SELF-BUILT ON WATER

Timber systems for self-built multi-storey housing on water

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Abstract

This study investigates the potential of floating and self-built multi-storey timber buildings in the Netherlands as a sustainable solution to urbanization and housing challenges. By combining light-weight timber construction and the potential of self-built housing on water, this research aims to enable a housing typology that addresses land scarcity, affordability and sustainability. A modified Analytic Hierarchy Process (AHP) is developed to evaluate timber building systems based on criteria such as tool complexity, freedom of design and adaptability. Nine building systems, including open-source, industrial, and case-specific methods, are assessed for their applicability in self-built multi-storey constructions on water. The findings highlight the promise of systems combining post-and-beam construction, prefabricated timber connections, and limited component dimensions, while addressing the challenges relevant to the Dutch context. The study offers recommendations for adapting high-scoring systems to floating applications, underscoring the need for standardized guidelines to accelerate the adoption of floating architecture.

Key words

Housing on water, self-build, multi-storey, timber, light-weight, building systems, AHP

Problem statement

The current housing crisis in the Netherlands calls for innovative solutions that create affordable and sustainable housing within the existing urban boundaries (Gemeente Amsterdam, 2021; Metropoolregio Amsterdam, 2021; Planbureau voor de Leefomgeving, 2023). Self-build housing is internationally recognized as an effective method to reduce housing shortages and create a more resilient construction market (Dol et al., 2012; Parvin et al., 2011; Tombesi, 2012), but it remains underutilized in the Netherlands due to the high cost and scarcity of building land (Ruimtelijk Planbureau, 2017). Building on water offers an opportunity to address these challenges: it creates new space within urban areas and makes self-building more accessible by eliminating land costs.

Timber construction has the potential to play a key role in this approach. The lightweight nature of timber makes it ideal for construction on floating structures and support the shift to a sustainable and circular construction industry. Moreover, the recent innovation of timber construction methods and products provide opportunities to make self-building affordable and scalable for multi-storey construction (Parvin et al., 2011; Taivainen, 2016). The combination of living on water, self-built housing, and multi-storey timber construction can therefore offer a solution that addresses both spatial and financial challenges. It is essential that this potential is explored and realized, to contribute to solving the current housing crisis and build a more resilient and inclusive construction sector for the future.

Scope and Structure

This research therefore addresses the potential of self-building on water in a high density. It researches the means that light-weight timber construction can offer to do so. The aim is therefore to propose recommendations for creating a light-weight timber construction method by which self-builders can create multi-storey housing on water. Despite the research into self-built housing systems, a multi-storey application of such systems forms a clear research gap. This focus can however result in designs that expand the current scale of floating housing, from an individual unit to a full building necessary for the contemporary city.

Research Question

To achieve this the research attempts to answer the main question *"How can light-weight timber construction be used to develop mobile multi-story self-built housing on water in the Netherlands?"* by investigating the following sub-questions:

1. What are light-weight multi-storey timber residential building systems and how can they be categorized? This question seeks to identify relevant lightweight, multi-storey building systems by establishing the key requirements for such systems and selecting those that align with these criteria.

2. How can suitable building systems be assessed for multi-storey self-built housing? Considering the unique challenges of self-building a multi-storey house, it is essential to define the criteria used to assess the selected building systems. This is done by reviewing and adapting established assessment methods, to create one that serves this specific purpose.

3. Which building systems are relevant for self-built housing on water in the Netherlands? The results of the assessment of building systems are tested to the rules and regulations for construction on water in the Netherlands, to finally propose adequate construction methods.

Structure

The paper is structured following these sub-questions (see figure 1). It begins with a chapter that outlines a pre-selection of timber building systems based on the criteria of being light-weight and suitable for multi-storey construction. The second chapter introduces an assessment method for evaluating the feasibility of these systems in self-building. In the third chapter, the findings are applied to the context of water-based housing in the Netherlands. Finally, the paper concludes by answering the main research question, and discussing its method and further questions raised.

By doing so, this research contributes to the field of research into self-built housing methods and aims to accelerate the position of floating architecture in the Netherlands.

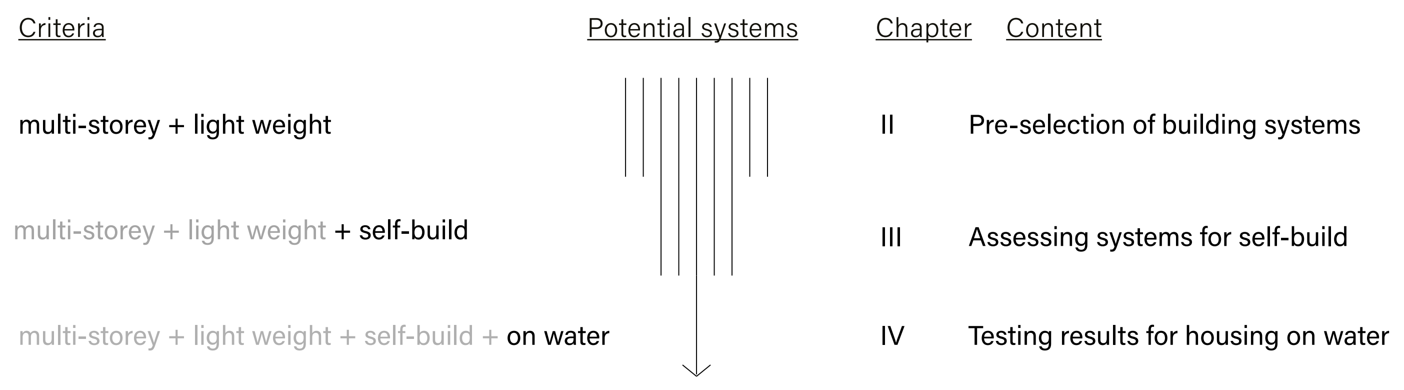

Figure 1: Schematic research overview, own work

II. LIGHT-WEIGHT AND MULTI-STOREY TIMBER BUILDING SYSTEMS

Both building on water and self-built housing require a light-weight building system. Buoyancy as determined by Archimedes' principle, states that an object floating in a fluid experiences an upward force equal to the weight of the fluid it displaces. For housing on water this means that increasing the buildings weight will demand more investments in the already costly support its needs beneath the waterline to remain afloat. Self-built housing demands the same requirement of light-weight construction. Heavier loads require heavier equipment, a larger skillset and increase the risk of injury or damage when handled by non-professionals (Parvin et al., 2011). A building system should therefore be found that minimizes its weight.

Categorization

The long tradition of timber construction has produced a wide variety of building systems, and many attempts have been made to categorize them. The most conventional way of organizing the dominant building systems is to divide them into panel, frame or solid building systems (Herzog et al., 2004; Kolb, 2008; Swedish Wood, 2022). The panel method is divided into two subcategories: platform-frame and balloon-frame. These determine whether the panels span the entire height of the building or just a single storey. This categorization highlights a clear distinction in the weight of its elements, separating buildings constructed with frames or structural panels from those made from solid timber slabs.

Although this organization is comprehensive, Kaufmann et al. (2018) claim that modern wood construction is no longer accurately defined as such. The recent development of wood products has led to a wide variety of elements that can be used vertically and horizontally, providing a range of interchangeable combinations. Contemporary multi-storey systems blur the boundaries between panel, frame or solid systems as they are often a hybrid of different timber products.

Additionally in such systems stability is often provided by including other materials such as steel frames or concrete cores for stability. Handling these materials require a skillset that cannot be met by an amateur builder, and add considerable weight to the building system. For this research a light-weight timber building system should therefore be defined as one where the load bearing structure is provided entirely by a timber frame or panel construction, or a combination of such elements.

Multi-storey + Self-build

According to Merriam-Webster Dictionary (n.d.), multistory is defined as *"having more than two stories".* This definition is used by many relevant publications in the field (Kauffman et al, 2018; Mahapatra et al., 2012; Markstrom et al., 2019). The apparent boundary drawn after two stories can be explained by a jump in scale of construction that is required after this building height. This jump in scale represents a clear challenge for self-built housing and is evident in the options available to this target group today.

The current market for building systems for self-builders can be divided into two main categories. The first option is to adopt an open-source systems, where the builder himself provides materials, and a design based on the freely available building plans. This requires the the self-builder to hire other professionals such as a structural engineer or designer, to help acquire proper planning and approvals necessary to build. The second option is to build according to a prefabricated system, where a manufacturer helps the self-builder get a design and the materials needed to do so. The manufacturer ensures that the building systems are approved and guides the self-builder with proper documentation and construction.

Currently, when a building has more than two floors, none of these two options are implemented. Construction is generally left to a professional contractor due to limitations of current building regulations and specialized tools. However, with the modernization of building systems and the greater affordability and availability of tools, multi-story construction by self-builders is now an achievable goal (Parvin et al., 2011; Taivainen, 2016). Therefore, to find relevant building systems, it is necessary not only to consider the systems currently available for self-build, but also to analyze unique realized projects that qualify for self-build. The incentive to find a system that can increase the construction scale of the self-builder to that of the professional builder encourages the inclusion of professional construction systems in this analysis. For this research, therefore, open-source, industrial, and one-off building systems are compared.

Pre-selection of building systems

A preselection of relevant building systems has therefore been done according to these requirements:

-the load bearing structure should be provided by timber elements
-the load bearing structure should be provided by a combination of frame or panel elements
-the building system should be able to reach a minimum of three storeys

Extensive research has been done to find building systems that meet these goals. Valuable resources included catalogues of the major producers of relevant building materials and their connectors, and literature on self-built housing and multi-storey timber. Of particular use was the research into the recent developments of multi-storey timber by Salvadori (2021). Through this search the following systems could be found that meet these criteria:

Open-source systems

Two open-source timber building system could be found that are mentioned to enable multi-storey construction. Both the Walter Segall Method and the Wikihouse Skylark building system claim a maximum height of three storeys, when braced in a row of houses. The Walter Segall Method applies building materials available from hardware stores, and uses their standard dimensions as much as possible to create a post-and beam system that requires minimal fabrication on site. The Wikihouse Skylark system uses plywood to create CNC-milled building blocks. Here extensive prefabrication is used to minimize the use of additional fasteners and create small and manageable components.

Industrial systems

A diverse selection of systems applied in the building industry has been made. These systems rely more on prefabrication, heavier components and larger spans. A traditional but entirely prefabricated panel framing method has been found in Japan, produced by the Mitsui company under the brand name Mocxion. Another relevant option is using LVL to reach large spans with manageable profiles as done by Sustainer. Lastly the Houtkernmethode provides a method where cube frames are joined by metal connectors, limiting the components dimensions to the height of a single storey.

Case-studies

The four selected case-studies represent different solutions to create a multi-storey building using a post-and-beam timber frame. The projects showcase a variety of ways to join members and provide lateral stability without using slabs or stable cores. Two of the selected projects, the Helio Olga house and Toyota family house, are residential buildings that apply a post-and-beam frame with prefabricated timber joints. A recent German case is introduced to compare these methods to contemporary fabrication of a traditional half-timbered house. Lastly, the Timber Weaver studio is included as an example of applying a balloon-frame with bolted connections.

III. ASSESMENT METHOD

An architectural design task can be understood as a complex or wicked problem due to its multidisciplinary nature, open outcome and conflicting interests (Bachman, 2008; Harputlugil, 2018). During a design process, the architect must balance the various interests and stakeholders to find an ideal outcome. This ensures that architectural design is not an intuitive process, and therefore benefits from the structure that decision making theory can provide (Siekelova et al., 2021). One of the most important methods within this science is Saaty's Analytic Hierarchy Process (AHP) (Pozzi, 2019; Van Veen, 2016).

Original AHP

Saaty (1982) states that he designed this Multi Criteria Decision Making (MCDM) method "to organize problems into complex structures that consider the interactions and interdependence of the factors, but still allow us to think about them one at a time" (p. 65). The model therefore organizes the complex relationships between design criteria into a hierarchical structure (see figure 2). At the top of this structure is the overall design goal. This goal is broken down into the various criteria that assess the extent to which the design goal is achieved. At the bottom of the hierarchy are the alternative design solutions, which are evaluated by the established criteria.

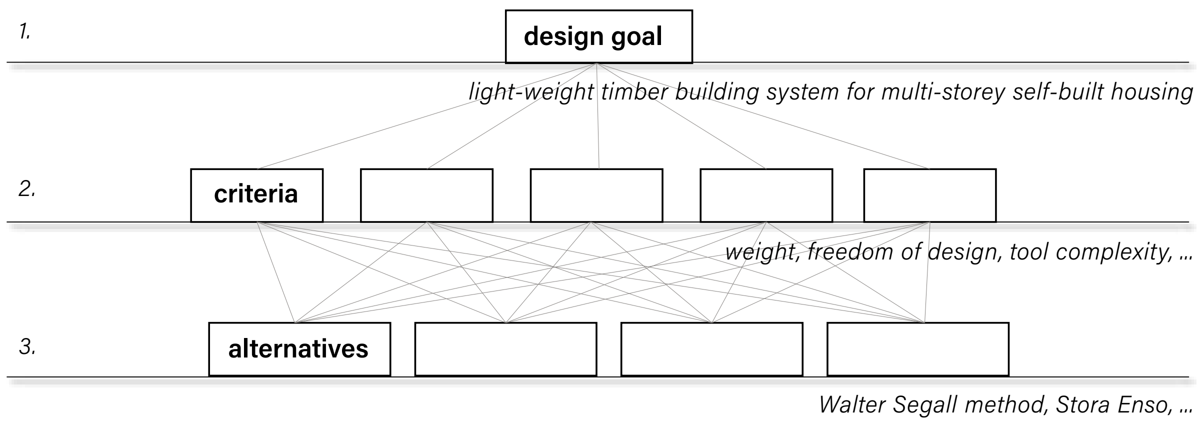

Figure 2: Hierarchy of the AHP, own work

The evaluation criteria are first weighed against each other in a matrix in pairs to finally get the relative weighting factor for each criterium (see Appendix A). In this way, the relationship between both qualitative and quantitative criteria can be examined and measured. The criteria are rated on a numerical scale that ranges from 1 to 9. If two criteria are equally important, both are assigned a value of 1. When one criterion is more important than the other, it receives a value between 2 and 9, while the less important criterion is assigned the reciprocal value, ranging from 1/2 to 1/9. The total scores for each criterion are then converted into a weighting factor, reflecting their relative weighted importance (Saaty & Vargas, 2012). This weighting factor isused to score the selected design alternatives, allowing the different design alternatives to be assessed and evaluated.

Adapted AHP

This repetitive comparison method normalizes inconsistencies that are inevitable with a subjective assessment method (Saaty & Vargas, 2012). However, the repetition of this comparison is also the biggest challenge of applying the AHP. The large number of assessment criteria and alternatives inherent to a design task quickly lead to a time-consuming assessment process (Kahraman, 2018; Leal, 2019 ; Pozzi, 2019).

The rating scale is therefore simplified by applying only the values 0 and 1 instead of the usual scale between 1 and 9. The criterion that is more important is given a value of 1, while the less important criterion is given a value of 0. This approach, proposed in previous student research by Van Veen (2016) and Mac-Lean (2018) and later confirmed by Pozzi (2019), reduces the time required for assessment without significantly affecting the final results. Furthermore, the weighting factor of the criteria is simplified by converting a numerical multiplication factor into a value between one and three. The effects of this simplification in a design context are negligible (Harputlugil, 2018)

Criteria for multi-storey + self-built

To establish the evaluation criteria for this research, a combination of different aspects of previous studies was done. These studies each have a different focus that have their own overlap with the design objective of this research: the application of a light-weight timber building system for multi-storey self-built housing on water.

The first study by De Graaf (2024) develops an assessment method to measure the degree of self-build for timber building systems. In this, De Graaf (2024) draws primarily on previous work by Berends (2021) and Favi and Germani (2013), to arrive at a list of assessment criteria. Importantly, these assessment criteria of self-build consider both the perspective of the user, and the characteristics of the building system.

Design objective

Topic	Criteria	Weight	Literature
User			
	required operator skill	●●	*De Graaf*
	tool complexity	●●	*De Graaf*
	weight	●	*De Graaf*
	dimensions	●●	*De Graaf*
System			
	connector integration	●●	*De Graaf*
	connection type	●●●	*De Graaf*
	prefabrication degree	●●	*Pozzi*
	freedom of design	●●●	*Pozzi*
	finishing	●●	*Pozzi*
Lifecycle			
	ease of disassembly	●	*Pozzi*
	reusability	●●	*Pozzi*
	maintenance	●●	*Mac-Lean & Van Veen*
	adaptibility	●●●	*Mac-Lean & Van Veen*

Alternatives

Figure 3: Categorization, sources and weighting of criteria, own work

Second, Pozzi's (2019) research on the assessment of reusable timber mid-rise building systems has been a highly valued source for this study. The scaling of the design goal relative to the work of De Graaf (2024) leads to the addition of a perspective that also assesses the the end-of-life phase of the building. Omdat elke vorm van nieuwbouw zou moeten proberen deze fase zo lang mogelijk uit te stellen, moeten ook criteria in acht genomen worden die de gebruiksfase beoordelen in de assessment opgenomen worden. Deze criteria worden ontleend aan het onderzoek Van Veen (2016) and Mac-Lean (2018). The criteria that assess the building systems use and re-use are therefore housed in the category of lifecycle criteria (see figure 3).

<u>Scale differences</u>

When comparing the chosen criteria of these researches, significant differences can be seen. All studies base their criteria heavily on the principles of design for (dis-)assembly (DFDA). The importance of this theory to optimize the ease of (dis-)assembly is evident for the context of self-build and product design, but is measured distinctly. For example, Pozzi (2019) uses a global parameter to assess the ease of (dis-)assembly. This parameter combines the assembly time, the ease of access of the connection, the operator's qualification, the specificity of the required tools and eventual protective equipment needed into one parameter as proposed by Das et al. (2000). De Graaf (2024), however, breaks this list down into individual parameters, as well as diving into more detailed specifications such as the number of components, connection types and fasteners.

While this level of detail is desirable, it is not possible to do so for all selected building systems in the context of this analysis. The building systems on which De Graaf's method was tested included only building systems currently available on the market. Because this study also covers case studies and industrial building systems, in most cases it is necessary to know the exact numbers of all components. For this reason, De Graaf's criteria for DFDA were adhered to whenever possible, but otherwise Pozzi's criteria were used. For a complete overview of the scales, sources and descriptions of the evaluation criteria, see Appendix B.

IV. HOUSING ON DUTCH WATERS

The application of the assessment method to each selected case (see Appendix C) has resulted in a ranking of the evaluated building systems. Based on these results, several key observations can be made about the application of a lightweight self-build system on water (see figure 4).

		Helio Olga house	Walter Segall Method	Wikihouse Skylark 250	Houtkernmethode	Toyota family home	Timber Weaver studio	Contemporary half-timbered house	Mitsui Mocxion	Sustainer
●●	required operator skill	6	6	8	6	4	4	2	4	4
●●	tool complexity	6	6	6	4	4	4	6	4	4
●	weight	3	4	4	3	1	2	1	2	3
●●	dimensions	2	8	8	6	2	4	2	6	6
●●	connection integration	8	2	6	4	8	2	8	2	2
●●●	connector type	12	9	9	9	9	9	12	9	6
●●	prefabrication degree	6	4	8	6	6	4	4	6	4
●●●	freedom of design	6	6	6	6	12	12	12	12	3
●●	finishing	6	6	4	6	6	4	6	8	8
●	ease of disassembly	3	4	3	4	3	4	2	1	1
●●	reusability	8	6	6	8	8	8	6	4	4
●●	maintenance	4	8	4	6	4	6	4	4	4
●●●	adaptibility	9	9	6	9	9	9	6	6	6
	TOTAL (max 108)	79	78	78	77	76	72	71	68	55

Figure 4: Overview of assessment, own work

Assessment results

Notably, the three analyzed industrial systems scored the lowest in the assessment. The building systems from Sustainer and Mitsui both utilize panels composed of many small components, leading to very low scores on lifecycle and system criteria. Additionally, the assembly and handling of these large panels place greater demands on the user. Thus, the use of such composite panel systems with large dimensions appears to be an undesirable design solution.

In the ranking these two methods are followed by four post-and-beam frame systems. The distinctions among these systems are mainly caused by their distinct connection methods and component dimensions. Among these, the contemporary half-timbered house scores the lowest due to its high required skill set and substantial component dimensions. However, it is the only analyzed system capable of achieving a building height of more than four stories. The Timber Weaver Studio case, despite its user-friendly bolted connections, presents a comparable alternative.

The Toyota family house and the Houtkernmethode emerge as two alternatives that score higher within this middle tier. These systems share a common approach of using smaller components and smart connections, resulting in higher scores on system and user criteria. The Toyota family house achieves this by applying a pre-cut skeleton with CNC wood connections within a small grid. The Houtkernmethode, on the other hand, divides load-bearing columns and beams into quarters that are structurally connected with a metal joint. A key consideration is the greater design freedom offered by the Toyota family house compared to the story-high construction approach of the Houtkernmethode.

Ranking second and third in the assessment are the two analyzed open-source systems. Despite their structural differences, these systems achieve the same score. The better lifecycle performance of an open post-and-beam frame proves to be equally valuable as the refined connections of the Wikihouse in this context. However, a significant limitation of both systems is the lack of built examples exceeding two stories in height.

The top rank in the assessment is achieved by the Helio Olga House case study. This system represents an improvement over the Walter Segal Method due to its intricate prefabricated wood connections and lighter dimensions while achieving greater story heights. A key factor enabling this is the use of hardwood, which raises questions within the Dutch context.

Building requirements on water

To select relevant building systems for self-built housing on water, the outcome of the assessment must be aligned with the technical limitations of building on water in the Netherlands. Despite a long tradition, building on water in the Netherlands remains a sector where rules and regulations have historically been unclear (Kloos, 2007; De). Firstly, there is confusion about whether water-based constructions are classified as buildings under the Housing Act or as houseboats. This distinction determines whether the construction must comply with the national Building Code or the highly variable municipal houseboat policies and zoning plans. To enable project-based development that can be applied nationally, water-based constructions must therefore be regarded as buildings under the Housing Act. A multi-storey timber construction system on water must, as a result, comply with the same requirements as a comparable building on land.

There are, however, many additional technical requirements that a floating home must meet in practice. The current Building Code does not include supplementary requirements relevant to building on water, such as stability, buoyancy, or collision resistance. To provide clarity and guidance, the Ministry of Housing, Spatial Planning, and the Environment (VROM, 2009) published a document explaining ambiguities in the Building Code and the standards commonly applied in practice.

Stability

One conclusion relevant to this research concerns deriving structural stability from adjacent homes, which would be necessary for three-story applications of systems such as the Wikihouse or the Walter Segal Method. This method of adjacent stability is discouraged in the context of water-based construction (VROM, 2009). Furthermore, floating buildings can experience large wind-forces or an unbalanced load which can create tilt. This should be limited to a maximum angle of five degrees, to maintain proper functioning of piping (VROM, 2009). A thoughtful orientation to the dominant winds and the design of the floating base can assure this.

Floating base

Without clear regulations in this area, the design of the floating base is granted significant freedom. However, based on the common requirements of insurers, a minimum remaining draft of 0.6 meters below the floating base is recommended (VROM, 2009). Other design guidelines for this component have been established in recent research by PosadMaxwan et al. (2023). This research recommends a floating base with 3-meter draft for every four building stories added. This depth can be halved by doubling the width of the floating base. Additionally, the floating base must be at least as wide as the height of the building.

	Class VI	Class V	Class III
Width (m)	22,8	11,4	6,7
Length (m)	193	110	82
Draft (m)	4	3,5	2,5
Available waterways	Main transportational axes	" + Port docks, large channels	" + channels and rivers connecting most cities

Figure 5: Maximum allowed CEMT-Classes, own work based on Rijkswaterstaat (2013)

Mobility

The mobility of floating structures is essential for performing maintenance on the vessel or waterway, but also presents an advantage over land-based homes when considering reuse and adaptability. To enable the nationwide implementation of floating structures, their width, height, and draft must comply with the limitations imposed by the waterways, locks and bridges. In European inland waterways, the rules for defining ship dimensions are set by the CEMT-classes.

A general overview of these regulations shows that a structure adhering to Class III dimensions can access most major cities in the Netherlands (see figure 5). The clearance height must also be assessed against key bridges, which range from 8.0 to 9.1 meters on primary waterways (Rijkswaterstaat, 2024). This clearance combined with a minimum floor height of 2.6 meters ("Besluit Bouwwerken Leefomgeving," 2025), would limit the number of stories to three[1].

Materials

When the assessed building systems are applied to Dutch water conditions, some of the best-performing systems reveal significant limitations. The Helio Olga building system, which utilizes Pau-brasil wood, would pose challenges in the Dutch context due to the high costs and the ecological concerns surrounding the harvesting of tropical hardwood. Replacing Pau-brasil with a local European wood species also proves undesirable, as these alternatives offer lower elasticity and similarly high costs. Even engineered wood products, such as Baubuche LVL, are not adequate substitutes due to their significantly lower modulus of elasticity and bending strength (see figure).

	Pernambuco	Robinia	Hornbeam	LVL
Density (kg/m2)	950–1,200	700–850	720–820	600–750
Elastic Modulus (E) (MPa)	20,000–25,000	12,000–16,000	13,000–15,000	10,000–14,000
Bending Strength (MPa)	150–200	80–130	110	50–90
Hardness (Janka) (N)	12,000	7,500	8,500	Not applicable
Elasticity	High (very flexible)	Moderate (stiff)	Low (brittle)	Uniform but less elastic

Figure 6: Possible alternatives for the use of Pau-brasil (Pernambuco), own work based on Ross (2010)

The application of the Wikihouse Skylark building system or the Walter Segall method on water would also involve considerable difficulties. Both systems would be pioneering in achieving a building height of three stories and rely partially on shared stability with adjacent structures. However, this form of shared stability is discouraged for floating constructions, making these systems in their current form unsuitable for multi-story applications on water.

1 > This minimum height applies from floor to ceiling, additional height is considered for the construction.

V. CONCLUSIONS

This study has researched the potential of existing lightweight timber building systems to be applied as multi-storey self-built housing on water. It aims to offer a clear and complete assessment of these systems, to finally propose recommendations for relevant systems that could be used in the context of the Netherlands. An assessment method was created for this purpose, building upon previous research of relevant themes and creating a methodology for this context.

The assessment method has provided a ranking of the nine selected building systems relevant to the design objective. These selected building systems represent a diverse range of systems that have been applied as either self-built, industrial or one-off projects. The combined assessment of these systems has been done to enlarge the scale of current options for self-built, towards the multi-storey systems that are professionally built.

Key findings

The results of this assessment are tested to meet the requirements of building on water in the Netherlands. This has exposed pitfalls of applying the three highest rated systems (the Helio Olga house, the Walter Segall method and Wikihouse Skylark), due to inadequate stability or material use. Their high overall scores do however motivate redesigning these systems for an application on water. The Walter Segall method could apply bracing following the examples of the Houtkernmethode or the Toyota-family house.

Floor-to-ceiling

Naturally, the two open-source systems score highest in terms of user criteria. Minimizing tool-complexity is not a decisive factor, because with a multi-storey building there is no escaping the use of heavier power tools. It is remarkable that the three highest-scoring systems show a significant similarity. This is the application of a floor-to-ceiling working method. The minimization of dimensions and thus weight that this allows has a clear advantage for the required operator skill. Limiting building elements to a single story height is therefore of great importance in designing a user-friendly system.

Wood-to-wood

An important conclusion can also be drawn when looking at the highest scores of the system criteria (see figure 7). The application of wood-to-wood connections, whether prefabricated or not, is clearly preferred. This ensures that the connector is fully integrated, requiring fewer components and eliminating incorrect assembly. The Toyota family house is a good example of how this could be applied as a multi-storey residential house, if it manages to limit the columns to a single floor. The division of columns and beams into quarters as the Houtkern-method does would be a relevant design solution for this purpose.

Post-and-beam

A third conclusion is reached by comparing the system criteria of the different systems. This reveals a fundamental distinction between frame or panel building systems. All systems that apply a frame consisting of individual columns score high by creating the flexibility needed for an adaptable and easily maintained building system. The application of a post-and-beam system, with a floor-to-ceiling method and prefabricated timber

		Helio Olga house	Walter Segall Method	Wikihouse Skylark 250	Houtkernmethode	Toyota family home	Timber Weaver studio	Contemporary half-timbered house	Mitsui Mocxion	Sustainer
User	required operator skill	6	6	8	6	4	4	2	4	4
User	tool complexity	6	6	6	4	4	4	6	4	4
User	weight	3	4	4	3	1	2	1	2	3
User	dimensions	2	8	8	6	2	4	2	6	6
User	connection integration	8	2	6	4	8	2	8	2	2
System	connector type	12	9	9	9	9	9	12	9	6
System	prefabrication degree	6	4	8	6	6	4	4	6	4
System	freedom of design	6	6	6	6	12	12	12	12	3
System	finishing	6	6	4	6	6	4	6	8	8
Lifecycle	ease of disassembly	3	4	3	4	3	4	2	1	1
Lifecycle	reusability	8	6	6	8	8	8	6	4	4
Lifecycle	maintenance	4	8	4	6	4	6	4	4	4
Lifecycle	adaptibility	9	9	6	9	9	9	6	6	6
	TOTAL (max 108)	79	78	78	77	76	72	71	68	55

Figure 7: Assessment results with three highest scoring systems per category marked, own work

connections would therefore be a good basis for realizing the design goal, a multi-storey light-weight timber construction on water. The found advantages and disadvantages of the assessed systems provide a wide range of references, to further elaborate this design objective. The implementation of these findings in a proposal for a building system can be found in Appendix D.

Limitations and further research

AHP-express

The application of the AHP has some well-known limitations that stem from it partly relying on subjective observations (De Graaf, 2024; Leal, 2019). It is also exactly this combination of objective and subjective assessing that make this method an interesting design-tool, and attempts can be done to overcome this pitfall. By including the perspectives of several individuals in the weighting of the assessment criteria, the subjectivity of one person can be mediated. Filling in a complete pairwise comparison matrix as done in Appendix A, is however a demanding job. A simplification of this pairwise comparison method as proposed by Leal (2019) could enable incorporating more perspectives. Further research should be done to approve the combination of this AHP-express method and the adjustments to the AHP as done in this research.

Search Method

The search for relevant building systems in this research has been done in a causal manner, building upon previous research for systems that meet the established requirements (Salvadori, 2021; Kaufmann et al., 2022). The rapid and diverse developments in timber construction, might have led to missing relevant sources. A systematized search method where several selected datasets are searched by specified keywords, could present a better alternative to this process that leads to new input for further research.

Integrated systems

The research could be further improved by expanding its focus from construction only, to include the assessment of smaller building components. The current scope of the research doesn't consider the integration of partition walls, façades and floors in a self-build context. Some analysed building systems offer smart integration of these elements, that can lead to a negative scoring when only assessing its construction method[1].

Regulations

Finally, the study considers the challenges of building on water in the Netherlands, such as managing wind forces, tilt angles, and mobility requirements. However, the recommendations for water-based constructions remain ambiguous, underscoring the need for clear guidelines tailored to floating multi-storey buildings. With the development of nationally uniform regulations, housing on water can at last become a full-fledged product that can address the need for sustainable housing and land scarcity.

1 > In this study, the Sustainer construction method is an example of this, where load-bearing walls provide rigidity but limit adaptability.

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APPENDIX A - AHP Matrix

The pair-wise comparison matrix used to calculate the criteria's weighting factor is shown below. The more important criteria gets assigned a one, the other a zero. For example, tool complexity is valued more than the required operator skill. When criteria are equally valued both are assigned a one.

		required operator skill	tool complexity	weight	dimensions	connection integration	connector type	prefabrication degree	freedom of design	finishing	ease of disassembly	reusability	maintenance	adaptibility	**total score**	**weight**
user criteria	required operator skill	■	1	1	0	0	0	0	1	0	1	1	1	0	6	●●
	tool complexity	0	■	0	1	1	0	1	0	0	1	1	1	0	6	●●
	weight	0	0	■	0	0	0	0	0	0	1	0	1	1	3	●
	dimensions	0	0	0	■	1	0	0	0	0	1	1	1	1	5	●●
system criteria	connection integration	1	0	1	0	■	0	0	0	1	1	0	1	0	5	●●
	connector type	1	1	1	1	1	■	0	0	1	0	1	1	1	9	●●●
	prefabrication degree	0	0	1	1	0	1	■	0	0	1	0	1	1	6	●●
	freedom of design	0	1	1	1	1	1	1	■	1	1	0	1	1	10	●●●
	finishing	1	1	1	1	0	0	1	0	■	1	0	0	0	6	●●
lifecycle criteria	ease of disassembly	1	0	0	0	0	1	0	0	0	■	0	1	0	3	●
	reusability	1	0	1	0	1	0	1	1	0	0	■	0	1	6	●●
	maintenance	0	0	1	0	0	0	0	1	1	0	1	■	1	5	●●
	adaptibility	1	1	1	1	1	0	0	1	1	1	0	0	■	8	●●●

APPENDIX B - Criteria descriptions

The criteria used in the research are rated and defined according to the following descriptions.

User Criterion: Required operator skill

The required operator skill rating is based on the type and amount of technical understanding and skillsets required to be able to construct the building system. Self-building aims at enabling non-professionals to construct their building, a low level of operator skill is desired.

1 Operator should be a killed carpenter
2 Operator requires technical understanding
3 Operator requires basic tool knowledge
4 Operator requires no prior knowledge

skilled 1 2 3 4 amateur

User Criterion: Tool complexity

The Tool Complexity Rating evaluates the complexity of mechanical tools required to mount or demount the element. In the context of self-building, basic tools are favoured over tools that require expert knowledge.

1 Special tools are required
2 Power (hand)tools are required
3 Common hand tools are required
4 Tools are not required; task can be done by hand

special tools 1 2 3 4 no tools

User Criterion: Weight

The projects key criteria of being self-built and built on water both require a low weight of the overall construction and its individual components. The weight descirbes the physical insensitivity of work that is needed to handle the heaviest component, and should therefore be minimized.

1 Component requires machinery to lift (101kg≤)
2 Component requires more than two people to lift (42,5-100kg)
3 Component requires two people to lift (20-42,5kg)
4 Components is liftable in accordance with working regulation (10-25kg)

heavy 1 2 3 4 light

User Criterion: Dimensions

Ease of handling derived from the scale of an average adult of 1.79cm.

1 Component is only movable with machinery
2 Component is movable by three to four people
3 Component is movable by two people
4 Component is movable by one person (≤2600x600x100, lxbxd)

one person 1 2 3 4 machinery

System Criterion: Connector integration

The integration aids the ease of assembly of individual part, by assuring correct assembly. Building systems can also clearly indicate where connectors should be fixed, or have part of a connector integrated.

1 Connectors not integrated into the element
2 Connectors not integrated into the element, but design aids affixing
3 Connectors partly integrated into the element
4 Connectors are fully integrated

seperated 1 2 3 4 integrated

System Criterion: Connection type

The type of connector used between components enables easy fixing or seperating of components. The building system is easier to assemble when connections are made with dedicated fasteners, or reversible connections such as bolts or screws.

1 Components are connected with a fixed connection such as glue
2 Components are connected with nails (or similar)
3 Components are connected with bolts or screws (or similar)
4 Components are connected without dedicated fasteners (friction fit)

glued 1 2 3 4 friction fit

System Criterion: Prefabrication degree

The prefabrication degree indicates the amount of steps taken in production off-site. Prefabrication can assure a quality standard in terms of accuracy, and minimizes the amount of steps necessary during construction. A high amount of prefabrication is therefore desired.

1 Fabrication of the building system is fully done on site
2 System is largely made on site
3 System requires minor work on site
4 System requires no adaptations on site

on-stie 1 2 3 4 prefab

System Criterion: Freedom of design

The influence of an alternative to the design freedom of the whole system. Starting from a building system which can create simple building forms, until a building system which can have more, and more complex configurations.

1 The system is limited to a single envelope and configuration
2 The system prescribes a few variations of envelopes and configurations
3 The system allows great freedom in envelopes and configurations
4 The system gives the designer total freedom to create any design

limiting 1 2 3 4 free

System Criterion: Finishing

The finishing determines the visibility of the connection system, categorizing it as visible, partially visible, or hidden. This affects not only the aesthetic appeal of the connection during its use but also factors such as fire safety, especially when metallic connections are involved. A hidden connection system is preferred for both aesthetic and safety considerations.

1 Connections are completely exposed, and can't be hidden
2 Connections are completely exposed, but can be hidden with extra effort
3 Connections are partly exposed
4 Connections are completely hidden

exposed 1 2 3 4 hidden

Lifecycle Criterion: Ease of disassembly

The ease of disassembly assesses the time, accessibility, required tools, operator skills, and protective equipment for disassembling elements. Based on the DEI model (Das et al., 2000), it impacts deconstruction time and costs. A connection system that maximizes disassembly efficiency is therefore preferred.

1 Disassembly is economically unfeasable
2 Disassembly is laborous and expensive
3 Disassembly is possible with reasonable effort
4 Disassembly is easily done by non-professionals

complex 1 2 3 4 easy

Lifecycle Criterion: Maintenance

The possibility to replace broken components or parts of it. The building system should be easily maintained to extend its lifetime, by having replacement components readily available

1 Components are produced in limited sets and can't be replaced
2 Replacement components should be custom crafted
3 Replacement components can made by non-professionals
4 Replacement components are widely available

expert 1 2 3 4 amateur

Lifecycle Criterion: Adaptability

The level of adaptability can range from a concrete building that requires complete demolition when a single part becomes inadequate to a building designed to be disassembled and replaced into multiple pieces when components become outdated or damaged.

1 Building doesn't allow future adaptations
2 Building allows future adaptations with major reworking
3 Building is open to future adaptations
4 Building is easily adapted

light 1 2 3 4 heavy

Lifecycle Criterion: Reusability

The end-of-life activities for modular elements and components include landfill disposal, combustion, recycling, re-manufacturing, and reuse. These options vary in environmental impact, with recycling, re-manufacturing, and reuse offering greater sustainability. Designing systems with circular principles enables higher-value end-of-life pathways and minimizes waste.

1 Components can't be re-used, and should be disposed after use
2 Components can be recycled into materials of lesser value
3 Components can be re-manufactured
4 Components can be reused without degredation

disposable 1 2 3 4 reusable

APPENDIX C - Individual assessments

In this appendix the full assessment of each individual building system is shown, in addition to a short description of the system, a link to relevant resources and a short note on the rating process.

Detailed information and illustrations of all building systems can be found by following the linked webpage under 'reference source'.

Mitsui home Mocxion system

	weight	score	w x s
required operator skill	2	2	4
tool complexity	2	2	4
weight	1	2	2
dimensions	2	3	6
connection integration	2	1	2
connector type	3	3	9
prefabrication degree	2	3	6
freedom of design	3	4	12
finishing	2	4	8
ease of disassembly	1	1	1
reusability	2	2	4
maintenance	2	2	4
adaptibility	3	2	6
Total weighted score			68

description

A seemingly traditional platform framing method, that applies entirely prefabricated panel modules in carryable dimensions.

reference resource https://www.mitsuihome.co.jp/property/...
materials pine panels, plywood
connections metal fasteners, screws
max. building layers 4

rating notes

The system shows some clear points of excellence in terms of flexibility and finishing, but construction demands a lot from its builder despite an emphasis on prefabrication. A better focus should be placed on its lifecycle criteria, and the integration of its flooring system to make this a feasible self-build method.

Walter Segall Method

	weight	score	w x s
required operator skill	2	3	6
tool complexity	2	3	6
weight	1	4	4
dimensions	2	4	8
connection integration	2	1	2
connector type	3	3	9
prefabrication degree	2	2	4
freedom of design	3	2	6
finishing	2	3	6
ease of disassembly	1	4	4
reusability	2	3	6
maintenance	2	4	8
adaptibility	3	3	9
Total weighted score			78

description

DIY-construction scheme popular during the 70s and 80s in England. The system is built on widely available materials, and minimize remanifacturing their standard dimensions.

reference resource https://www.designingbuildingsco.uk/...
materials pine post and beams, multiplex panels
connections bolted construction, clamped panels
max. building layers 3

rating notes

The system scores high on its user criteria, due to manageable part size and simple fabrication method. The usage of mostly screwed connections and working with readily available stock does have a negative influence on the rating of its system criteria.

Wikihouse Skylark 250

	weight	score	w x s
required operator skill	2	4	
tool complexity	2	3	
weight	1	4	
dimensions	2	4	
connection integration	2	3	
connector type	3	3	
prefabrication degree	2	4	
freedom of design	3	2	
finishing	2	2	
ease of disassembly	1	3	
reusability	2	3	
maintenance	2	2	
adaptibility	3	2	
Total weighted score			

description

Open-source building system that uses CNC-milled plywood to create stackable box components.

reference resource https://www.wikihouse.cc/blocks/skylark-250
materials plywood
connections friction-fit, screwed
max. building layers 3

rating notes

The system has a large forcus on decreasing the skillset needed to build, and scores very high on its system and user criteria. This also results in a more restricted system in terms of its lifecycle and freedom of design.

Houtkernmethode

	weight	score	w x s
required operator skill	2	3	6
tool complexity	2	2	4
weight	1	3	3
dimensions	2	3	6
connection integration	2	2	4
connector type	3	3	9
prefabrication degree	2	3	6
freedom of design	3	2	6
finishing	2	3	6
ease of disassembly	1	4	4
reusability	2	4	8
maintenance	2	3	6
adaptibility	3	3	9
Total weighted score			77

description

Circlewood's construction system features stackable modules with flexible floorplans, connected via a metal corner joint. Completed projects have utilized CLT (cross-laminated timber) floors, though these can be substituted with Kerto Ripa box floor panels if desired.

reference resource https://abt.eu/impact/circulair-in-de-toekomst...

materials solid timber posts and beams. LVL floor panels

connections bolted construction, screwed floors and walls

max. building layers 4

rating notes

The Houtkernmethode scores high in terms of its system-criteria because of its well-designed connector. By eliminating the need for bracing walls it creates a large open plan that is very flexible to adaptations. The large dimensions of its components does require more form the builder.

Sustainer

	weight	score	w x s
required operator skill	2	2	4
tool complexity	2	2	4
weight	1	3	3
dimensions	2	3	6
connection integration	2	1	2
connector type	3	2	6
prefabrication degree	2	2	4
freedom of design	3	1	3
finishing	2	4	8
ease of disassembly	1	1	1
reusability	2	2	4
maintenance	2	2	4
adaptibility	3	2	6
Total weighted score			55

description

This system stands out as a light-weight prefabricated module, in contrast to the CLT-based modules dominant in the industry. The analysis applies this system as if assembed on-site, to test its potential as a self-built method.

reference resource https://www.metsagroup.com/metsawood...

materials Pine LVL beams and panels, solid pine frames

connections Bolts and screws

max. building layers 3

rating notes

The application of this modular system as a self-built construction methods proves unattractive, due to . Lessons can be learned however from it's construction principle and material selection.

Timber weaver studio

	weight	score	w x s
required operator skill	2	2	4
tool complexity	2	2	4
weight	1	2	2
dimensions	2	2	4
connection integration	2	1	2
connector type	3	3	9
prefabrication degree	2	2	4
freedom of design	3	4	12
finishing	2	2	4
ease of disassembly	1	4	4
reusability	2	4	8
maintenance	2	3	6
adaptibility	3	3	9
Total weighted score			72

description

A self-built mixed use building, containing two appartements and a studio. The building uses a solid timber frame, with both timber and steel bracings.

reference resource https://divisare.com/projects/...

materials solid timber (presumably cedar) and hempcrete

connections bolted construction

max. building layers 3

rating notes

The simple and exposed construction creates an easy to assemble multi-storey construction. Higher amounts of on-site labour and the required technical knowledge to do so decrease the systems score.

Helio Olga house

	weight	score	w x s
required operator skill	2	3	6
tool complexity	2	3	6
weight	1	3	3
dimensions	2	3	6
connection integration	2	4	8
connector type	3	4	12
prefabrication degree	2	3	6
freedom of design	3	3	6
finishing	2	3	6
ease of disassembly	1	3	3
reusability	2	4	8
maintenance	2	2	4
adaptibility	3	3	9
Total weighted score			79

description

One-off residential project in São Paulo, Brasil designed by the architect Marcos Acabaya in 1990. The building features intricately crafted joinery and metal bracings. The usage of pau-brasil hardwood allows very thin profiles and limited dimensions, suitable for self build.

reference resource https://block.arch.ethz.ch/eq/... (pp.222-258)

materials pau-brasil hardwood

connections friction-fit, bolted

max. building layers 4

rating notes

The system scores well on all criteria, because of its material properties and well-designed connection system. It will prove an interesting challenge to rethink the system with materials that are available on the local market.

Contemporary half-timbered house

	weight	score	w x s
required operator skill	2	1	2
tool complexity	2	3	6
weight	1	1	1
dimensions	2	1	2
connection integration	2	4	8
connector type	3	4	12
prefabrication degree	2	2	4
freedom of design	3	4	12
finishing	2	3	6
ease of disassembly	1	2	2
reusability	2	3	6
maintenance	2	2	4
adaptibility	3	2	6
Total weighted score			71

description

This case-study shows the construction of a three-storey half-timbered house using a traditional German method. The building stands as an example for the timber construction method that was once dominant all over Europe, and could reach up to 6 storeys built without using heavy machinery.

reference resource https://www.fachwerkhaus.de/ein-drei...

materials pine post and beams, loam walls

connections friction fit joinery with wooden dowels

max. building layers 6

rating notes

The example scores very high on it's system criteria, due to its connections and design freedom. Exactly these components demand however a very skilled builder. A prefabricated system with smaller dimensions could be suitable in a self-built context.

Toyota family home

	weight	score	w x s
required operator skill	2	2	4
tool complexity	2	2	4
weight	1	1	1
dimensions	2	1	2
connection integration	2	4	8
connector type	3	3	9
prefabrication degree	2	4	8
freedom of design	3	3	9
finishing	2	3	6
ease of disassembly	1	3	3
reusability	2	4	8
maintenance	2	2	4
adaptibility	3	3	9
Total weighted score			75

description

A simple post-and-beam frame structure is built from all precut components. The building follows a common construction method widely applied for Japanese timber structures up to three storeys, due to its good seismic resistance.

reference resource http://norihisakawashima.jp/minimum-house...

materials solid pine

connections friction-fit, bolted

max. building layers 3

rating notes

The systems simplicity enables a high overall score, despite it's low rating on the user criteria.

APPENDIX D - Testing design

This research was written as scientific support for the graduation project of the Master of Architecture at TU Delft. During this graduation year, a design project is made with a major focus on the integration of research and design. The final design was therefore based on the findings of this research to create a self-build housing system on water. This system uses a folding timber frame support structure, in which various components are applied (see figure 8). These components can be produced on-site using local materials.

As a method of reflection on the relationship between design and research, this building system is assessed in this chapter. This is done at the scale of the total building system according to the developed MCA, and on a components scale by physically building the designed components.

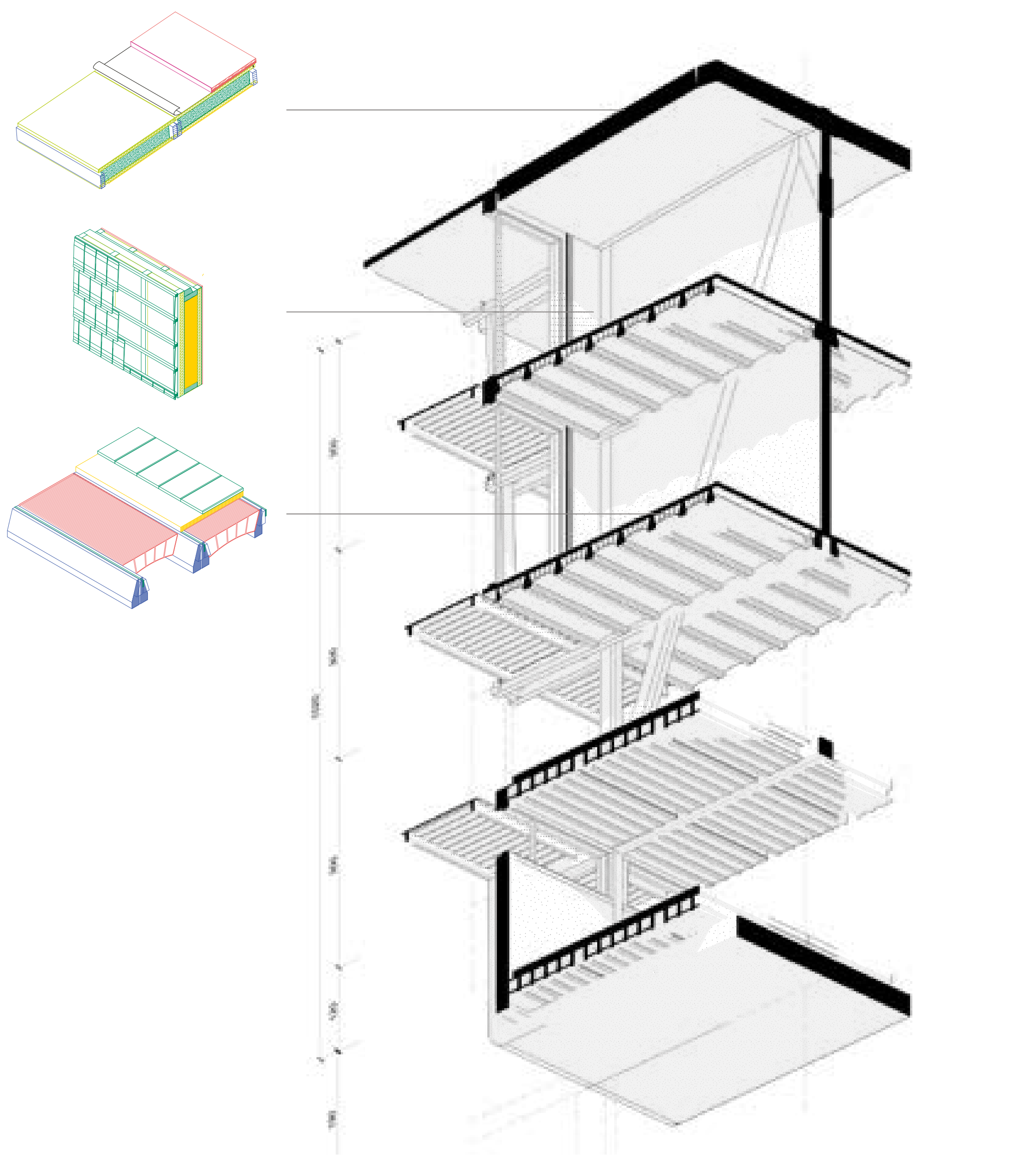


Figure 8: Choisy projection of building system, with roof, wall and floor components highlighted (own work)

System assessment using MCA

The building system scores very high when compared to the previously analyzed building systems (see figure 10). It does so without excelling in the separate criteria or categories. In fact, in the category of system criteria, the building scores relatively low. This is because the final design provides a clear prescription of how to build and little room for freedom on the part of the self-builder. This is because the project puts a priority on affordability through collective self-build. Repeatability and simplicity were therefore deemed more important than the ability to create different layouts and envelopes.

The building system manages to achieve a very high score despite this trade-off by scoring well across all criteria. The results of the research came together in a building system where manageability, prefabrication and assembly are the starting points. The breakdown into smaller building components has led to a system in which repair and disassembly are possible. Also,

Graduation project

	weight	score	w x s
required operator skill	2	3	6
tool complexity	2	3	6
weight	1	3	3
dimensions	2	3	6
connection integration	2	3	6
connector type	3	3	9
prefabrication degree	2	3	6
freedom of design	3	1	3
finishing	2	4	8
ease of disassembly	1	4	4
reusability	2	3	6
maintenance	2	4	8
adaptibility	3	3	9
Total weighted score			79

description

A timber frame is designed that can be assembled from smaller components. The buildings height is enabled by raising a three storey high timber frame that is assembled from smaller components. This structure is then completed with self-buildable floor-, wall- and ceiling components.

reference resource -

materials douglas, earth, reeds, typha, coppice

connections dowels, joinery, metal fasteners

max. building layers 4

rating notes

The system scores high across the different criteria. The system doesn't maximize prefabrication but nonetheless puts reasonable demands on the user. It's material choices and modular approach lead to very high scores in the lifecycle criteria.

Figure 9: Assessment of the proposed building system (own work)

	Graduation design	Helio Olga house	Walter Segall Method	Wikihouse Skylark 250	Houtkernmethode	Toyota family home	Timber Weaver studio	Contemporary half-timbered house	Mitsui Mocxion	Sustainer
required operator skill	6	6	6	8	6	4	4	2	4	4
tool complexity	6	6	6	6	4	4	4	6	4	4
weight	3	3	4	4	3	1	2	1	2	3
dimensions	6	2	8	8	6	2	4	2	6	6
connection integration	6	8	2	6	4	8	2	8	2	2
connector type	9	12	9	9	9	9	9	12	9	6
prefabrication degree	6	6	4	8	6	6	4	4	6	4
freedom of design	3	6	6	6	6	12	12	12	12	3
finishing	8	6	6	4	6	6	4	6	8	8
ease of disassembly	4	3	4	3	4	3	4	2	1	1
reusability	6	8	6	6	8	8	8	6	4	4
maintenance	8	4	8	4	6	4	6	4	4	4
adaptibility	9	9	9	6	9	9	9	6	6	6
TOTAL (max 108)	80	79	78	78	77	76	72	71	68	55

Figure 10: Inclusion of the building system in the overall ranking (own work)

the choice of simple manufacturing processes and common materials has ensured that the system performs well on user criteria. These design choices have not been explicit conclusions or prescriptions of the research but have resulted from the extensive knowledge of building systems for self-building gained during the research.

Component assessment through self-building

The study approaches the assessment of a complete building system, evaluating a total score for the combination of construction and building components. In order to also assess the designed components, it was chosen to build them as a 1:1 scale model. In doing so, research topics such as designing for limited skills or resources are transferred from the paper to the workshop. This building process is documented and provided with a reflection that explains the relationship between the research and the feasibility of the design.

Facade element

description

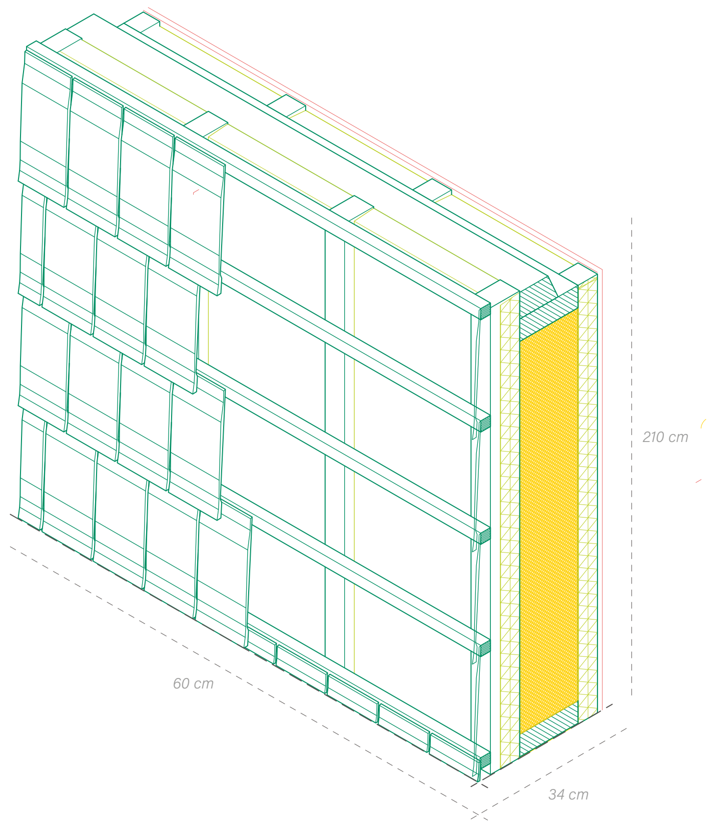
A simple prefabricated timber frame element is used to compress parallel reed stalks into a wall element. Typha-board panels provide lateral stability to the element and are finished with clay plastering and shingles.

dimensions

60 x 34 x 210 cm
74 kg

build-up

Earth plaster
Typhaboard 40mm, between alder battens
Compressed reed 160mm
Typhaboard 40mm
Earth plaster
Alder sub-construction and air gap
Ash, alder, poplar and willow shingles



Assembly

Cleaving shingles

Compressing reed

Trimming excess material

Applying jute as reinforcement

Finishing with clay plaster

Final mock-up

Reflection

The model represents a third of the final facade element. Despite this smaller size, weight and carry-ability already form an issue. Installing the facade and plaster after placement can overcome this.

Processes such as cleaving shingles or applying a clay plaster proved to be intuitive and easy to learn. Despite the inclusion of tool complexity as a criteria, more attention should be payed to integrate this aspect in the design.

<u>adaptations:</u>
- apply jute reinforcement everywhere to prevent cracking of plaster
- integrate attachments for compression straps
- cut tree-trunks to equal lengths to enable a single length for shingles
- arrange different wood types of shingles depending on their durability over the facade
- apply clay finishing and shingles after installation

Floor element

description

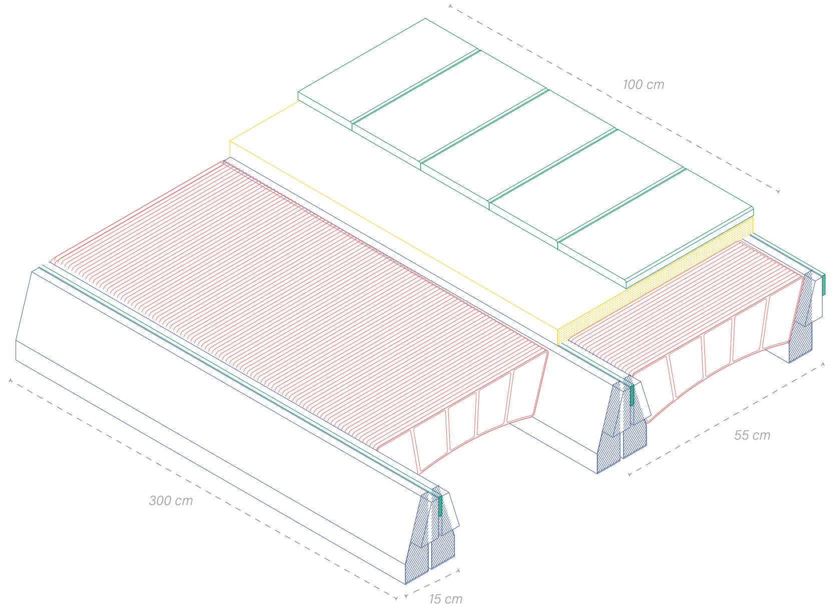
The floor consists of different elements that are installed on-site. This enables long spans with minimal component weight. Printed clay casettes are fitted between long floor joists. These are finished with a reed underfloor, over which a reclaimed timber floor is applied.

dimensions

15 x 55 x 110 cm
32 kg

build-up

Profiled 70 x 220mm douglas floor joists
Poplar spacing batten 20x40 mm and lighting rails
Printed clay casettes 550 x 1100 mm
Reed mat 40mm underfloor, cable gutters
Reclaimed wood flooring 18mm



Assembly

Preparing materials

Mixing clay and water

Printing

Compressing clay magazine

Layering reed matts

Final mock-up

Reflection

Printing the floor cassettes occupied most of the construction time. It will take much more time to turn this into a mature product, but the model proves that it is a feasible idea.

The biggest modifications are found in the assembly of the reed mats and the addition of an adjustable wood fiber board as a subfloor. The 1:1 model clearly shows these errors in assembly, and proves the importance of making these models.

<u>adaptations:</u>
- Decrease cassette height to ensure stability during printing and drying
- Use a robotic arm to have a larger workbed and continuous printing
- Add an additional wood fibre panel as an underfloor, to level and compress the reed matts
- Replace a single reed matt for several cross-layered matts.
- Join the two floor joists and spacer into one single beam before installing