by the construction and residential preparation. This does include costs for utility.*	*The infrastructure are covered by the municipality by the construction and residential preparation. This does include costs for utility.*	*The municipality providesd fully developed and ready to build land, including the necessary infrastructure for residential use.*	*Costs for residential site preparations and restoring the land to its original state are for Housing association D*	- Free ready to build land from muncipality - With utility infrastructure - Residential prep and restoring for housing assocation
Maintenance and overhead						
1.5	What costs are distinct in temporary housing as compared to conventional housing? If so, which specific costs are involved?	*The costs do not differ from regular housing.*	*The costs do not differ from regular housing.*	*The costs do not differ from regular housing.*	*The costs do not differ from regular housing.* *There does tend to be a target group that needs more social management in temporary housing. This is not specific to temporary housing. n.*	- *The costs do not differ from regular housing.* - *Target group that needs more social management in temporary housing. This is not specific to temporary housing.*
1.6	Do maintenance cost fundamentals differ compared to a regular housing project?* Are there variations in the maintenance costs between temporary housing and a standard housing project? If so, why and how much?	*Housing association A has not calculated the Total Cost of Ownership (TCO) yet. Housing Association A a nticipates upon that that maintenance costs will likely be lower than regular housing.*	*It is anticipated that there won't be significant issues associated with the Startblock housing units. These dwellings are relatively low-maintenance. The exterior of these units has been clad with a type of synthetic siding known as "kunststof rabatdelen." This cladding material comprises a portion of wood waste generated during the panel manufacturing process and a portion of surplus plastic from the production of plastic window frames.*	*Housing Association C uses Total Cost of Ownership (TCO), which means taking into account not only initial construction costs, but also future maintenance costs. Their approach does not take into account detachability and or repairability.*	*Housing association D e xpects to build low-maintenance homes with the chosen products. They ex pect less maintenance than an average new-build home. This results in a higher front-end investment cost. The association expects this cost of investment to be recouped. No TCO is used to analyse this.*	- *Lower maintainance* - *Using TCO for future maintainance*
1.7	Are there disparities in the overhead expenses when compared to a regular housing project? What are these expenses comprised of? *	*Overhead costs do not differ compared to a regular projects.*	*Overhead costs do not differ compared to regular projects.*	*Overhead costs do not differ compared to regular projects.*	*Overhead costs do not differ compared to regular projects.*	All housing associations indicated that overhead costs did not differ.
Valuation						
1.8	What financial model valuing method is used?	*A Discounted Cash Flow (DCF) valuation method is used.*	*A Discounted Cash Flow (DCF) valuation method is used.*	*A Discounted Cash Flow (DCF) valuation method is used.*	*A Discounted Cash Flow (DCF) valuation method is used.*	All housing associations indicated that they use the DCF model.
1.9	What lifespan is assumed for the temporary houing ?	*The depreciation period for these units is set at 36 years as opposed to the 50-year depreciation period for regular housing.*	*Depreciate housing in 50 years. However, the property must comply with permanent construction.*	*The lifespan of 50 years is considered for the flexhousing*	*The lifespan of 50 years is considered for the flexhousing*	- 36 years lifespan - 50 years lifespan
1.10	How is the financial return assessed? Is the Internal Rate of Return (IRR) used? What is the intended target return?	*IRR is used for the calculations of the return. To maintain robust operations, a minimum return must be achieved; 1% is considered insufficient. Internally, it is recognised that due to the urgency of the ho using crisis, this can be seen as a temporary solution and therefore the yield requirement is somewhat flexible. However, a lower limit is set to ensure that the project remains financially viable. It has to cover the financing and management of such a project, otherwise it will lead to annual losses.*	*Housing Association B has also chosen to use the Discounted Cash Flow (DCF) method, incorporating the Internal Rate of Return (IRR) as the financial metric. The IRR is directly influenced by the level of rental pricing. For the initial rental rate ceiling, Housing Association B aims for an approximate internal rate of return of 1.4%. Nevertheless, this rate represents a relatively bad return on investment, raising concerns about its long-term financial viability.*	*Housing association C uses the IRR as the financial metric. The housing are not feasible. This was a challenging revelation for the board of directors. However, it is important to emphasise that the decision to proceed was fundamentally rooted in a political consideration.*	*Houses association D is on the edge of being able to execute the project with this low IRR. There is a piece of unprofitable top in there.*	- IRR - Financially unprofitable

1.11	Has a residual value been computed? If so, how is the residual value determined?	The residual value at year 36 is estimated to be equal to the relocation costs at that time, which have been estimated at €10,000 - €15,000. This represents the minimum value required to facilitate relocation to a third location, where the units would continue to operate until the 50th year. Unlike regular housing, which increases in value due to their fixed location, flexible housing do not show this increase in value. Housing Association A has had to carefully consider financing, as in the event that these properties are not provided with a subsequent location, they will need to be sold in year 15. It is expected that the market will likely be saturated with flexible housing units that do not have a follow-up location by that time. Consequently, Housing Association A may need to depreciate faster.	The depreciation period for these housing units is set at 50 years, with a strict requirement that these units adhere to permanent construction standards. The residual value remaining after the end of the project is deliberately not included in the revenue modelling. If there is a surplus at the end of the 50-year period, it can be used to build new homes that would otherwise be considered financially unfeasible. The overarching goal is to accumulate a surplus over this 50-year period.	A proposal came from the Ministry to calculate residual value, which essentially amounts to a residual value assessment. Internally, housing association C consulted extensively during the decision-making process, asking whether it was realistic to expect these properties to retain a value. They drepiciate the house to zero in 50 years.	Houses association D depreciates the house in 50 years to zero. There is no residual value that is taken into account in the financial model.	- Depreciate temporary housing in 50 years - Housing does not increase in value because of fixed location
1.12	What assumption is made regarding the frequency of house relocations?	The next location is stipulated in the agreement with the municipality that in our cases 15 years every time, because they can't make financial viability with 10 years, relocation costs are just a drama. It has to be 15 years at the first location and 21 years at the second location. They need fullfill permanent regulation for the second location.	Ensuring that Housing Association B received the guarantee from the municipality of an alternative location once the 10-year permit expires is crucial. This assurance effectively provides them with a 50-year window for the continued operation of the housing units. Housing Association B recognized that frequent relocations lead to extended payback periods. The associated relocation costs typically amount to approximately 10% of the total investment, which, over time, erodes the overall return on investment. After the relocation of the units, Housing Association B intends to acquire the land for the third location. The municipality Duurstede has established a land pricing policy, as outlined in its land price document (grondprijzen nota). This document specifies the cost associated with a social plot, which includes both the infrastructure for residentail and construction readiness.	Housing association C considers the project in Arnhem the most optimistic scenario, mainly because of the cooperative attitude of the municipality. Both the municipality and the housing associations, as key stakeholders, have committed to jointly look for a second site where these buildings can be situated permanently. The design phase, including engineering, is aimed at achieving a permanent building quality. Housing Association C initially started with an approach for the 500 flexible housing units in Nijmegen, aiming to depreciate the units during the initial 15-year operating period. However, during this initiative period, construction costs for temporary housing increased significantly. This made it impossible to realise a viable business case for this project. In the agreement of housing association C with the municipality of Nijmegen, they made a strategic decision to extend the operating period of the flexhousing project, with the aim of making the project feasible. This shift to a longer operating period of 25 years is driven by the understanding that meeting the permanent building regulations is essential.	Housing association D has an agreement with the municipality for searching for a new location. Currently, they are focused on realizing permanent loaction in a new construction project. The first location is 15 years temporary.	- Agreement with municipality for new location - Search for permenant location - First location 25 years second permanent - First location 15 years second location 21 years - First 15 years second permenant - First location 10 years, second temporary, third permanent
Circularity						
2.1	What is your housing associations' approach and vision to circularity?*	Housing Association A has set the goal of achieving circularity by 2050 of the netherlands. This overarching vision has been translated into a strategy and implemented at the project level. The housing association has drawn up a sustainability strategy that includes several alternatives, such as using wood instead of plaster. Subsequently, these alternatives are assessed for financial feasibility.	Housing Association B did not establish vision or approach to circularity within their organization. Housing Association B highlighted their flexible approach to circularity, adapting to each unique case rather than sticking to rigid, one-size-fits-all policies.	No vision is chosen. As of now the housing association approach is the MPG score. They are legally mandated MPG standard stands at 0.8. Housing Association C acknowledges the possibility of this standard decreasing by 2025. Nevertheless, the association has consistently adhered to the current 0.8 threshold, except when the local municipality imposes a more stringent requirement, such as 0.5, as observed in select projects over the past two years.	Housing Association D has chosen for a st sustainability ambitions .. While there were numerous promising concepts, Housing Association D decided to take a more abstract approach. Their focus is set on BCI and MPG for sccore. This approach allows Housing Association D to steer clear of delving into detailed discussions about which specific components to use while ultimately realizing their circularity goals. Within the organization, Housing Association D has allocated a budget for the next 5 years that can be utilized at the project leve. This reserve fund is earmarked to support the additional circular ambitions, ensuring that these extra circular goals are financially secured in this manner.	Sustainability ambitions BCI MPG budget for the next 5 years No vision on circularity
2.2	How does your housing association incorporate circularity principles into its temporary housing projects?*	They are implemented in the strategy.	No the circularity are not incorperated standard in projects, only if national or municapility laws force them.	Only the circular principle of low environmental impact of materials is implemennted.	The circular princples are integrated into the scoring of the BCI and MPG.	Housing assocation has implemented the circularity principles into their strategy. Housing assocaiton B has not implemented one of them. Housing assocation C only implemented the low environmental impact. Housing assocation D has integrated it into their minimum scores by using the BCI and MPG.
2.3	What challenges have you faced in implementing circularity in your temporary housing projects?*	Housing association A has recognised that the market perceives their circularity goals as to rapid, while at the **market** at the same time is lobbying for their sustainability initiatives. They also encounter challenges related to matching circular **technical** demolition and supply. In addition, they face **technical** and **legal** hurdles. For example, in the case of a beam installed at some point in the past, determining its structural integrity becomes complex in the context of certification. Furthermore, they currently receive minimal **financial** compensation for the materials and products they supply.	They stressed their commitment to adhering to circular principles, recognising that this commitment poses significant financial challenges. They highlighted the **financial** complications of achieving circularity, where revenue generation tends to stagnate or decline while costs tend to rise. They indicated that local municipalities have additional **law** requirements, which they hope will disappear over time. The housing association's wish is that municipalities do not add additional layers of regulation to existing national regulations, as this adds a lot of complexity. Moreover, the houses association highlighted the challenge of constant updates to **building regulations**. With the movement towards circularity, there are cases where existing regulations stand in the way of reuse and repurposing, such as reusing a door that was made 10 years ago to the standards then in force. Housing Corporation B's experiences highlight the difference between circularity, financial sustainability and regulatory constraints within the housing sector. Their adoptive approach and recognition of these challenges.	The association recognizes the evolving landscape of sustainability and circularity and has encountered internal discussions on aligning their practices with sustainability and circularity goals. This shift has required adaptation, and some members have found it challenging. The absence of a proactive sustainability focus is attributed to the association's stringent **financial** constraints. Previously, they had the opportunity to engage in direct development and generated substantial profits from property sales, with increased risks. However, regulations have since curtailed these practices, limiting their financial options. In addition, the burden of taxes, including corporate taxes (cooperatie belastingen), has posed significant financial challenges.	The housing assocation has observed that the current objectives they have set are easily achievable using the current construction methods. Any financial setbacks are mitigated by tapping into the reserves designated for investments in circularity. Barrieres zijn de samenwerkingsvormen, financiering en onbekendheid met de inkoop en vraag aan markt. Daarnaast wetgeving dat dat zit dan soms soms nog wel even in de weg. Of zeg gewoon hé, die wetgeving die die zit nou goed. Die deur van 10 jaar geleden, die mogen we niet meer gebruiken, want is niet breed en hoog genoeg meer.	Financial Hurdles Regulatory Constraints Adaptation and Internal Alignment Market Perception Supply and Demolition Challenges
2.4	Do you measure circularity? If so, how do you measure it in the projects? Do you have BCI scores?	Housing association A does not use a scoring method.	Housing association B does not use a scoring method.	Housing association C does use a the MPG scoring method.	Housing association D does use a the BCI and MPG scoring method.	Housing assocation A and B did not implement a scoring method. Housing assocation C and D both
2.5	Can you explain how circularity is incorporated into its financial/revenue models?	Housing association A does not know what circular revenue models are.	Housing association B does not know what circular revenue models are.	Housing association C does not know what circular revenue models are.	Housing association D does not know what circular revenue models are.	All housing associations are unknown to the revenue models
2.6	From your perspective, how can the concept of circularity be effectively integrated into the financial considerations of these endeavors?	Housing association A does not know what circular revenue models are.	Housing association B does not know what circular revenue models are.	Housing association C does not know what circular revenue models are.	Housing association D does not know what circular revenue models are.	
2.7	Based on my study, the following circularity principles have emerged. Do you concur with these principles, and do you perceive any additional circular principles that may be absent from this list?	Housing Association A has no additions to the list that might be of interest.	Housing Association B has no additions to the list that might be of interest.	Housing Association C has no additions to the list that might be of interest.	Housing Association D has no additions to the list that might be of interest.	

Circular revenue models

	Cazas	Heuvelrug	Portaal	AREA	Themes
Create smaller personal spaces and more shared (pay-per-use) spaces	Housing Association A has adopted this approach. They repurposed ground-floor units into communal spaces, effectively creating communal living rooms. These areas allowed residents to socialize, relax, and enjoy shared amenities, all without sacrificing the size of their individual homes. Cleaning and utilities for these shared spaces were covered within the service fees, with a small monthly contribution from each resident to ensure proper maintenance. In cases where extensive upkeep was required, Housing Association A appointed a part-time manager to oversee the space and encourage residents to maintain its cleanliness. Housing Association A is about introducing additional charges for shared spaces such as pay per use, as it might deter residents who are already on tight budgets. However, for commercial entities and organizations with specific needs, Housing Association A offered flexible arrangements. These organisations often need access to (shared) spaces for different purposes, such as meetings, events or services. Housing Association A accommodated these spaces in a shared way and ensured that residents could access these spaces.	Housing Association B recently completed the construction of a new senior citizens' facility, which is situated somewhat away from the city center. Recognizing the need for a central communal space, Housing Association B explored the possibility of downsizing individual apartments to create larger shared areas. Making appartment smaller and thus larger shared spaces you have to deal with a lot of rules. The rental prices for these apartments are already capped, and although enhancing amenities is an option, it doesn't yield additional revenue unless these costs can be absorbed within the service charges or be supported through an energy performance program. Additionally, they face stringent regulations governing service charges, even in cases as seemingly straightforward as installing solar panels on the roof. The concept of pay-per-use, given their specific circumstances, presents certain discomfort and challenges. Housing Association B believes it may not be suitable for residents already on tight budgets.	Housing Association C has transformed ground-floor units into shared communal areas, effectively establishing communal living spaces. These spaces have enabled residents to interact. They maintained the size of their individual residences. Maintenance and cleaning costs for these communal spaces are integrated into the service fees, with a nominal monthly contribution from each resident to guarantee proper upkeep. Housing Association B is cautious about introducing additional charges for shared spaces, as it could be burdensome for residents with limited budgets. ??????	Housing Association D is actively engaged in the creation of additional shared spaces. This initiative is in response to the trend of decreasing dwelling sizes, and the association has recognized that a limit has been reached in this regard.	- Realizing communal spaces - Cleaning in service fee component - Residents on tight budget not pay per use - Sharing with commercial company - The rent is capped
The laundry machine room. (Bocken et al., 2018)	The introduction of pay-per-use laundry rooms in for housing association A generally received positive feedback from residents, particularly students who appreciated the cost-effective solution. With the ability to share laundry facilities with housemates, residents found it convenient and economical, eliminating the need for individual purchases. However, occasional issues arose. Instances of theft were reported in some cases.	Housing Association B has experienced challenges with the implementation of pay-per-use laundry rooms in some of the properties. In an effort to provide shared laundry facilities for the residents, they engaged a third-party company to manage these facilities. Unfortunately, this arrangement did not yield the expected results, and issues persisted.	Housing Association C have in some projects shared laundry facilities, such as the project in Nijmegen. This is especially true for their studio units, which typically offer limited space, often around 20 square meters, making it challenging to accommodate a traditional washing machine.	Housing Association D has had good experiences with the introduction of shared laundry facilities. In this system, residents pay for each use of the washing or drying machines, promoting a cost-effective and equitable approach.	- Pay-per-use shared laundry is used - Good experience with model - Target to small studio (students) - Issues
Pay per lux business model for light (Case Study: Signify Light-as-a-Service, n.d.).	Housing association A reveals that owning is often more attractive than renting or paying for a service after all, financially speaking.	Housing Association B expressed scepticism about the pay-per-lux model. Housing Association B has the desire to retain control over their properties. They were inclined towards a more traditional approach, which involved managing their own housing units, rather than relying on external solutions. Housing Association B perceived that the annual costs associated with the pay-per-lux model might surpass what they would typically spend on managing lighting themselves. This raised questions about the financial viability of adopting this model. Housing Association B considered an alternative approach. They considered the idea of tenants entering into direct relationships with manufacturers for various services. Housing association B also considered the biggest portion being of eldelry age of their tenants, there is an appreciation for the convenience of a more traditional service approach, where tenants could simply call a designated number to report issues, and someone would take care of it. Finally, Housing Association B recognised that there was much discussion about the characteristics of pay-per-lux contracts. This complexity posed considerable challenges, especially for smaller housing associations like theirs. Given their smaller size, they expect a big workload of lawyers on a small matter.	Housing Association C indicated that the market is not ready for it. Producers are there for the construction services rather than financial institutions.	Housing association D is familiar with the usage-based payment model and they have effectively implemented it for their heating system. They are open to the concept of "pay per lux" but have not yet put it into practice.	- Scepticism about performance procurement - Open for pay - per lux - Financial barriers - Retaining ownership and maintenance - Social acceptence - Legal and regulatory connsidertations - market dynamics - implemented at projects - Guarentees
Procure products kitchens, facades (Circle Economy et al., 2020) or mechanical installations with technical performance as a product as a service, guaranteeing performance (Trevor, 2021).	Housing Association A has encountered various challenges and explored different approaches. The first challenge are the unreliable guarantees.In some instances, Housing Association A attempted to work with contractors for services. However, issues arose when these contractors underwent mergers or changes in ownership. Suddenly, guarantees became uncertain, and reaching out to them became a challenge, leading to legal complexities. The second challenge is the unreachability of the service. Residents pay for services, they expected consistent support. However, Housing Association A found that, at times, service providers only visited once a year and left residents with underperforming results. The third challenge is the deferred maintenance. Housing Association A recognized the need for regular maintenance, especially for components like window frames. Initially, contractors estimated the lifetime of such elements at 10 years because this is their maintenance period, but realised that they deteriorated rapidly if they were not maintained every five years. This situation presented both technical and legal challenges. The fourth challenge is the technology adoption challenges. While Housing Association A introduced innovative sensor technologies for efficiency and sustainability, residents initially struggled to adapt. The integration of more sensors led to an increase in maintenance issues, particularly concerning devices like an example of Wi-Fi-connected solar panels. When the Wi-Fi connection failed, it resulted in service calls and highlighted the need for better social acceptance and technical solutions.	Housing association B does not trust third parties to do the maintenance and management. They prefer to control it themselves.	No answer on this question is given	Housing Association D faces constraints when considering the rental model for kitchens or facades. While the details may not be entirely clear, they understand that there are regulations prohibiting the leasing and subleasing of residential properties. The demarcation between leasing technical installations and leasing actual living spaces delineates the boundaries they must navigate.	
In the circular building catalogues of the Netherlands there are companies which procure kitchens, elevators, façades and lighting (De Circulaire Bouwcatalogus - Circulaire Diensten, n.d.).					

Use underutilised by others; parking, offices, fitness, childcare, training by sharing (Aalto-Yliopisto, 2019) (Arup Group & Ellen MacArthur Foundation, 2020)	This is not their core business, see the first model for more explantion on what they do.	Housing association B tries to stay out of shared spaces or facilities as much as possible. They have had bad experiences in the past providing these facilities. For example, managing a gym turns out every time the housing association is not very good at it.			- Unknown in market Furthermore same answer as first question
Co-living concepts (Arup Group & Ellen MacArthur Foundation, 2020).	Housing Association A has recognized the demand for housing options that cater to young adults who prefer to live with friends or housemates rather than in alone in a studio or apartment.	Housing Association B has carefully considered the revenue model of co-living concepts, and their response has been somewhat cautious. Although there has been occasional discussion about this, they are not excited to implement by past experience	Housing association C note that their involvement in co-living concepts tends to be more situational or occasional, primarily driven by external factors such as demand from the community or the municipality. Housing association C expresses curiosity and a degree of interest in the co-living concept, they also acknowledge their limited knowledge in this area.	Housing Association D has conducted research in this co living, revealing that there is limited demand. Tenants of housing assocation D tend to have more elderly with traditional preferences, expressing a desire for individual bathrooms, kitchens, and amenities within their living spaces.	- Demand with young tenants - limited demand with traditional tenants - Bad experiences - Situational - Curious
Set building requirements that allow for materials and products to be easily reused. (Arup Group & Ellen MacArthur Foundation, 2020).	Housing Association A has encountered regulatory hurdles that restrict the incorporation of materials that can be easily disassembled, but also for the residual value. Housing Association A places an emphasis on ensuring that their systems can accommodate mid-term modifications efficiently. Their approach is rooted in convenience, and they aim to work with systems which can be supplied with different suppliers. Notably, Housing Association A views this flexibility as an added value in their revenue models by using TCO. In their pursuit of long-term maintainance, Housing Association A evaluates the total cost of ownership (TCO). They consider factors such as material and equipment longevity, replacement costs, and maintenance requirements. This comprehensive assessment informs their decision-making process and financial planning. For instance, if materials or installations have extended lifecycles, resulting in reduced replacement and maintenance expenses,	Housing Association B recognises the relevance of this concept within the circular economy framework and emphasise the importance of responsible resource management in the construction sector. Housing Association B highlights is the challenge posed by constantly changing building regulations. While the concept of a circular economy encourages reusability, they point out that if a door or building component from 10 years ago cannot be reused because of current regulations, this can hinder progress towards a more circular construction sector.	Housing association C is actively involved in a unique pilot project, collaborating with three prominent demolition companies. This pioneering project is being conducted in Leiden, where three interconnected flats within a complex are systematically deconstructed to explore opportunities for material reuse. However, the association acknowledges the complexities associated with material reuse, particularly in the design phase of projects. While the concept of reusing materials or products is appealing, the practical implementation requires careful consideration of design processes, material availability, and storage logistics and costs. One such challenge is the need to maintain an inventory of available materials over an extended period, given the significant gap between the design phase and actual construction. This poses storage and cost challenges that must be addressed for successful implementation. Housing association C recognizes that their current approach may not fully consider easy to replace systems and there fore reducing planned replacement costs. However, the association points out that their systems are not yet fully equipped to support such cost adjustments. They highlight the need to adapt and reconfigure their systems to accommodate this important consideration, suggesting that it is an area of ongoing development within the organization. The conversation touches upon the concept of Total Cost of Ownership (TCO), indicating that Housing Association C is increasingly recognizing its significance. They note the growing urgency to factor TCO into their decision-making process, emphasizing the importance of aligning their systems and practices with this approach.	Housing Association D encounters challenges with existing regulations in this regard. They note that, due to evolving regulations, even doors built just a decade ago may no longer meet the current width and height requirements, restricting their use. Housing Association D follows the standard financial residual value assignment practices. They do not factor in extra residual value stemming from detachability. Their loans are secured through the WSW, with a requirement set by the WSW that the assets used as collateral must be non-movable.	- Regulation - design precesses, material availibilty and logistics and costs - No extra residual value for detachbility - TCO - Working with interchangable suppliers
Reuse the entire building in another location (Arup Group & Ellen MacArthur Foundation, 2020).					
Built following the permenant buidling requirementes (form interview with Jorg Kroes).		Housing Association B is open to the idea of constructing a dwelling while obtaining temporary permits and other necessary arrangements. They plan for the long-term operation of these homes, spanning a period of 50 years. To emphasize this extended duration, they prefer to label them as "Flexwoningen" instead of temporary housing.	Housing Association C operates with the understanding that once they obtain the environmental permit, they have secured the requisite rights for their buildings. This flexibility allows for the potential relocation of these structures in the future without concerns about compliance with evolving building code specifications. It's important to note, though, that certain aspects like BENG (Nearly Energy-Neutral Buildings) calculations may be influenced by the orientation of the buildings, which could impact future planning considerations when nno requisite rights are given. .	Housing Association D chooses the permanent building code. This decision is based on their commitment to ensuring the longevity aof the housing units. In this way, they aim to deliver a consistent high-quality product that meets the needs of their residents. The municipality provide the land for free for a period of 15 years. Housing assocaiton D gets a right of superficies from the municipality.	*- Permanant building code* *- legally obtained level*
It may be of interest for a new ownership structure in which the housing association is not the owner of all shearing layers (Arup Group & Ellen MacArthur Foundation, 2020).	Housing Association A recognizes that ownership is a pivotal consideration within the housing sector, with legal ownership being a central aspect. They say that it's not just about having different contracts for different aspects of a project, like Contract A for construction and Contract B for interior work. It's about the intricate web of legal responsibilities and accountabilities that come with each facet of the project. One of the core challenges lies in coordinating the various interfaces and ensuring seamless alignment between different components of a project. As they've found, there's always some degree of space or misalignment between the contractors. Attempting to bridge these gaps and synchronize them perfectly is a complex undertaking. In scenarios where they consider separating ownership across different layers such as structure, facade, interior, and installations, Housing Association A identifies a potential accountability gap. When different parties are responsible for different layers, there's a risk of leaving a void where no single entity is accountable for the overall result. This can lead to confusion, inefficiencies, and challenges in resolving issues.	Same answer as the procurement of products.	Same answer as the procurement of products.	Same answer as the procurement of products.	
Procure products (facades or mechanical installations) with technical performance as a product as a service, guaranteeing performance (Arup Group & Ellen MacArthur Foundation, 2020)..	En ja bezit is vaak toch nog aantrekkelijker dan het huren of betalen van de service, financieel gezien.	Same answer as the procurement of products.	Same answer as the procurement of products.	Same answer as the procurement of products.	
Buy products, guaranteeing sell back to producer, example are kitchens, furntiure and carpet tiles (Arup Group & Ellen MacArthur Foundation, 2020).	Housing association A now has contracts with one chain partners who do all kitchens. Therefore can reuse parts of the kitchens in different buildings. They have carpet in the office which was bought according to the buy back model. But it can't go back now either apparently. You don't want to run that kind of risk.	Geen afhaneklijkheid van derde partijen.	Housing Association C distinguishes the role of bank and contractor or supplier. They express reservations about the need to set aside substantial funds for potential buybacks over an extended period, which could impact the financial stability of suppliers. Therefore does not believe in this model.	Housing Association D is considering the possibility of implementing a buyback kitchens. However, they acknowledge that this is a financially expensive option.	- Financially expensive option - financial stability suppliers - Afhankelijkheid van derde partij - chain partner

Appendix 5 DCF base scenario case study

Scenario Basis 30 yr - Housing association X

Naam	Uitgangspunt
Inversteringsbedrag per unit	-€ 94.000
Subsidie centrale overheid of bijdrages gemeente	€ 2.020
Netto investeringsbedrag	-€ 91.980
Verplaatsingskosten	-€ 17.000
Grondkosten woonrijp	€ 0
Restwaarde na 50 jaar	€ 0
Huurinkomsten per unit per maand	€ 525
Huurinkomsten per unit per jaar	€ 6.300
Exploitatie lasten per maand	-€ 240
Exploitatie lasten per jaar	-€ 2.880
Aantal eenheden	99
Looptijd exploitatie locatie 1	15 years
Looptijd exploitatie locatie 2	15 years
Looptijd exploitatie locatie 3	0 years
Indexatie huur	2,50%
Disconteringsvoet	2,30%
Internal rate of return	1,8%

Jaartal	Totaal	0	1 2025	2 2026	3 2027	4 2028	5 2029
Investeringsbedrag	**€ (9.106.020,00)**	-€ 9.106.020					
Exploitatie lasten	**€ (12.517.538,73)**		€ (285.120,00)	€ (292.248,00)	€ (299.554,20)	€ (307.043,06)	€ (314.719,13)
Huur inkomsten	**€ 27.382.115,96**		€ 623.700,00	€ 639.292,50	€ 655.274,81	€ 671.656,68	€ 688.448,10
Verplaatsingskosten + groot onderhoud	**€ (2.437.485,81)**		€ -	€ -	€ -	€ -	€ -
Residuele waarde	**€ -**						
Netto inkomsten	**€ 3.321.071,42**	€ (9.106.020,00)	€ 338.580,00	€ 347.044,50	€ 355.720,61	€ 364.613,63	€ 373.728,97
Netto contante waarde	**€ (623.351,18)**	€ (9.106.020,00)	€ 330.967,74	€ 331.614,80	€ 332.263,11	€ 332.912,70	€ 333.563,55
Netto contante waarde per unit	**€ (6.296,48)**						

Jaartal	6 2030	7 2031	8 2032	9 2033	10 2034	11 2035	12 2036	13 2037	14 2038	15 2039
Investeringsbedrag										
Exploitatie lasten	€ (322.587,11)	€ (330.651,79)	€ (338.918,08)	€ (347.391,03)	€ (356.075,81)	€ (364.977,71)	€ (374.102,15)	€ (383.454,70)	€ (393.041,07)	€ (402.867,10)
Huur inkomsten	€ 705.659,30	€ 723.300,78	€ 741.383,30	€ 759.917,89	€ 778.915,83	€ 798.388,73	€ 818.348,45	€ 838.807,16	€ 859.777,34	€ 881.271,77
Verplaatsingskosten + groot onderhoud	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ (2.437.485,81)
Residuele waarde										
Netto inkomsten	€ 383.072,19	€ 392.649,00	€ 402.465,22	€ 412.526,85	€ 422.840,02	€ 433.411,02	€ 444.246,30	€ 455.352,46	€ 466.736,27	€ (1.959.081,14)
Netto contante waarde	€ 334.215,68	€ 334.869,09	€ 335.523,77	€ 336.179,73	€ 336.836,97	€ 337.495,50	€ 338.155,31	€ 338.816,42	€ 339.478,82	€ (1.392.893,52)

Jaartal	16 2040	17 2041	18 2042	19 2043	20 2044	21 2045	22 2046	23 2047
Investeringsbedrag								
Exploitatie lasten	€ (412.938,77)	€ (423.262,24)	€ (433.843,80)	€ (444.689,89)	€ (455.807,14)	€ (467.202,32)	€ (478.882,38)	€ (490.854,44)
Huur inkomsten	€ 903.303,57	€ 925.886,16	€ 949.033,31	€ 972.759,14	€ 997.078,12	€ 1.022.005,07	€ 1.047.555,20	€ 1.073.744,08
Verplaatsingskosten + groot onderhoud		€ -	€ -	€ -	€ -	€ -	€ -	€ -
Residuele waarde								
Netto inkomsten	€ 490.364,79	€ 502.623,91	€ 515.189,51	€ 528.069,25	€ 541.270,98	€ 554.802,75	€ 568.672,82	€ 582.889,64
Netto contante waarde	€ 340.807,50	€ 341.473,79	€ 342.141,38	€ 342.810,28	€ 343.480,49	€ 344.152,00	€ 344.824,83	€ 345.498,98

Jaartal	24 2048	25 2049	26 2050	27 2051	28 2052	29 2053	30 2054
Investeringsbedrag							
Exploitatie lasten	€ (503.125,80)	€ (515.703,94)	€ (528.596,54)	€ (541.811,45)	€ (555.356,74)	€ (569.240,66)	€ (583.471,68)
Huur inkomsten	€ 1.100.587,68	€ 1.128.102,37	€ 1.156.304,93	€ 1.185.212,56	€ 1.214.842,87	€ 1.245.213,94	€ 1.276.344,29
Verplaatsingskosten + groot onderhoud	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Residuele waarde							
Netto inkomsten	€ 597.461,88	€ 612.398,43	€ 627.708,39	€ 643.401,10	€ 659.486,13	€ 675.973,28	€ 692.872,62
Netto contante waarde	€ 346.174,44	€ 346.851,22	€ 347.529,33	€ 348.208,76	€ 348.889,52	€ 349.571,61	€ 350.255,03

Appendix 6 Assumptions for case study

Base Model

Variables	Input	Reference
Investment per dwelling	€94,000	Project housing association
Government subsidy	€2,020	Project housing association
Net investment per dwelling	€91,800	Project housing association
Relocation costs including major maintenance	€17,000	Project housing association
Land costs	€ 0	Project housing association
Residual value after 30 years	€ 0	Project housing association
Rent income per dwelling per month	€525	Project housing association
Rent income per unit per year	€6,300	Project housing association
Exploitation costs per month	€240	Project housing association
Exploitation costs per year	€2,880	Project housing association
Amount of dwellings	99	Project housing association
Index rent	2.5%	Project housing association
Discount rate	2.3%	Project housing association

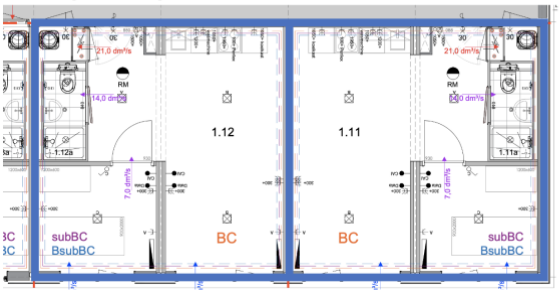
Permanent Quality Model

Variables	Input	Reference
Extra investment per dwelling for permanent quality	+10%	Project housing association
Extra investment per dwelling for permanent location	€15,000	Project housing association

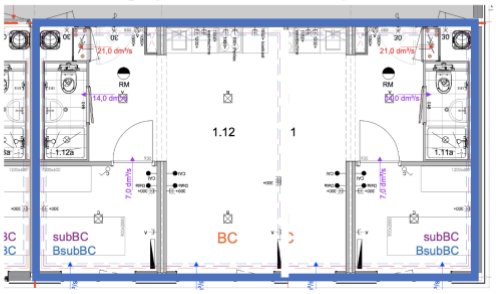
Co-living Model

Variables	Input	Reference
Living room for one apartment	36 m^2	Project housing association
Living room for two normal apartments	72 m^2	2 x 36 m^2
Living room for co-living apartment	54 m^2	1.5 x 72 m^2, (floorplan below)
Savings area per apartment	9 m^2	(72 m^2 – 54 m^2) / 2 apartments
Total savings	891 m^2	9 m^2 x 99 apartments
Maximum % savings total area total building	17%	891 m^2 / 5.071 m^2 total area
Maximum rent	€420	Calculation following the rent pointsystem (huurpunten)

Two separate apartments



One co living apartment for two persons



Shared Unused Space Model

Variables	Input	Reference
Total area shared living room	142 m^2	Ground floor reference project
Third party sharing 50% (between 8.30- 17.00)	71 m^2	This way, the living room can still be used by residents. During the most common working hours, (when fewest people are present) there is less space.
Income rent (€ per year)	€18,000	Equates to 30x renting out the space for €50 (for 2 hours)
Extra investment for sharing space	€30,000	Extra wall, table, presentation screen and share key
Extra exploitation costs per month	€400	0.1 FTE with a loan of €4,000

Shared Laundry Room Model

Variables	Input	Reference
Laundry per apartment	1.5 m^2	Reference project housing
Total laundry room all apartments	148.0 m^2	1.5 m^2 x 99 apartments
Shared laundry per floor	10.0 m^2	Circa 20 apartments per shared laundry room
Total laundry room building	50.0 m^2	5 floors x 10 m^2
Saving area	98.0 m^2	148 m^2 – 50 m^2
Payment for laundry machines bill	PPU	Pay-per-use washing machine pays for itself

Performance Procurement Model

Variables	Input	Reference
Operations and maintenance cost savings for skins and services	20%	(Arup Group & Ellen MacArthur Foundation, 2020)
Lifespan service procured	30 yrs	Shearing layers
Lifespan skin procured	30 yrs	Shearing layer
Service % investment costs	15%	Arup Group & Ellen MacArthur Foundation, 2020)
Skin % investments costs	15%	
Interest rate financial lease	0%	-

Appendix 6 Ethical review approval

Ethical review research approval

EINDHOVEN UNIVERSITY OF TECHNOLOGY

Date	Project	Subject	Ethical Review Board TU/e
August 15, 2023	ERB2023BE55	Designing a Financial Model for Circular Temporary Housing: A Case Study for Housing Associations	T +31 (0)40 247 6259 ethics@tue.nl intranet.tue.nl/ethics

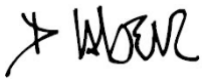
Dear ERB-applicant,

The Ethical Review Board (ERB) has received your application for ethical approval. Based on your answers on the form, you are granted ethical approval by means of the fast-track procedure. This means that you can start your project. Please note that in this fast-track procedure, your application has not been reviewed by the ERB nor by the Data Stewards team.

We assume that you have answered all questions correctly. We will perform regular spot-checks so you need to keep your documentation (ERB form, informed consent forms, surveys/interview questions, description of experiment/prototype etc.) available for at least 6 months.

For ID students: please make sure to upload your ERB form and this approval letter in your Canvas assignment.

Sincerely,



Dr. D. Lakens
Chair Ethical Review Board TU/e

Enclosures
1

The ERB retains the right to revise its decision regarding the implementation and the WMO[1]/WMH[2] status of any research study in response to changing regulations, research activities, or other unforeseen circumstances that are relevant to reviewing any such study. The ERB shall notify the principal researcher of its revised decision and of the reasons for having revised its decision.

[1]WMO: Law on Medical Scientific Research involving Human Beings (in Dutch: Wet medisch-wetenschappelijk onderzoek met mensen)

[2]WMH: Medical Device Directive (in Dutch: Wet op de medische hulpmiddelen)

APPENDIX 1

Terms and conditions

Amendments
When considerable amendments are made to the design of the study or educational activity, or when the time period between ERB approval and start of the study is longer than one year, please consult the ERB.

Privacy and research data management
The ERB would like to point out that collecting, handling and storing personal information is subject to the General Data Protection Regulation. Please visit TU/e intranet for the latest information and regulations on www.tue.nl/rdm