Modular

Incremental Housing :

Design and Construction with a Focus on Timber Construction and Digital Customization

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Summary

The global housing crisis necessitates solutions that are both immediately affordable and adaptable for future needs. This research explores incremental housing systems, with a particular emphasis on user participation and modular timber construction, to address the evolving demands of urban living. Drawing upon historical precedents such as Belapur Housing by Charles Correa, Elemental's "Half House," and incremental projects in India, the study identifies key principles of flexibility, community, and sustainability. The research critically examines timber structural systems—ultimately adopting the flexible Houtkern Bouwmethode developed by Noordereng Groep—and integrates user-driven design through digital tools such as Grasshopper and Human UI. By developing a configurator that enables residents to personalize and expand their homes, this project demonstrates how incremental, modular, and participatory approaches can enhance quality of life, foster community, and promote sustainable urban development.

Keywords: Incremental housing; Modular construction; User participation; Timber systems; Digital configurators

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1 Introduction

1.1 Context and Background

The rapid pace of urbanization and the growing demand for affordable, adaptable housing have exposed the limitations of traditional housing models. Globally, over 1.6 billion people are expected to face housing challenges by 2025 (UN-Habitat, 2020). This crisis is not only about quantity but also about quality and adaptability: homes must evolve with their inhabitants, supporting changing family structures, social needs, and environmental priorities.

Inspired by the work of John Turner (1972), who conceptualized housing as a continuous process rather than a finished product, this research seeks to develop housing systems that empower residents to shape their living environments. The philosophy of “housing as a verb” is central to this approach, emphasizing adaptability, participation, and long-term community building.

1.2 The Desire for Stable, Long-term Housing Connections

Today, there is an increasing desire for homes that not only provide shelter but also foster long-term connections with both the dwelling and the surrounding community. As Turner (1976) and Habraken (1972) have highlighted, residents seek spaces they can personalize and grow with overtime. This stability is vital for the development of cohesive communities, as long-term residents tend to establish stronger social networks (Braide, 2019). In contrast, neighborhoods dominated by rental properties often experience high resident turnover, disrupting community bonds (TIP, 2018).

To address these challenges, many municipalities have shifted their focus toward promoting homeownership through various policies (City of Gothenburg, 2021). However, traditional homeownership models often fail to support the necessary spatial adaptability over time. Coulter and van Ham (2013) argue that current housing practices often require residents to relocate when their spatial needs evolve, disrupting social ties. A potential solution to this problem lies in housing systems that allow residents to modify their living spaces incrementally, allowing homes to evolve in response to changing family dynamic and lifestyle needs.

Braide (2019) argues that homes should not be static; they should grow with the residents, supporting the need for residents to shape their environments over time. This adaptability fosters more sustainable and socially cohesive communities.

1.3 The Challenge of Contemporary Housing

Contemporary housing faces numerous challenges, particularly in rapidly urbanizing regions, where conventional solutions are often unaffordable or inadequate. Bredenoord et al. (2014) identify several key issues impacting housing today:

- Rising land and construction costs
- Changing household compositions
- Environmental sustainability requirements
- The need for community engagement
- Limited government resources

These challenges require innovative housing solutions that can address issues such as affordability, sustainability, and adaptability while also fostering strong community connections. Traditional housing models often struggle to provide the necessary flexibility for residents to modify their living spaces over time.

1.4 Research Objectives and Questions

1.4.1 Research Objectives

The aim of this study is to explore how incremental housing approaches, combined with modular design principles, can provide adaptable, sustainable, and affordable housing solutions. The study will specifically focus on the role of user participation in the housing process and the integration of modern technologies such as parametric tools and configurators to facilitate customization and design flexibility.

1.Analyze incremental and modular housing approaches, with a focus on timber systems and user participation.

2.Evaluate the potential of different modular timber systems for flexible, sustainable housing.

3.Develop and test a user-driven digital configurator to facilitate customization and incremental expansion of housing units.

By integrating these elements, this study seeks to advance the discourse on affordable, adaptable, and sustainable urban housing.

1.4.2 Research Questions

The study will address the following key research questions:

1 - What systematic framework can effectively balance user customization freedom with structural integrity constraints in housing systems?
2 - How digital tools and interfaces would support users in navigating customization options within established parameters?

3- How can a modular expansion system be designed to accommodate changing user needs while maintaining architectural coherence?

2. Theoretical Framework

2.1 Evolution of Incremental Housing Concepts

Incremental housing refers to a flexible and gradual approach to housing design, where residents are allowed to build or modify their homes over time as their needs change. This approach has its roots in early 20th-century architectural experiments that sought to address the growing demand for affordable and adaptable housing.

A pivotal contribution to this field came from John Habraken in the 1960s and 1970s. In his seminal work "Supports: An Alternative to Mass Housing" (1972), Habraken introduced the concept of "supports" and "infill." He proposed that housing should be divided into two components: the support, which includes the basic structural framework (foundations, external walls, etc.), and the infill, which includes the internal partitions, finishes, and services that can be adapted or expanded by the users themselves. This system allows for greater flexibility in how homes can evolve over time, empowering residents to make changes according to their needs and preferences. Habraken's work laid the foundation for user participation in housing design by making it possible for residents to actively shape their living environments.

John Turner (1976) further expanded on this idea in his research on housing and selfhelp. Turner argued that housing should not be seen as a finished product but rather as a process that allows users to have autonomy in shaping their homes. He emphasized the importance of enabling residents to incrementally add or modify spaces as their circumstances change, making their homes more personalized and adaptable to family growth or shifts in lifestyle. This shift towards user-driven design marked a significant change in housing theory, promoting the idea that residents, not architects or planners alone, should have authority over the development of their living spaces.

2.2 Core Principles of User Participation

User participation in housing design is a multi-level process where residents are involved in decisions about their living spaces, from basic design choices to the timing of changes or expansions.

2.2.1 Decision-Making Authority

In incremental housing, residents are granted decision-making authority at various stages of the housing process. This empowerment can include:

• Choice in spatial organization: Residents are given the flexibility to organize rooms or spaces to suit their needs. This could involve altering internal walls or adjusting layouts to accommodate changing family sizes or functions, allowing for adaptability (Turner, 1976).

• Control over expansion timing: Users are not constrained by preset designs and can decide when and how to expand their homes as their family grows or their economic situation changes. This autonomy aligns with the principles of incremental housing, allowing for gradual adaptation over time (Mota, 2021).

• Material and finish selection: The ability to choose materials and finishes enables residents to personalize their homes, reflecting their tastes, cultural preferences, and budget constraints, which is central to creating a sense of ownership and satisfaction (Hamdi, 1995).

• Resource allocation: Residents can prioritize spending on specific parts of the house, directing resources where they are most needed at any given time. This approach supports flexible financial management, making it possible for homes to evolve incrementally as resources allow (Mota, 2021).

2.2.2 Professional Support Framework

For user participation to be successful, a professional support framework is essential. This includes:

• Technical guidance systems: Clear instructions and guidelines help users make informed decisions about design and construction. This may include manuals or digital tools that guide residents through self-building processes, ensuring that they are equipped to make choices that align with technical and regulatory standards (Mota, 2021).

• Expansion guidelines: Providing residents with clear information about how to expand their homes over time, including structural guidelines and advice on when and how to extend the home safely and cost-effectively. This allows for a structured approach to growth, facilitating long-term housing adaptation (Kendall & Teicher, 2000).

• Professional consultation: Access to professionals such as architects, engineers, or contractors is critical for supporting more complex design or construction decisions. By providing expert advice, incremental housing models ensure that residents can make informed decisions for more technical tasks (Hamdi, 1995).

• Quality control mechanisms: Implementing systems to ensure the quality and safety of housing, even when much of the work is carried out by residents themselves. These systems, such as inspections or feedback loops, ensure that the final product adheres to safety and construction standards, preserving structural integrity (Kendall & Teicher, 2000).

Kendall and Teicher (2000) emphasized the importance of this framework in supporting the autonomy of users while ensuring that the housing remains functional, safe, and of high quality.

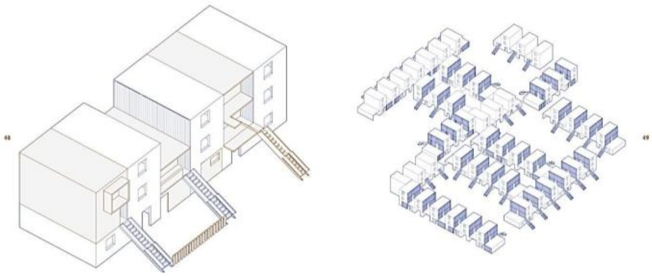

Figure 1:Incremental Housing in the Global South (by Maja Sorabjee)

2.3 Open Building and Bottom-up Strategies

The Open Building approach is a key framework for understanding the levels of intervention that are possible in housing. It separates the housing structure into two key components: support and infill, with varying levels of intervention allowed for each.

2.3.1 Support Level

The support level refers to the basic, permanent elements of the housing, which include:

• Basic structure: The foundation and frame of the house, which should be designed to accommodate future expansions or changes.
• Infrastructure systems: These are the essential services such as plumbing, electrical systems, heating, and water that provide the basic functions of the house.
• Common facilities: Shared spaces and amenities such as hallways, elevators, or communal areas.
• External envelope: The building's outer shell (walls, roof, windows) that protects the interior from the external environment.

The idea is that the support level should be designed to be robust, flexible, and capable of handling future changes without requiring major structural modifications.

2.3.2 Infill Level

The infill level consists of the more flexible, changeable elements of the house, which are:

• Interior partitions: Non-loadbearing walls that can be modified or moved to reorganize the internal layout of the space.

• Service installations: These include internal plumbing, electrical fixtures, heating, and cooling systems, which can be adapted or expanded as the house grows.

• Finishes: Elements such as flooring, wall coverings, and decorative touches, which can be easily changed or upgraded by the residents.

• Individual adaptations: These are the personal modifications that residents can make to the space to suit their needs, such as adding new rooms, changing the layout, or installing new systems.

In an open building system, the support level remains largely unchanged over time, while the infill level is subject to modification as the needs of the residents evolve. This division allows for a balance between structural stability and flexibility, giving users the power to adapt their homes to their changing needs without disrupting the basic structure of the building.

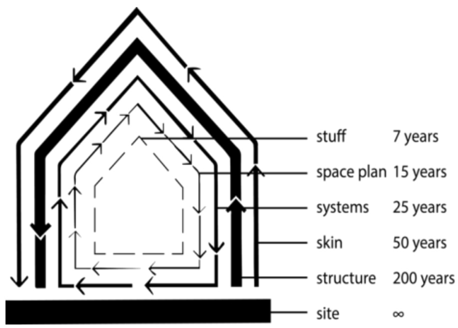

Figure 2 : Diagram of Building Layers and Their Lifespans (adapted from Stewart Brand, "How Buildings Learn")

2.4 Modular Construction Methods

Modular construction involves the pre-fabrication of building modules in a controlled factory setting, which are then transported and assembled on-site. This approach is particularly beneficial for incremental housing as it offers flexibility for future expansion, allowing residents to add modules over time based on their changing needs. One of the key advantages of modular systems is the reduction in construction time and cost. Prefabrication in factories is typically faster and more efficient than traditional construction methods, reducing the overall time spent on-site and lowering labor and material costs (Bredenoord et al., 2014). Additionally, modular construction is more sustainable, generating less waste and reducing the environmental impact compared to conventional methods (Khemlani, 2018).

The modular approach also supports the adaptability of housing, a core principle of incremental housing, by enabling easy modifications as families evolve. As identified by Bredenoord et al. (2014), modular systems allow for the integration of diverse needs, ensuring that homes can grow with their inhabitants over time. This aligns with the principles of user participation, as it enables homeowners to make modifications based on their preferences and needs without significant disruptions to the community or the environment. Thus, modular housing systems offer a promising solution to address both affordability and flexibility in housing development.

2.5 Digital Tools for User Participation

Digital tools play a critical role in enhancing user participation in housing design, allowing residents to be more involved in shaping their living spaces. Tools such as parametric design software, online platforms, and configurators enable users to engage directly in the design process, giving them the ability to personalize and adapt their homes according to their evolving needs (Ratti et al., 2005). These tools provide real-time feedback, helping residents visualize the changes they make to the design and ensure that the end product aligns with their preferences and requirements.

In the context of incremental housing, digital tools offer the potential to continuously adapt homes as residents' needs change over time. Configurators, for example, allow users to select different module configurations or adjust layouts based on their current and future needs (Graham & Zook, 2017). These tools not only support personalization but also foster a sense of ownership and engagement among residents, contributing to stronger community bonds and social sustainability (Coulter & van Ham, 2013). By incorporating these technologies, architects and developers can create more responsive and adaptable housing solutions that better serve the needs of their residents, making the process more inclusive and sustainable.

2.6 Design Philosophy and User Experience

Sarah Susanka's "Not So Big House" philosophy emphasizes quality over quantity, flexible spaces, and user-centered design (DSMHBA, n.d.). Key principles include building in layers, shifting walls, creating hierarchy at entrances, borrowing space visually, and varying ceiling heights to make spaces dynamic. These ideas align with incremental and modular housing, prioritizing adaptability, comfort, and personalization for long-term satisfaction. The philosophy advocates investing in features and materials that enhance livability and reflect the lifestyle and values of the occupants. Digital configurators further enhance user experience by enabling real-time customization, visualization, and participation in the design process (PLOS ONE, 2024)

3. Case Studies Analysis

The analysis of case studies offers valuable insights into the principles of incremental housing and how these concepts have been applied across various projects. By examining both historical examples and contemporary applications, we can better understand the evolution of modularity and user participation in housing design.

3.1 Incremental housing Examples

3.1.1 Quinta Monroy (2003)

Quinta Monroy, a housing project in Chile completed in 2003, is a pioneering example of strategic incompleteness, a concept that emphasizes the provision of basic infrastructure with the intention of allowing residents to incrementally complete their homes. This project, led by architect Alejandro Aravena, was designed with the understanding that many low-income families would not have the immediate resources to fully develop their homes. Instead, the initial design provided families with a framework—a basic structure—that they could expand upon and personalize over time.

The success of Quinta Monroy lies in its ability to balance affordability with user involvement. By providing a foundational structure that could be added to and customized by the residents, the project not only made housing more accessible but also empowered families to take control of their living spaces. The design approach has since been adopted in numerous other social housing projects as an innovative solution to housing shortages in developing countries (Aravena, 2012).

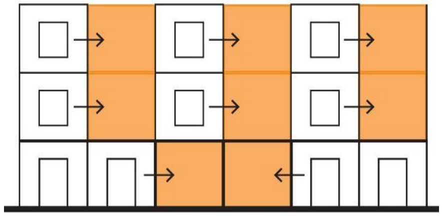

Figure 3 :Quinta Monroy Housing Project and Expansion Principle (designed by Alejandro Aravena, image sources: project photo and expansion diagram

3.1.2 Incremental Housing in Pune, India (Filipe Balestra & Sara Göransson)

This strategy focused on upgrading informal settlements into permanent urban districts through gradual improvement rather than demolition (ArchDaily, n.d.). The architects provided simple structural frames that allowed for vertical and horizontal expansion. Residents participated in workshops and were given grants to support future development. Each family could choose from several incremental prototypes, ensuring that the design could adapt to their specific needs. The approach preserved community ties and allowed for organic, user-driven growth. The involvement of community-based organizations ensured that the process was inclusive and responsive to the needs of low-income urban residents (ArchDaily, n.d.).

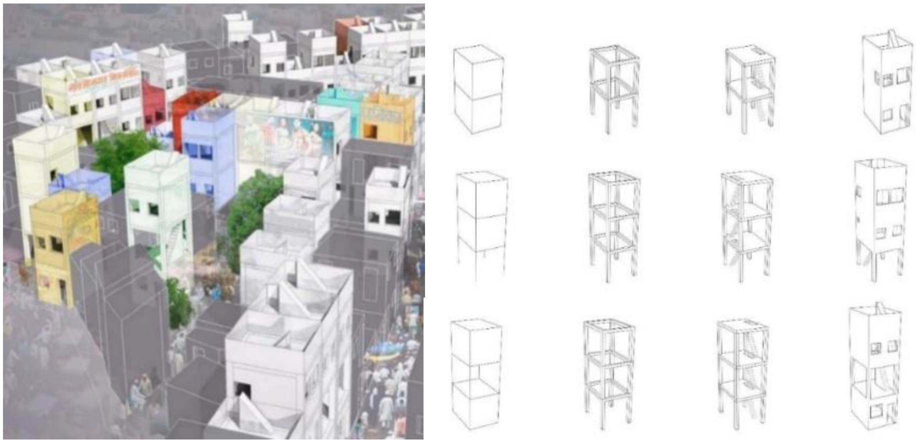

Figure 4 : Incremental Housing Strategy in India: structural frames and growth stages. Source: Filipe Balestra & Sara Göransson, Pune, India (ArchDaily)

The project demonstrated how incremental housing can transform informal settlements while maintaining social networks and community identity. By providing flexible structural frameworks rather than complete housing units, the architects enabled residents to invest in their homes gradually according to their resources and changing family needs. This approach supports long-term community development and empowers residents to shape their own living environments.

3.1.3 Belapur Housing by Charles Correa (Navi Mumbai, 1983–1986)

Belapur Housing is a landmark example of incremental, community-focused design. Correa's project provided individual plots for each dwelling, enabling future expansion as needed (Re-thinking the Future, n.d.). Homes were arranged in clusters around communal courtyards, balancing privacy with opportunities for social interaction. The use of local materials and context-sensitive design allowed residents to modify their homes to suit their cultural and social needs. The project remains successful decades later, with a strong sense of community and ongoing adaptability. The presence of open and green spaces in the heart of development contributes to the well-being of residents and fosters a sense of belonging (Re-thinking the Future, n.d.)

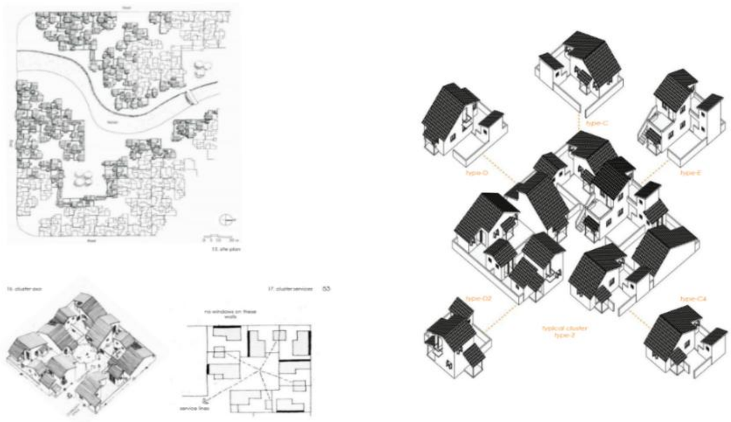

Figure 5: Incremental Housing Cluster Development: Site Plan, Axonometric Views, and Unit Layouts (adapted from design diagrams by Alejandro Aravena and Elemental)

3.2 Sustainable Timber Construction, Modular Systems, and Recyclability

3.2.1 Sustainable Timber Construction

Timber is increasingly recognized as a cornerstone of sustainable building due to its renewable nature, low embodied carbon, and ability to sequester CO_2 throughout its lifecycle. Building with wood not only reduces the environmental impact compared to conventional materials like steel and concrete but also supports local economies through regional sourcing and processing (Pfleiderer, 2023). Timber structures provide excellent thermal performance and a healthy indoor climate, further enhancing their appeal for residential and social housing projects (Pfleiderer, 2023; Blumer Lehmann, 2025).

3.2.2 Modular and Reusable Timber Systems

Modular timber construction systems, such as the Houtkern Bouwmethode, TRIQBRIQ, and engineered timber panels, exemplify the integration of sustainability, flexibility, and circularity. The Houtkern Bouwmethode, developed by Circlewood, uses stackable wooden modules connected by steel nodes, enabling rapid assembly, disassembly, and reuse. This method was first showcased in The Natural Pavilion at Floriade Expo 2022, demonstrating its potential for both temporary and permanent structures (Circlewood, 2024). The system's reversibility and flexibility allow for significant CO_2 and nitrogen emission savings, while accommodating the latest design and construction techniques for high sustainability performance (Circlewood, 2024).

Similarly, the TRIQBRIQ system consists of micro-modular timber building blocks ("BRIQs") manufactured from industrial and calamity wood using robotic technology. These blocks are assembled on-site using only wooden dowels, eliminating the need for artificial fasteners and ensuring 100% reusability at the end of a building's life (TRIQBRIQ, 2025). The system is designed for minimal waste, efficient transport, and rapid construction, making it a holistically sustainable alternative to conventional materials (TRIQBRIQ, 2025).

3.2.3 Recyclable and Circular Timber Solutions

Recyclable and reusable timber systems are central to advancing circular economic principles in the construction industry. Projects such as the REUSE initiative by the Joint Research Centre use engineered timber panels designed for deconstruction and reuse, minimizing construction waste and supporting rapid reconstruction in disaster-affected regions (JRC, 2024). Prefabricated cross-laminated timber (CLT) modules with easy-to-assemble connections further reduce embodied carbon and construction waste, while enabling adaptable and resilient buildings (JRC, 2024).

Digital fabrication and computational design are also transforming timber construction by enabling the efficient reuse of reclaimed and non-standard timber, extending the lifecycle of wood resources and reducing waste (Reisach et al., 2024). These innovations, combined with modular systems like the Houtkern Bouwmethode, ensure that buildings can be easily adapted, expanded, or dismantled for reuse—maximizing resource efficiency and minimizing environmental impact.

3.3 Digital Configurator Examples

The integration of digital configurators in housing design has enhanced the ability for users to actively participate in the design and adaptation of their homes. Configurators are digital platforms that allow users to interact with housing designs in real-time, modifying layouts, selecting modules, and visualizing changes before construction starts. In Germany, companies such as DMG have developed browser-based 3D house configurators that allow users to select floor plans, customize materials, and visualize changes in real time, significantly improving customer satisfaction and streamlining the sales process (DMG, 2025). Urban Beta offers the Beta Builder, a web platform enabling users to design modular buildings and receive immediate feedback on buildability and cost (Urban Beta, 2024).

Internationally, configurators like MOOS Modular Housing Configurator in the Netherlands empower users to experiment with countless layout options, view real-time 3D models, and access pricing information, supporting informed decision-making and creative exploration (Bitbybit.dev, 2024). Research on digital tools for co-design highlights the importance of user-friendly interfaces that allow non-experts to express their needs and visualize outcomes, bridging the gap between designers and inhabitants (PLOS ONE, 2024). These digital solutions are increasingly adopted in modular housing projects worldwide, fostering greater user engagement and more personalized living environments.

These tools not only improve the user experience but also streamline the construction process by ensuring that the final design is tailored to the user's specific requirements. Configurators are part of the broader trend toward digitizing architecture, where architects and residents work together to co-create solutions (Graham & Zook, 2017).

3.4 Prefabrication Approaches

In recent years, prefabrication has become a central strategy in the development of modular housing. Prefabricated components are manufactured in a controlled environment and then assembled on-site, which significantly reduces both time and costs. This method is particularly beneficial in addressing the growing demand for affordable housing, as it allows for faster construction times and higher-quality control than traditional methods (Khemlani, 2018).

Prefabrication is also advantageous in creating adaptable housing systems. The modular nature of prefabricated components allows for easy expansion, reconfiguration, and modification, ensuring that homes can grow with the needs of their residents. Additionally, it supports the integration of sustainable practices, such as energy-efficient designs and the use of eco-friendly materials, contributing to more environmentally conscious housing solutions.

3.5 Social Aspects and Shared Spaces in Housing

The integration of shared spaces—such as community kitchens, laundry facilities, rooftop gardens, and open gathering areas—plays a critical role in fostering social interaction, well-being, and long-term community resilience. In modern housing developments, especially those with limited private living space, the provision of communal amenities encourages residents to connect, collaborate, and support one another, thereby strengthening social cohesion and reducing feelings of isolation (Virtu Property, 2023; CIB, 2022).

Shared spaces serve as intentional interventions in the built environment, designed to cultivate social bonds and address specific community needs. Research demonstrates that well-designed communal areas can significantly enhance residents' sense of belonging and psychological well-being, leading to longer tenancies and greater satisfaction (Virtu Property, 2023; SOWVITAL, 2025). For example, rooftop gardens not only provide opportunities for relaxation and access to fresh food but also act as social hubs where residents can interact, collaborate on gardening projects, and build stronger relationships (SOWVITAL, 2025).

Community kitchens and laundry facilities are particularly effective in promoting social inclusion and collective responsibility. Projects like the Community Kitchen and Oven in Cascais, Portugal, have shown that shared food preparation and dining spaces encourage intergenerational and intercultural exchange, reinforce local food systems, and foster sustainable living practices (Food CLIC, 2025). Similarly, shared laundry rooms create informal meeting points where residents can interact, share experiences, and build trust, as observed in co-living and modular housing developments (Sharing Housing, 2024; Zancanella, 2024).

Shared spaces also contribute to sustainability by optimizing the use of resources and reducing individual energy and water consumption. By centralizing amenities such as kitchens and laundry, housing projects can minimize redundant infrastructure, lower maintenance costs, and reduce their environmental footprint (CIB, 2022; Zancanella, 2024). Moreover, the design and management of these spaces must be inclusive and responsive to the diverse needs of the community, ensuring accessibility and fostering a sense of ownership and responsibility among residents (Sustainability Directory, 2025).

4. Methodology

4.1 Research and Design Approach

This research employs a mixed-methods approach that integrates literature review, case study analysis, and digital design prototyping to investigate incremental modular housing.

Literature Review:

A comprehensive review of existing literature on incremental housing, modular construction, and user participation was conducted. This step identified key theories, challenges, and best practices in the field.

Case Study Analysis:

Several notable incremental and modular housing projects were analyzed to understand their design strategies, user engagement methods, and adaptability features.

Material and System Selection:

Different structural materials and modular systems were evaluated based on sustainability, flexibility, and technical feasibility. Timber-based solutions were prioritized for their environmental benefits and adaptability.

Digital Design and Prototyping:

Digital tools such as Rhino, Grasshopper, and Human UI were used to develop and test modular housing components. These tools enabled the creation of a configurator for exploring customization options within set parameters.

Iterative Design Process:

The research followed an iterative process, where initial designs were refined through repeated prototyping and feedback, focusing on both technical feasibility and user experience.

5. Design Development

5.1 Core Principles and Conceptual Framework

This research developed a modular housing system that prioritizes user participation, adaptability, and community interaction, drawing from incremental housing precedents such as Belapur Housing, Elemental's "Half House," and projects in Pune, India. The design philosophy integrates principles from Sarah Susanka's "The Not So Big House," emphasizing quality over quantity and flexible spaces (Susanka, 1998). The system follows incremental housing principles as a step-by-step development process where choice remains with the owner (CIB, 2022).

5.2 Site Organization and Cluster Configuration

The system uses a six-module cluster configuration consisting of:

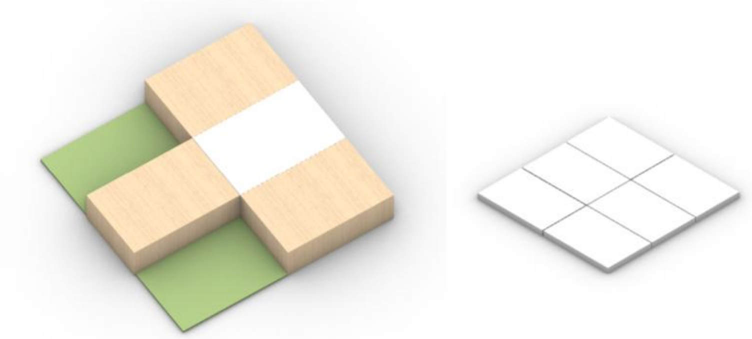

Figure 6: Six-Module Cluster Configuration: Open Spaces, Shared Facilities, and Studio Units (by the author)

Two green modules: Open spaces for outdoor activities
One white central module: Shared facilities (staircases, community kitchen, laundry)
Three wooden modules: Individual studio units

This hub-and-spoke arrangement serves three studios through a central shared module, with two units accessing from the shared space and one from the opposite side. This layout balances community connection with privacy options, following principles that shared spaces reduce the need for large private housing while creating generous communal areas (Virtu Property, 2023).

5.3 Neighbourhood-Scale Development

The six-module clusters can be replicated incrementally to create row housing developments. Clusters arranged linearly form traditional row housing configurations while maintaining social and spatial benefits. This approach follows incremental development principles that emphasize thoughtful growth rather than large-scale developments (CIB, 2022). The modular system enables flexible neighborhood planning, accommodating varying lot sizes and urban contexts from infill projects to suburban developments.

5.4 Individual Unit Design

Each studio maximizes spatial efficiency through three-zone organization following Susanka's principle:

Zone 1: Entrance and Terrace - Transition spaces with outdoor access

Zone 2: Living Area and Kitchen - Central multipurpose space with integrated facilities

Zone 3: Bathroom and Sleep Area - Private areas with flexible sleeping arrangements

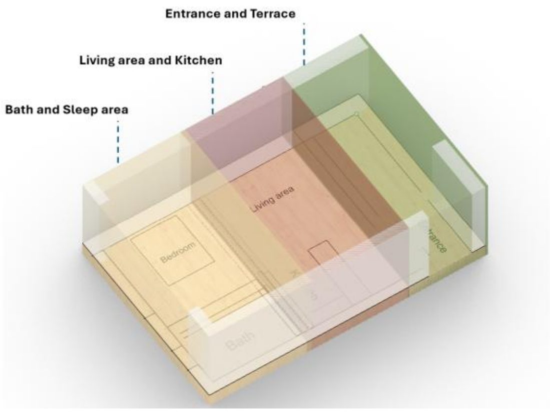

Figure 7 :Spatial Zoning of Individual Unit (by the author)

5.4.1 Flexibility Features

The design incorporates spatial flexibility through Susanka's "borrowed space" and "shifting walls" principles (Susanka, 1998):

-Movable partitions between living and sleeping areas enable reconfiguration

-Bifold doors between interior and terrace allow complete opening

-Pattern elements provide privacy control and architectural character

-Fixed/flexible balance ensures infrastructure stability while enabling customization

The design prioritizes quality through spatial variety, natural light optimization, personalization opportunities, community connection options, and privacy choices, following participatory design principles.

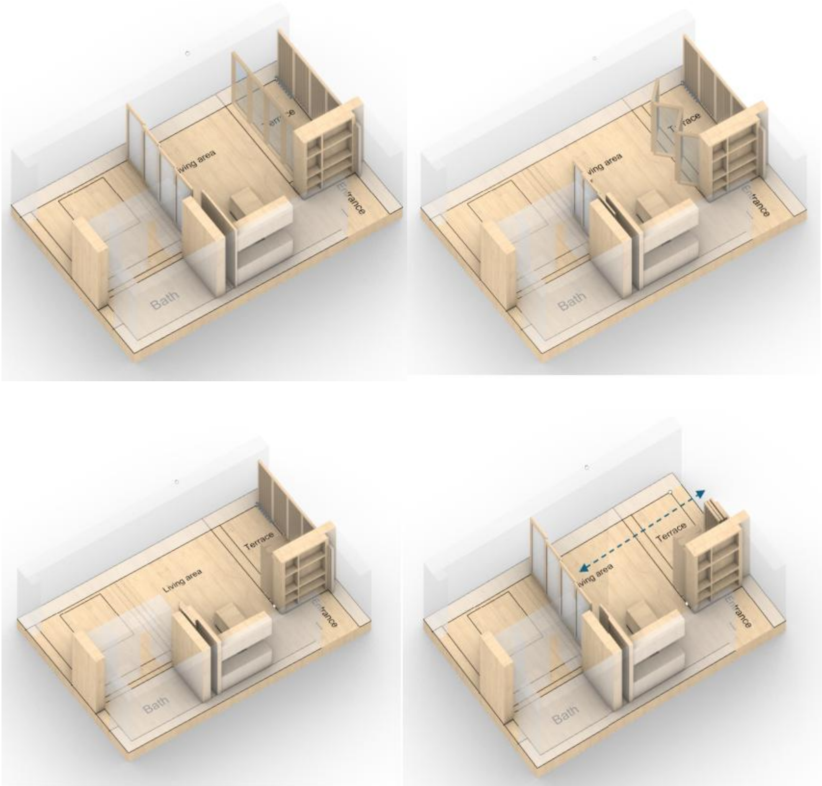

Figure 8 :Axonometric Views of Modular Unit Variations: Spatial Layouts and Privacy Patterns (by the author)

5.5 Community Integration

The central shared module contains vertical circulation, community kitchen, laundry facilities, and flexible gathering spaces. This strategy reduces individual unit requirements while fostering social connections (Virtu Property, 2023). Community kitchens encourage intergenerational exchange and foster sustainable living practices (FoodCLIC, 2025).

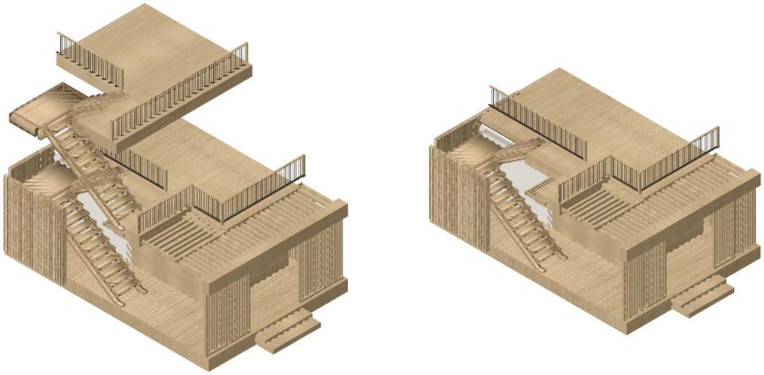

Figure 9 :Modular Shared Units: Roof and Circulation Options (by the author)

5.6 Structural system

5.6.1 Structural system type

The construction system chosen for this project is the Houtkern Bouwmethode (Wood Core Building Method), developed by Noordereng Group in collaboration with DP6 and Oosterhoff (ABT, 2024).

This system was selected because it supports incremental housing principles through its modular flexibility, cost-effectiveness using standard timber materials, and ability to be easily expanded or reconfigured as user needs change.

Figure 10 :Houtkern Modular Timber Structure: Flexibility and Expandability in Construction (photos by Noordereeng Group, 2024

The system consists of modular timber post and beam structures connected by steel corner plates and L/T brackets that bolt directly to the timber frame members. These blocks can be configured in various ways, allowing easy expansion or reconfiguration in width, length, or height.

Module dimensions: Based on Douglas fir span limitations - approximately 3.6m wide by 4.0m long
Materials: Bundled wooden elements made from Douglas fir, larch, or ash timber
Height: Up to three stories through module stacking

-Expandability: The system offers high expansion potential - phasing is integral to the system, and modules can stack to 3 floors. The standardized connections enable various configurations.

- Joints and Recyclability
The steel corner plates are bolted connections that allow for moderate disassembly and relocation. The bolted joints use standard, readily available hardware that can be reused when buildings are dismantled.

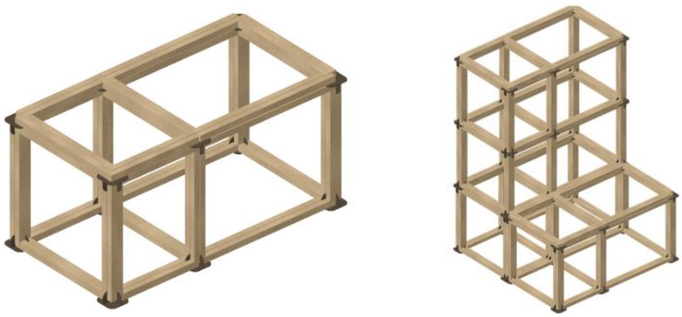

Figure 11 : Modular Frame System: Single- and Multi-Story Configurations for Vertical Expansion (by the author)

Three-Module Housing Configuration

As illustrated in the provided images, each complete house consists of three modular frames that work together to create a functional living unit. The timber post-and-beam structure with steel corner connections enables this modular assembly while maintaining structural integrity throughout the expansion process.

Vertical Capacity and Limitations

The structural system supports vertical expansion up to a maximum of three floors, ensuring structural safety while providing significant growth potential. The standardized frame connections and steel joint system maintain load-bearing capacity throughout the stacking process, allowing residents to double or triple their living space through vertical expansion.

This approach transforms the initial single-story dwelling into a multi-level home that can accommodate changing household sizes and evolving spatial needs, demonstrating how modular construction can support long-term adaptability in incremental housing development.

Vertical Expansion Methodology

The system is designed to support incremental vertical growth through a systematic roof detachment and reassembly process. When homeowners decide to expand their homes vertically, they can:

1- Detach the existing roof structure from the current top level

2- Add new frame components on top of the existing structure

3- Reattach the roof system to the new uppermost level

Figure 12 :Vertical Expansion Sequence: Detachable Roof and Modular Frame Addition (by the author)

This process enables residents to expand their homes as resources become available and family needs change, supporting the incremental housing principles central to this research.

6. Building System Components

6.1 Floor System

6.1.1 Structure

The floor system utilizes cross-laminated timber (CLT) floor panels as the primary structural element, supported on standardized timber columns connected with steel corner plates (MaterialDistrict, 2024). The CLT panels provide the structural deck while enabling modular assembly and disassembly capabilities essential for incremental expansion.

6.1.2 Insulation

Insulation is integrated between floor joists using natural materials such as wood fiber, cellulose, or mineral wool, providing thermal and acoustic comfort. This insulation layer sits below the CLT panel, creating an effective thermal barrier.

6.1.3 Floor Finish

A durable floor finish is placed above the structure, with options including engineered wood flooring, linoleum, or other natural, high-wear materials that maintain the sustainable material palette.

6.2 Wall System

6.2.1 Panel Construction

The wall system employs prefabricated, bio-based wall panels with timber frame construction filled with wood fiber or hemp insulation. All wall panels are designed as non-load-bearing elements to provide maximum flexibility for interior reconfiguration and easy modification as user needs change. The use of durable, economical, and returnable materials with minimal waste is essential for incremental housing construction (Azizibabani & Bemanian, 2019).

6.2.1 Wall Assembly Layers (exterior to interior):

1. Outer Cladding (Larch Tongue and Groove)

Vertical timber slats mechanically fixed (screwed or nailed) to battens .(Exposed to weather and serves as the primary rainscreen)

2. Ventilated Air Cavity (25-38 mm)

Vertical battens and counter-battens create airflow gap,(Allows moisture evaporation and prevents condensation)

3. Breather Membrane

Thin waterproof but vapor-permeable membrane. (Protects insulation and structure from wind-driven rain and Allows moisture to escape outward while preventing water infiltration

4. Main Wall Structure (Timber frame with insulation)

Timber frame typically filled with mineral wool or wood fiber insulation.(Enclosed by structural sheathing (such as plywood))

5. Internal Finish

12.5 mm plasterboard, Wood or similar interior finish material

6.3 Detachable Roof System

6.3.1 Structure

The roof employs prefabricated roof panels with timber ribs, filled with insulation, and sheathed on both sides with OSB or plywood. This construction enables the critical detachment and reattachment capability necessary for vertical expansion. Advanced automated manufacturing technologies for timber-based panelised systems have been developed to create robust and innovative prefabricated solutions (University of Melbourne, 2021).

6.3.2 Roof Assembly Layers (exterior to interior):

1. Exterior Finish

Vertical tongue and groove cladding providing weatherproof exterior finish

2. Ventilated Cavity

25 x 38 mm battens and counter-battens forming 50 mm ventilated cavity

3. Weather Protection

Breather membrane allowing vapor escape while blocking water infiltration

18 mm marine grade plywood providing structural sheathing

4. Structural Insulation

140 mm timber structure with full-fill mineral wool insulation

150 mm internal mineral wool insulation between battens

5. Interior Finish

Vapor Control Layer (VCL) managing interior moisture

Plasterboard with plaster skim and paint finish

Figure 13 : Section of Timber Roof and wall Assembly: Layered Construction from Exterior to Interior (by the author)

6.3.3 Water Management

All roof panels incorporate overlapping waterproof membranes at joints, sealed with compatible tapes. Metal flashing and drip edges are integrated at all roof-to-wall and roof-to-roof connections. Novel prefabricated water and weatherproofing methods have been developed that act between panels, significantly reducing installation time while not requiring access from the outer face (University of Melbourne, 2021). Roof panels include integrated gutters or scuppers to efficiently direct water away from the structure.

6.3.4 Connections and Detachment System

The roof system uses removable bolts or proprietary modular connectors at all roof-to-wall and roof-to-roof joints, enabling easy detachment and reinstallation during vertical expansion. Lifting points are integrated into roof panels for safe handling during removal and reinstallation processes. Contemporary strategies for multi-story modular timber buildings emphasize the importance of efficient inter-module joining techniques that support both assembly and disassembly operations (Tenório & Ferreira, 2024).

This detachable roof system allows residents to expand vertically by temporarily removing the roof, adding new structural modules, and reinstalling the roof system while maintaining full weather protection and structural integrity.

7. Representative Floor Plans and Renders

This section presents representative floor plans and renders that illustrate the spatial organization, layout, and design intent of the project. The floor plan shown provides a detailed overview of the functional zones, circulation paths, and connections between interior and exterior spaces. These visual materials serve as key references for understanding the architectural concept and guiding further development of the design

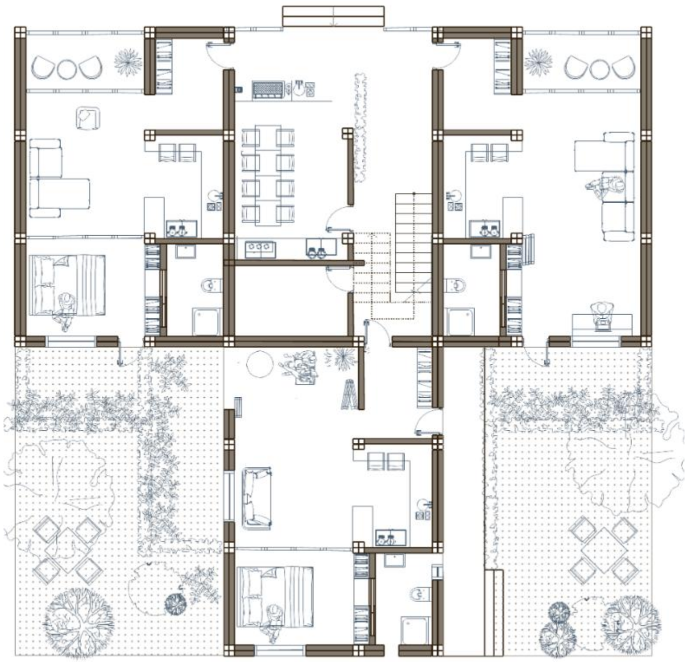

Figure 14. Three distinct residential layouts, each connected to a central shared space, illustrating the integration of private and communal zones within the compound (by the author).

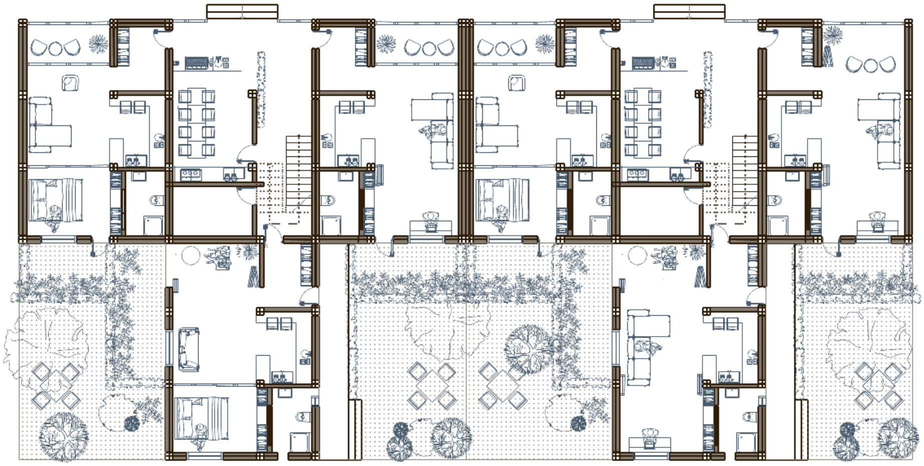

Figure 15. Aggregated floor plan showing the spatial relationship and direct connections between the three unique units and the middle-shared area (by the author).

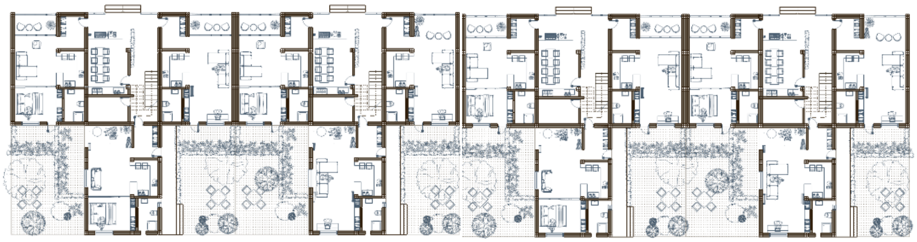

Figure 16. Linear arrangement of the three layouts, emphasizing the continuity of the central communal space across the compound (by the author).

Figure 17. Axonometric render of the compound, highlighting the interplay between individual units and the central shared courtyard (by the author).

Figure 18. Top-down render of the assembled micro-neighborhood, showcasing the overall organization and the integration of private and communal outdoor environments (by the author).

8. Digital Configurator Design

8.1 Configurator Overview and Purpose

The Incremental House Configurator was developed as a digital tool to enable user participation in the design and customization of modular housing units. The configurator supports the research goal of empowering residents to understand, visualize, and personalize their living environments while maintaining structural integrity and design coherence. The tool demonstrates how digital interfaces can make complex modular systems accessible to non-expert users, facilitating informed decision-making in incremental housing development.

8.1.1 Technical Development and Tools

The configurator was built using Grasshopper for Rhino as the primary computational design platform, with Human UI providing the user interface framework. Python scripting was integrated to control complex component behaviors, manage data flow between interface elements, and implement the intelligent constraints that ensure structural safety. This technical stack enables real-time parametric modeling while maintaining an intuitive user experience for non-expert users.

8.2 User Journey and Interface Flow

8.2.1 Step 1: System Introduction

When users first open the configurator, they encounter introductory pages that explain the incremental housing concept and the modular system principles. These opening screens provide essential context about how the housing system works, what incremental development means, and how users can participate in shaping their homes over time. This educational foundation helps users understand the possibilities and constraints before they begin making design decisions.

8.2.2 Step 2: Ground Floor Configuration

On the ground floor, the user selects between three different house units, each positioned on one side of a shared core space. The configurator activates options based on which unit is chosen. Depending on the selected house, specific layouts and features become available for customization.

The user can interactively control the partitions, experimenting with opening and closing rooms to create a single large space or multiple smaller areas. The configurator also allows users to open and close windows, adjust partition positions, and select from a range of shader patterns for the partitions. This playful interface enables users to visualize how they might live in the house, exploring different spatial arrangements and lighting effects in real time.

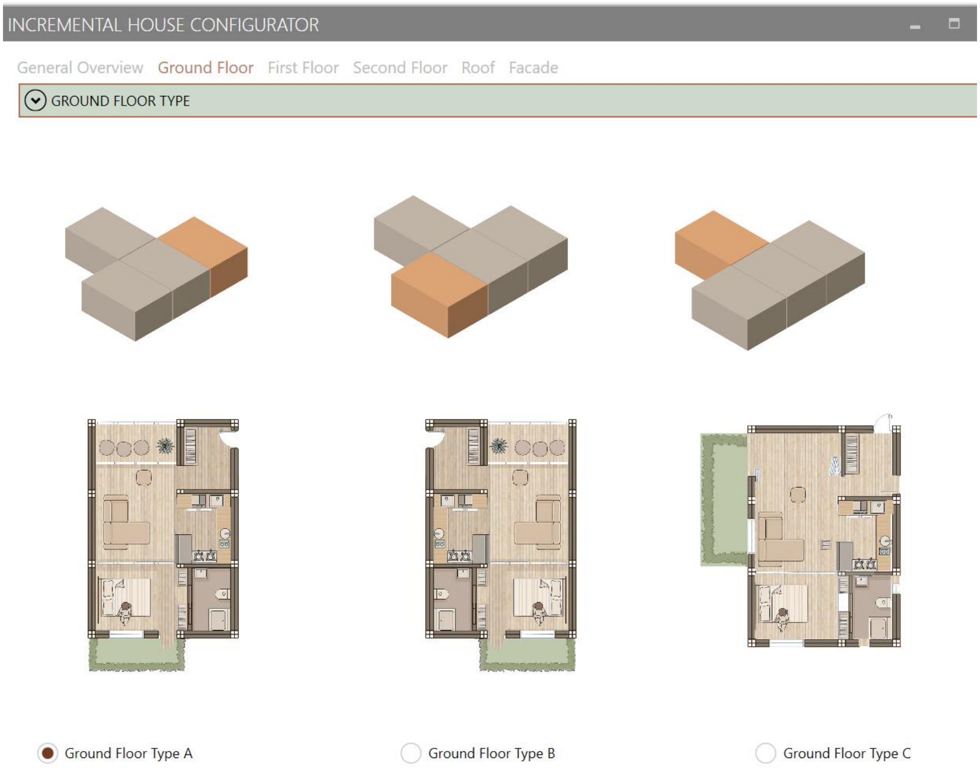

Figure 19. Ground floor layout selection interface in the Incremental House Configurator (by the author).

8.2.3 Step 3: Upper Floor (First and Second Floor) Configuration

On the first and second floors, the configurator is structured differently. Here, users customize the layout by selecting options for the back part, middle part, and front part of each unit. The available options are as follows:

These options are not all available for every part at every level; the configurator enforces constraints to ensure only feasible combinations are selected. Users can see real-time changes as they make selections, helping them understand how each choice affects the overall layout and spatial quality.

Back Part Options:

None, One Space + Entrance door, One Space, Green House, Green House + Room, Corridor + Room, Room + Bath, Dining + Kitchen, Terrace, Room + Terrace,

Middle Part Options:

None, One Space + Entrance door, Green House, Green House + Room, Terrace,

Front Part Options:

None, One Space, One Space, Green House, Green House + Room, Corridor + Room, Dining + Kitchen, Terrace, Room + Terrace,

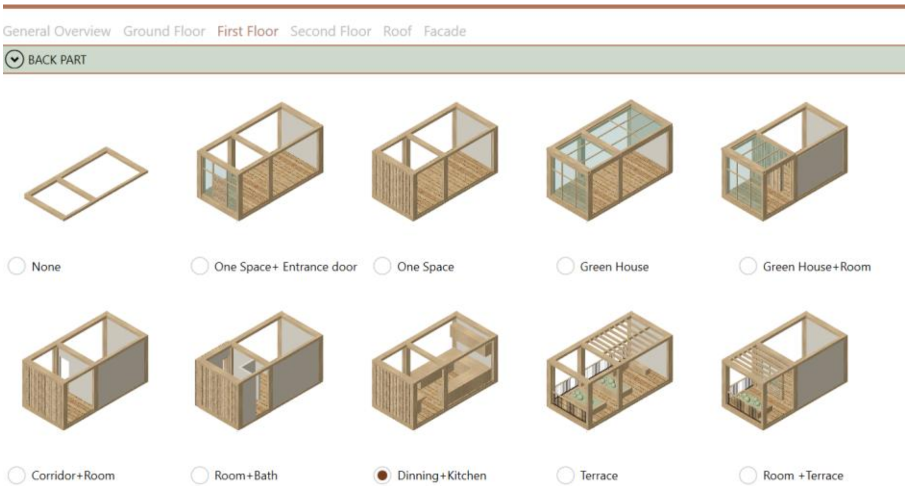

Figure 20. Ground floor unit layout options displayed in the configurator interface (by the author).

8.2.4 Step 4: Vertical Expansion Options

Users then move to roof configurations. users can visualize removing the roof, adding a second level, and reinstalling the roof structure. Scripts implement constraints that prevent unsafe configurations, such as restricting certain roof types over open spaces, while maintaining design flexibility. Then in next step user decides between different options of Roofs.

8.2.5 Step 5: Facade Customization

The final step involves facade selection and customization. Users can choose from various exterior treatments and patterns through the Human UI controls, with Python and grasshopper managing the facade component libraries and ensuring proper attachment to the underlying structure. The configurator shows how different facade options affect both the building's appearance and its relationship to outdoor spaces.

Figure 21. Facade customization options displayed in the configurator, showing various exterior treatments and window patterns (by the author).

8.3 Real-Time Visualization and Feedback

The configurator provides instant visual updates as users modify their selections through the Human UI interface. When someone adjusts sliding doors, changes shading patterns, or selects different spatial arrangements, grasshopper and Python algorithms recalculate the geometry and immediately display results in 3D view with material. This real-time feedback helps users understand spatial relationships and make informed decisions about their living environment.

Figure 22. Real-time 3D visualization of user-selected spatial configurations in the Incremental House Configurator (by the author).

9. Discussion

This research set out to explore how incremental, modular housing can be made more accessible and adaptable through a user-driven digital configurator and a practical timber structural system. The project combined precedent research, design development, digital prototyping, and the creation of a physical scale model.

9.1 Key Findings and Interpretation

The modular system, utilizing standard timber and steel connectors, proved workable for the intended scale and flexibility. The decision to avoid engineered wood (like glulam) was driven by cost and local material availability, in line with the goal of making incremental housing more broadly applicable. This choice, however, limited the maximum span and some spatial possibilities—a trade-off that future projects may address differently depending on priorities and resources.

The digital configurator, developed in Grasshopper with Human UI and Python, enabled users to explore modular expansion and customization in a clear, step-by-step workflow. Real-time visualization of design choices, and the ability to experiment with layouts, partitions, window patterns, and facades, were well received. Even though the configurator required Rhino and Grasshopper, users familiar with these tools found the process intuitive and the visual feedback helpful.

9.2 Limitations

Several limitations were identified. The configurator's dependence on Rhino and Grasshopper restricts accessibility for a broader audience. Human UI's visualization capabilities are limited, especially regarding realistic material rendering and interior perspectives. Time constraints meant that some features were simplified or only worked in specific scenarios, indicating a need for further refinement. Cost estimation was not included, as reliable, region-specific data was difficult to collect within the project timeframe. The physical model, while valuable for spatial understanding, was not built at full scale, so structural and assembly details remain theoretical. Regulatory issues and real-world construction were beyond the scope of this study.

9.3 Implications

This study demonstrates that a user-centered, incremental approach to modular housing is feasible and that digital tools can empower users to make meaningful design decisions. The importance of balancing design freedom with technical constraints, and providing clear visual feedback, was underscored throughout the process.

9.4 Future Developments

- Building on these findings, several avenues for future work are recommended:

- Web-Based and AI-Enhanced Tools: Transitioning the configurator to a web-based platform, potentially using Rhino Compute, would make it more accessible. Integrating AI-driven prompts could allow users to describe their needs in natural language and receive customized design suggestions.

- Enhanced Visualization: Adding real-time interior views and perspective navigation would help users better understand spatial qualities and the living experience. Virtual viewpoints inside the building could further improve engagement.

- Greater Flexibility and Robustness: Expanding the configurator's logic to handle a wider range of scenarios and removing current limitations would enhance its practical value.

- Integrated Cost Estimation: Incorporating cost estimation features, based on reliable and region-specific data, would make the tool more practical for real-world decision-making.

- Physical Prototyping and Regulatory Integration: Future research should include full-scale prototyping and address regulatory requirements to validate the system's constructability and compliance.

10. Conclusion

This thesis demonstrates the potential of combining modular timber systems with digital configurators to support incremental, user-driven housing. By addressing the research questions, it shows that such systems can empower residents to meaningfully participate in the design and adaptation of their homes, while maintaining structural integrity and design coherence. Despite technical limitations, the approach offers a promising path toward more affordable, adaptable, and sustainable housing. Future developments should focus on improving accessibility, visualization, and regulatory integration, paving the way for broader adoption. Ultimately, this research contributes to the ongoing discourse on participatory housing and highlights the role of digital tools in shaping the future of urban living.

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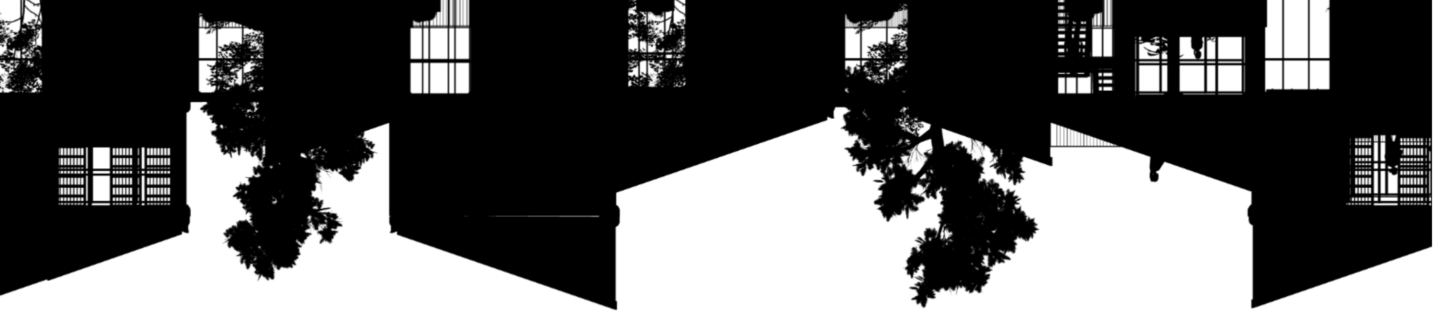
12. Table of Figures



Modular

Incremental Housing :

Design and Construction with a Focus on Timber Construction and Digital Customization

(Documentation and User Manual)

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Keywords |

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This document provides a comprehensive overview of the Incremental Modular House project, guiding readers through each phase from initial design to final architectural documentation. It is organized into five main sections: design process, digital configurator backend, , digital configurator user manual, construction guide, and architectural design documentation.

Table of Contents

1. Design Process Documentation

Introduction

The initial phase of this research was shaped by a broad investigation into strategies for affordable housing. Various approaches—including modular systems, prefabrication, and incremental housing—were identified as potential solutions to the challenges of cost and adaptability. As the study progressed, incremental housing systems became the primary focus, with attention given to their capacity for phased growth and user-driven adaptation.

Throughout the research process, numerous case studies and precedents were examined to understand how modularity, sustainability, and digital methods have been integrated in contemporary housing projects. Insights from these examples informed the subsequent development of the project, with sustainability and digital customization established as key priorities.

A range of alternatives and conceptual frameworks was explored, and comparative analyses were conducted to evaluate their suitability for the project's objectives. The documentation that follows presents the research, case studies, digital tools, and alternative scenarios that informed the design process, including material that was not included in the main thesis for the sake of clarity and conciseness.

1.1 Comparative Analysis of Expandable Timber Structural Systems

1.1.1 Pillar Connection System

The Pillar Connection System is a column-to-floor connection method designed for multi-storey mass timber construction (Arch-Products, 2024). It uses engineered steel bases anchored to the foundation, with timber columns bolted on and CLT or laminated veneer lumber (LVL) panels resting between columns (Rothoblaas, 2024). The system can transfer very high vertical loads and supporting large spans between columns.

Positive aspects for the project:

- The system allows for the construction of multi-storey timber buildings with significant load-bearing capacity.
- Engineered steel bases and connectors provide structural robustness and reliability.
- The method supports vertical expansion by stacking joints (Arch-Products, 2024).

Limitations:

- Assembly and disassembly require professional handling and are not intended for frequent modification.

- The high level of engineering increases costs and complexity.
- The technical, industrial aesthetic created by prominent steel bases and connectors may not align with all project requirements.

Figure 1 :Mass Timber Column-to-Floor and Column-to-Foundation Connection (: Simpson Strong-Tie, MCB™ Mass Timber Column Base)

1.1.2 Urban Beta Modular Timber System

The Urban Beta Modular Timber System uses a grid of timber columns and beams joined by steel connectors, with expansion possible both horizontally and vertically The system is designed for disassembly and recycling, with all components intended to be reused at the end of their lifecycle (ArchDaily, 2023).

Positive aspects for the project:

- Modular grid logic enables flexibility in both plan and section.
- All parts are engineered for reversibility, supporting circularity.

Limitations:

- The system relies on a high degree of engineering, with visible steel connectors that define the aesthetic and may not be suitable for all contexts.
- The complexity of digital integration and engineered parts can increase costs and require specialized knowledge for assembly and planning.
- The visual impact of the blue steel connectors is significant and may dominate the interior and exterior character .

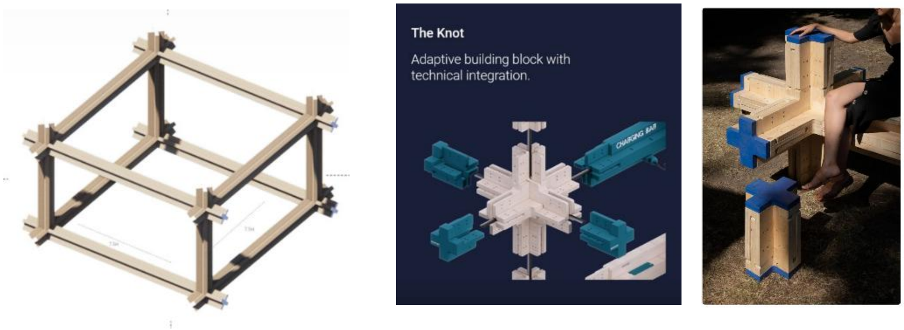


Figure 2 : Modular Steel Connector System for Timber Structures (images from The Knot by Blue Engineering, bluetrailengineering.com, and designboom.com)

1.1.3 Houtkern Bouwmethode

The Houtkern Bouwmethode (Wood Core Building Method) is a modular system based on standardized timber columns and cross-laminated timber (CLT) floor panels, connected by recycled steel nodes (ABT, 2024). Modules can be assembled, disassembled, and reconfigured, which allows for adaptation to changing spatial needs. Partition walls are non-load-bearing, so layouts can be changed without affecting the structure. This system was implemented in The Natural Pavilion at Floriade Expo 2022 (ABT, 2024)

Positive aspects for the project:

- Modular construction and non-load-bearing partitions allow for incremental expansion and reconfiguration.
- Factory-controlled digital production supports precision and efficient assembly.
- Components are designed for reuse, supporting circular construction and reducing waste (ABT, 2024).

Limitations:

- The system is limited to a certain number of stories due to timber span and connection constraints.
- The use of steel nodes introduces a level of engineering that may increase costs compared to purely timber solutions.

Figure 3 :Houtkern Modular System: Timber Columns & Steel Nodes (ABT, 2024, Floriade Expo 2022)

Table 1 :Comparative Structural Systems Table: Timber and Modular Frame Methods (table by the author)

Comparative Structural SystemsTable			
Criteria	Width in points (300ppi)	Urban Beta Modular Timber System	Houtkern Bouwmethode
Structure	Timber columns + CLT/LVL panels, engineered steel bases	Modular timber grid, steel connectors	Modular timber frames, CLT floors, steel nodes
Expandability	High; stacking joints for multi-storey	Very high; flexible grid, up to 3 stories	High; horizontal & vertical, up to 3 stories
Assembly/Disassembly	Moderate; engineered steel parts, not for frequent disassembly	Rapid, fully reversible, all parts reusable	Fast, easy, by bolted steel joints
Vertical Capacity	Multi-storey, very high load transfer	Up to 3 stories	Up to 3 stories
Digital Integration	Strong; compatible with BIM/CAD	Strong	Factory digital control, compatible with BIM
Circularity	High; steel/timber reusable, less optimized for change	High; full disassembly & recycling	High; all parts reusable, low emissions
Material Source	Timber, glulam, LVL, steel, concrete	Regional timber, steel nodes	Standard timber, CLT, recycled steel joints

Cost	High; engineered steel, precise parts	Moderate–high; digital/engineered parts	Moderate; standard timber, some engineered
Engineering Level	Very high; precise steel, technical	High; visible connectors, engineered	Balanced; modular, not excessive
Aesthetic Impact	Technical/industrial, visible steel	Blue steel nodes visually dominant	Natural wood, integrated joints

After analyzing the structural, technical, and aesthetic characteristics of the three options, the Houtkern Bouwmethode was selected due to its balance between modular flexibility, ease of assembly and disassembly, and the ability to support incremental, user-driven housing expansion without introducing excessive technical complexity or visually dominant engineered elements.

1.2 Design Development Process

In the development phase of the project, several alternative design options were explored and systematically compared to identify the most suitable configuration for the intended goals and context. Each option was assessed using a range of criteria, including land efficiency, flexibility, construction cost, expandability, sense of home, social interaction potential, urban suitability, construction complexity, shared resource use, contextual flexibility, and aesthetic variety. Comparative analysis allowed for a balanced evaluation of both quantitative and qualitative aspects, highlighting the strengths and limitations of each approach in relation to project objectives.

Through this process, the comparative table provided a clear overview of how each design option performed across the selected criteria, making it possible to objectively weigh the trade-offs and prioritize features most aligned with the project's vision. The final decision was based on achieving an optimal balance between adaptability, community potential, construction feasibility, and long-term sustainability. This structured approach ensured that the chosen design option was not only technically and economically viable but also responsive to user needs and contextual demands.

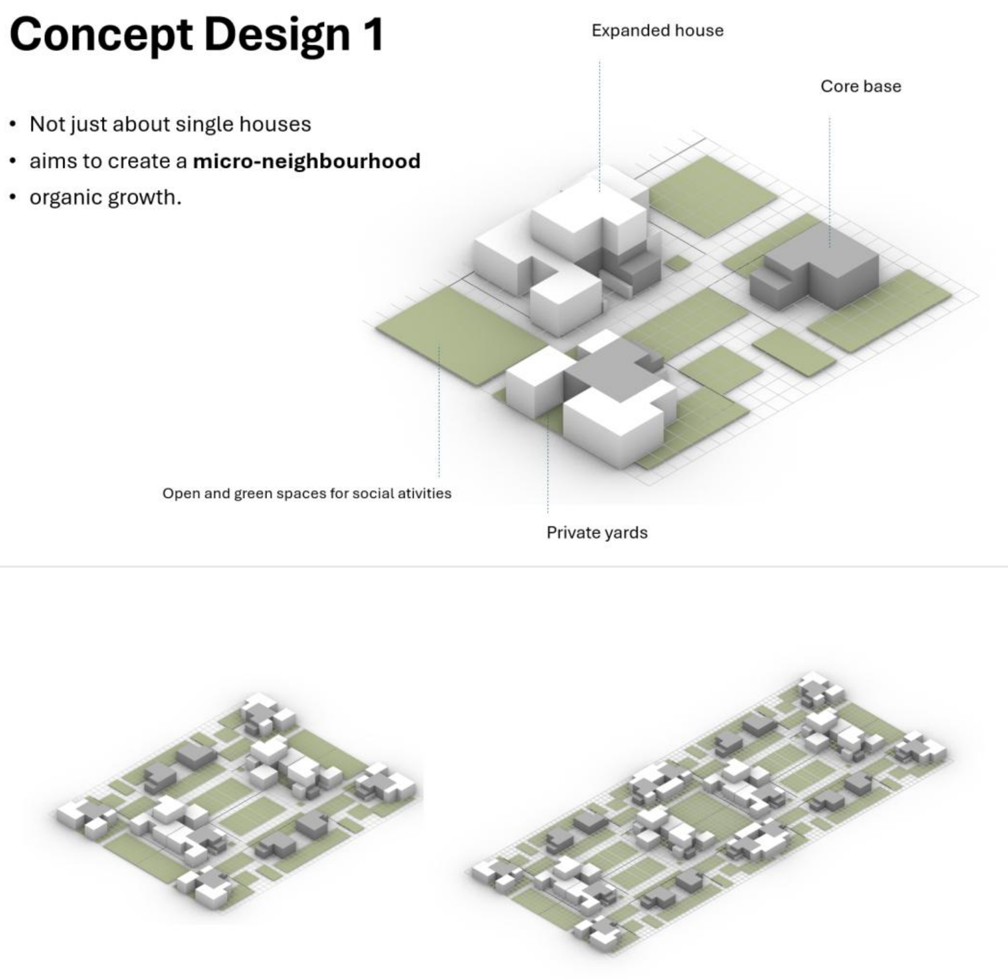
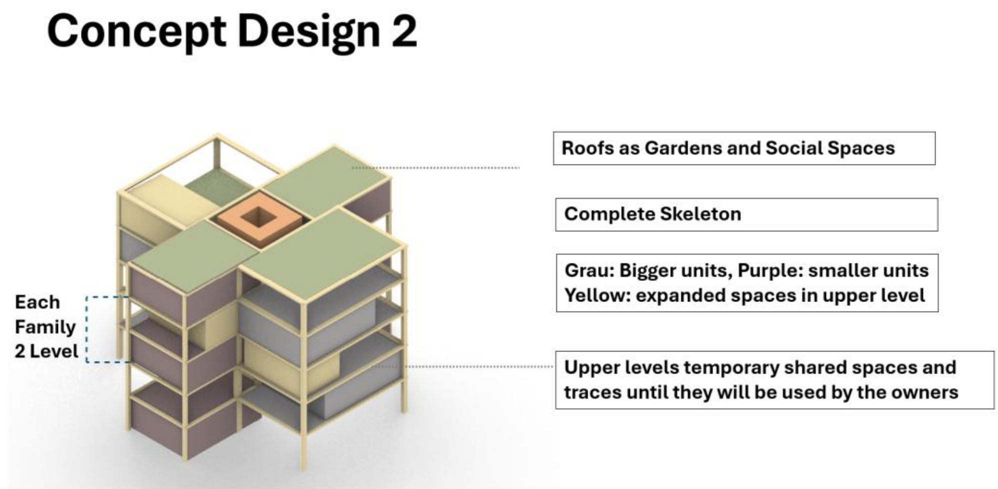


Figure 4 :Concept Design 1: Micro-Neighbourhood with Expandable Houses and Shared Green Spaces (by the author)



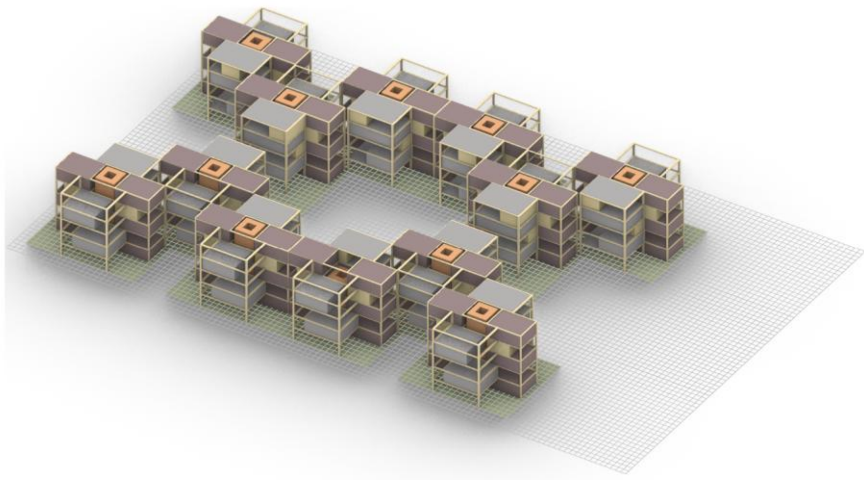


Figure 5 :Concept Design 2: Modular Multi-Story Units with Shared Roof Gardens (by the author)

Concept Design 3

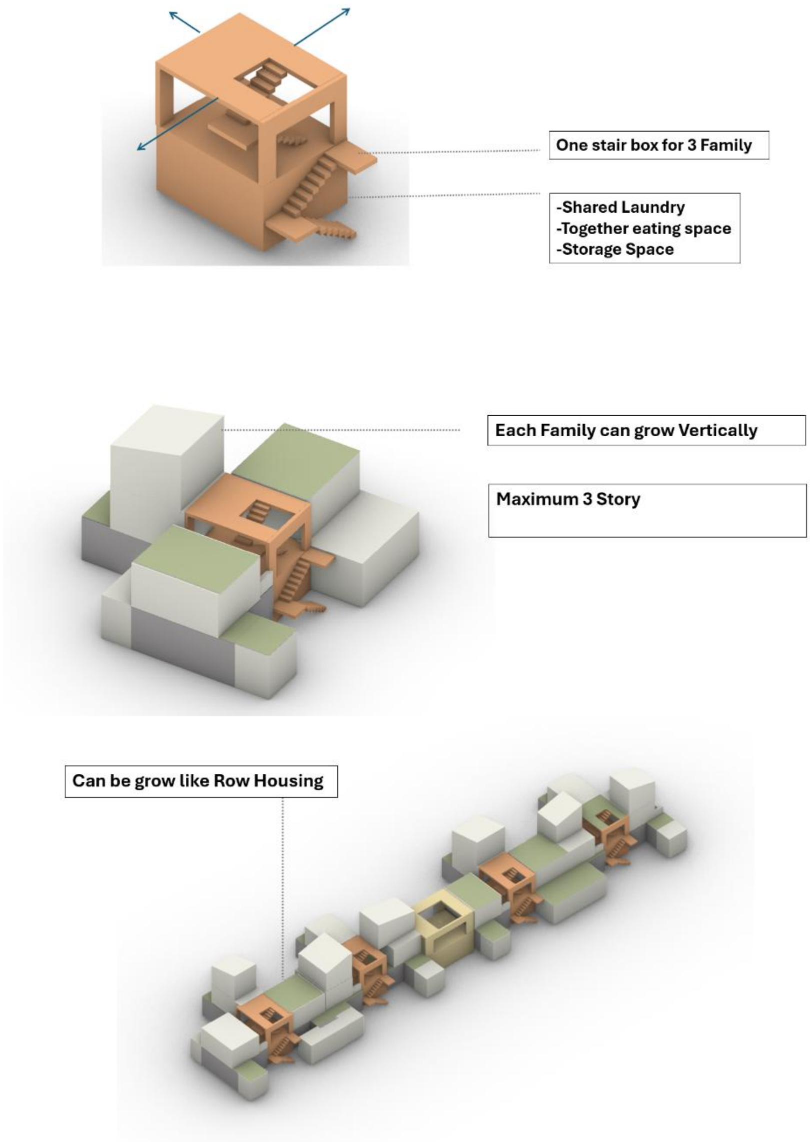
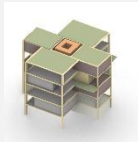


Figure 6 :Concept Design 3: Shared Stair Core and Expandable Row Housing (diagrams by the author)

Table 2 :Design Options Comparison Table (by the author)

Comparative Design Options



Criteria	Option 1 Horizontal Cluster	Score	Option 2 Vertical Structure	Score	Option 3 Shared Stair Cluster (Preferred)	Score
Land Efficiency	Uses more land per family	2	High density — 4 units per floor connected to central stair core	5	3 families share one footprint	4
Flexibility / Adaptability	Limited structure but high potential	4	Fixed structure, low adaptability	3	Highly adaptable — vertical & phased	5
Construction Cost Efficiency	Simple but more land = higher site cost	3	Prebuilt structure saves cost overall	5	Shared core reduces cost, phased material use	4
Level of Expandabilit y	Allows max 2 floors per unit, but requires land	5	Each user has one pre-built floor and one customizable expansion layer above — offering limited but meaningful flexibility.	3	Strong vertical phasing, less horizontal expansion, with compact footprint	5
Sense of Home / Identity	Strong — individual house feel	5	Moderate — more like compact apartments	3	Strong — semi-private stairs, unit individuality	5
Social Interaction Potential	Depends on landscape & cluster form	3	On roof , ground level spaces or common corridor	4	Designed with shared stair & cores for community	5
Urban Suitability	Not ideal in high-cost urban zones	2	Well-suited to dense urban infill	4	Perfect for mid-density urban edges	5
Construction Complexity	Simple to build, harder to phase	3	Complex structure, but efficient	5	Moderate complexity, supports step-by-step growth	4
Shared Resource Use	Informal use of yards/shared paths	3	Temporarily shared rooftops and open upper platforms can	4	Efficient use: kitchen, laundry, stair in one core	5

			function as communal spaces until they are developed			
Contextual Flexibility	Mostly rural/suburban applications	2	Mostly fits rigid, urban apartment-style settings	3	Works in both row and village layouts	4
Aesthetic Variety & Form Expression	High — organic layouts, open-ended forms, village-like charm	5	Moderate — some variation in upper-level layouts, but base form is repetitive	3	Very High — mix of vertical growth, staggered units, user-driven form, balanced with system logic	5
		37		**42**		**51**

The selected option, Option 3, not only offers practical construction benefits but also puts people at the center of the design. By allowing the living environment to adapt and grow with its residents, this approach recognizes that homes and communities are always evolving. It supports flexible, incremental changes over time, making it possible for individuals and families to shape their spaces according to their real needs. At the same time, it maintains a strong commitment to sustainability and thoughtful design, ensuring that both the technical and human aspects work together to create a livable and resilient environment.

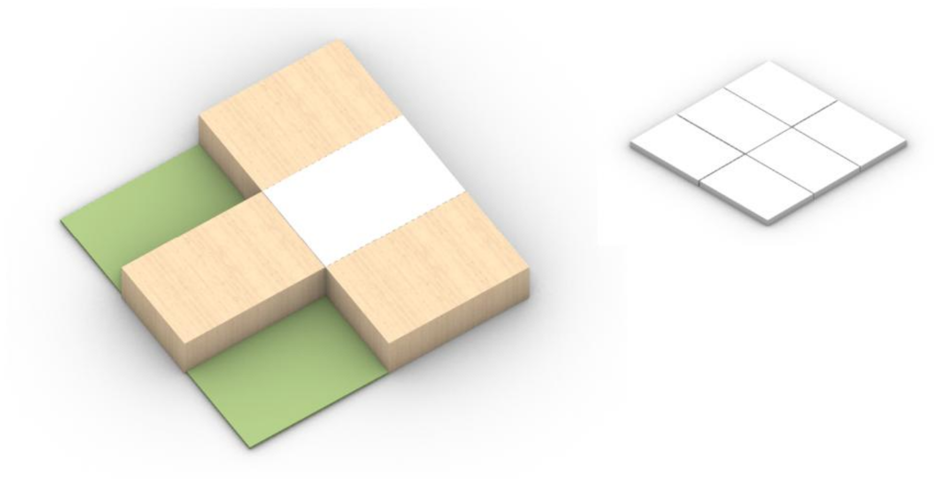


Figure 7 :Six-Module Cluster Configuration: Open Spaces, Shared Facilities, and Studio Units (by the author)

One white central module: Shared facilities (staircases, community kitchen, laundry)
Three wooden modules: Individual studio units

This hub-and-spoke arrangement serves three studios through a centrally shared module, with two units accessing from the shared space and one from the opposite side.

The six-module clusters can be replicated incrementally to create row housing developments. Clusters arranged linearly form traditional row housing configurations while maintaining social and spatial benefits. This approach follows incremental development principles that emphasize thoughtful growth rather than large-scale developments (CIB, 2022). The modular system enables flexible neighborhood planning, accommodating varying lot sizes and urban contexts from infill projects to suburban developments.

Digital Configurator Design

Individual Unit Design

Each studio maximizes spatial efficiency through three-zone organization following Susanka's principle:

Zone 1: Entrance and Terrace - Transition spaces with outdoor access

Zone 2: Living Area and Kitchen - Central multipurpose space with integrated facilities

Zone 3: Bathroom and Sleep Area - Private areas with flexible sleeping arrangements

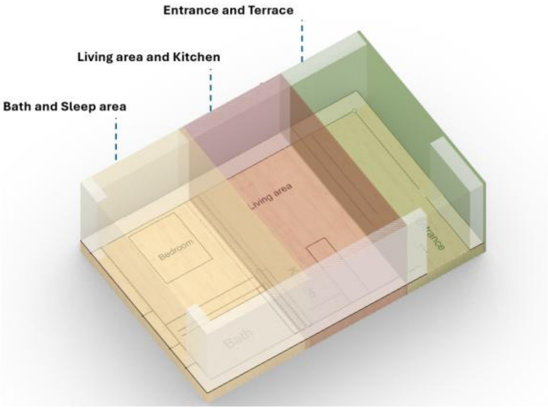


Figure 8 : Spatial Zoning of Individual Unit (by the author)

The design incorporates spatial flexibility through Susanka's "borrowed space" and "shifting walls" principles (Susanka, 1998):

-Movable partitions between living and sleeping areas enable reconfiguration

-Bifold doors between interior and terrace allow complete opening

-Pattern elements provide privacy control and architectural character

-Fixed/flexible balance ensures infrastructure stability while enabling customization

The design prioritizes quality through spatial variety, natural light optimization, personalization opportunities, community connection options, and privacy choices, following participatory design principles.

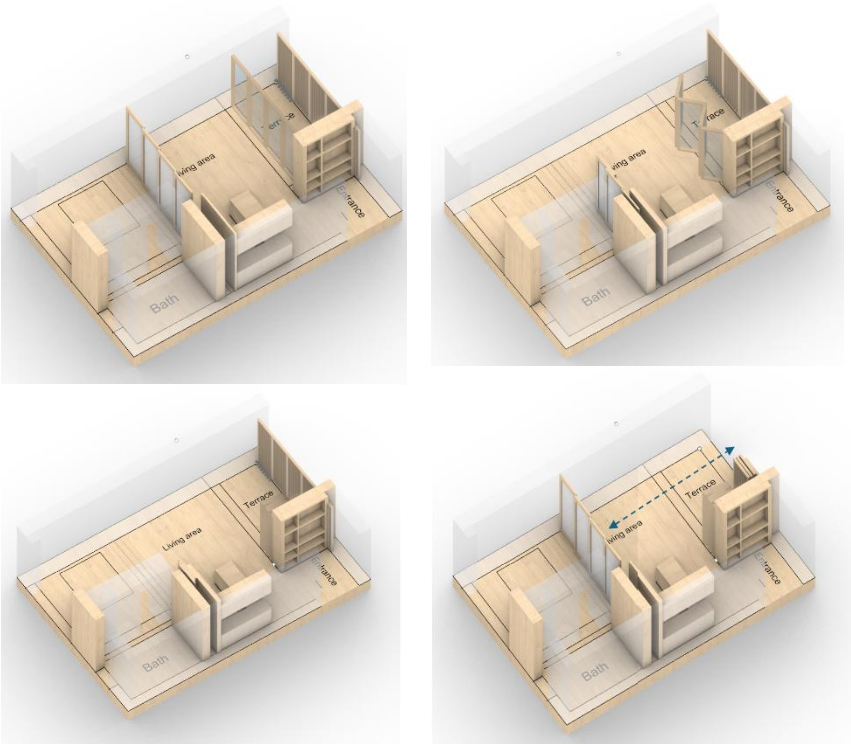


Figure 9 :Axonometric Views of Modular Unit Variations: Spatial Layouts and Privacy Patterns (by the author)

1.3 Community Integration

The central shared module contains vertical circulation, community kitchen, laundry facilities, and flexible gathering spaces. This strategy reduces individual unit requirements while fostering social connections (Virtu Property, 2023). Community kitchens encourage intergenerational exchange and foster sustainable living practices (FoodCLIC, 2025).

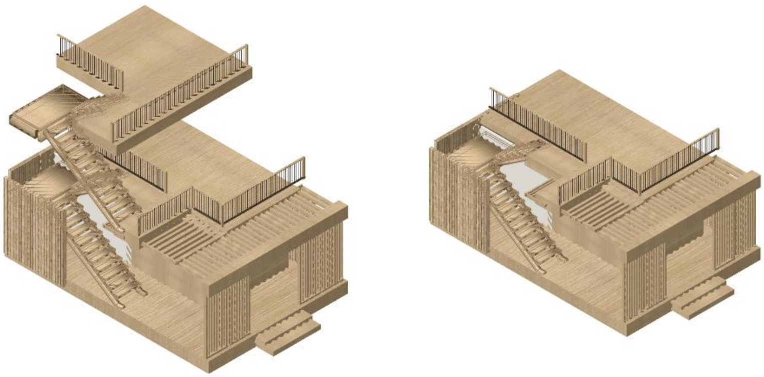


Figure 10 : Modular Shared Units (by the author)

2. Digital Configurator Backend

The digital configurator developed for this project is a user-centered tool designed to enable residents to actively participate in the design, customization, and incremental expansion of modular housing units. Built using Grasshopper, Human UI, and Python scripting within the Rhino environment, the configurator provides an interactive platform where users can visualize, modify, and personalize their living spaces in real time, all while ensuring structural feasibility and design coherence.

Technical Architecture

- Grasshopper: Handles parametric modeling, defining the spatial logic and modular relationships of the housing units.

- Human UI: Provides the graphical user interface, enabling users to interact with design options through buttons, sliders, and visual previews.

- Python Scripting: Manages dynamic behaviors, enforces design constraints, and synchronizes data flow between the interface and the parametric model.

- Rhino: Used for 3D visualization and material rendering, especially where Human UI's capabilities are limited

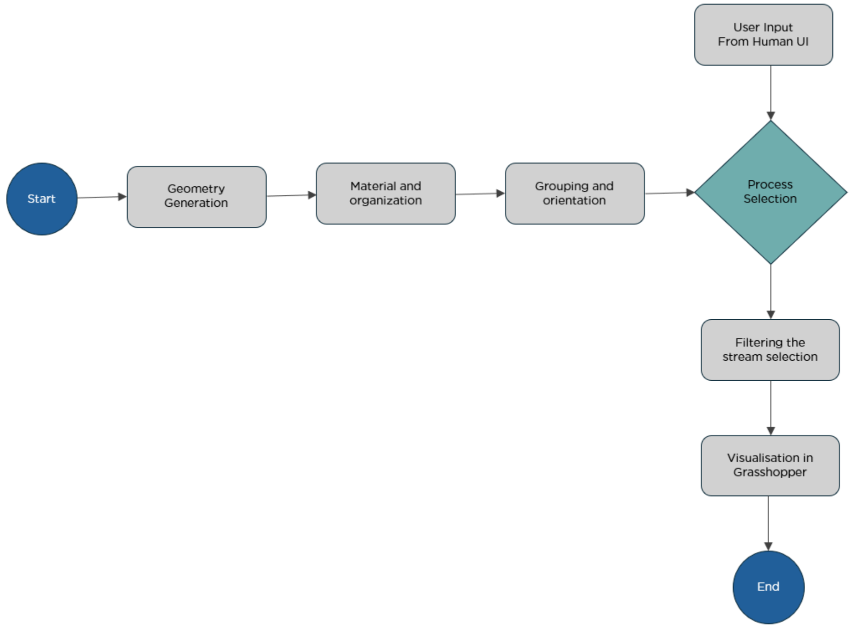


Figure 11 : Digital Configurator Workflow: User Input to Visualization (by the author)

2.1 Base Geometry Generation and Material Organization

The backend process begins with the generation of base building components as B-Rep geometries. Each category—joints, frames, floor, floor cover, interior wall and roof, and exterior—is created separately and organized according to its material type. These components are then merged into a unified data structure, making it possible to maintain material distinctions throughout the workflow. This organization is essential for later filtering and visualization steps, especially since the Human UI interface does not inherently recognize material properties.

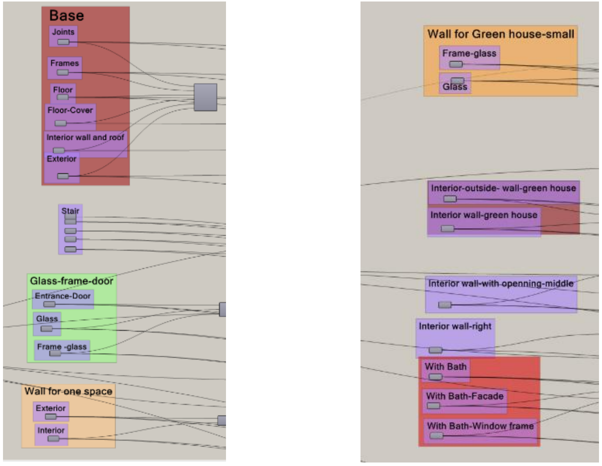


Figure 12 :Base Geometry and Material Organization Workflow (by the author)

2.2 Grouping, Orientation, and Data Management

After the initial generation, the geometries are bundled using the Entwine component, which groups the data streams for geometry, material, and orientation. The grouped elements are then oriented to their correct positions within the overall design using the Orient component. The Explode Tree component is used to separate the grouped data back into individual streams when needed, ensuring that each component retains its associated material and positional information. This step allows for precise control over how each part is displayed and manipulated in the configurator.

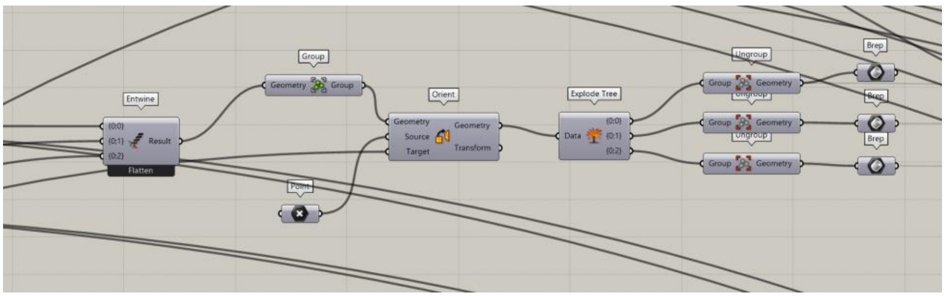


Figure 13 :Grouping and Data Management Workflow in Grasshopper (by the author)

2.3 Option Mapping and User Selection Logic

A dropdown menu labeled "First Floor Space options" presents various spatial configurations, each mapped to a specific index value. The Value List Constants panel defines these mappings, assigning a numerical index to each option (e.g., None = 0, One

Space + Entrance door = 1, Green House = 3, etc.). This system enables the backend to process user selections programmatically, ensuring that the configurator responds accurately to changes made in the Human UI interface.

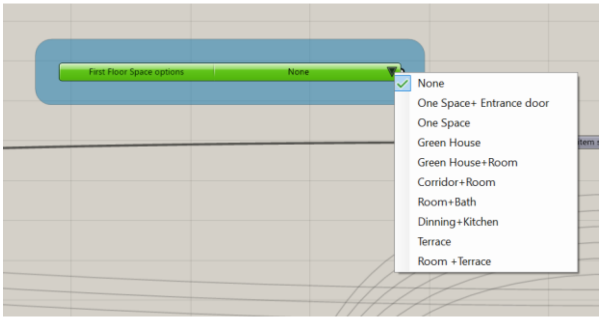


Figure 14 :Dropdown Menu for Floor Space Options in Configurator (by the author)

2.4 Filtering and Stream Selection

User selections are processed through a filtering mechanism that utilizes Entwine to organize selection data and a Stream Filter component to direct the appropriate geometry and material information to the correct output. The Stream Filter uses gate controls corresponding to each index value, ensuring that only the relevant components and materials are displayed based on the user's choice. This approach effectively addresses the limitation of Human UI regarding material recognition, as all possible combinations are pre-processed and filtered in real time according to user input. The active data path for the current selection is visually indicated, allowing for clear and responsive updates in the interface.

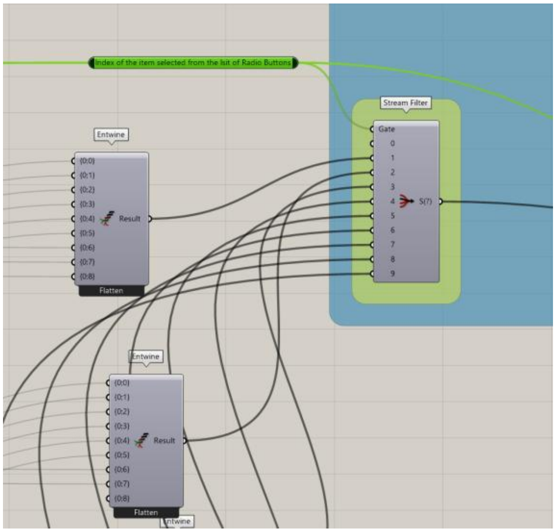


Figure 15 :Filtering and Stream Selection Workflow in Grasshopper (by the author)

2.5 Visualizing filtered geometry and material assignment in Grasshopper

After the Stream Filter component processes the user's selection, the filtered geometry and associated material data are routed through a series of data management and visualization steps. The Explode Tree components separate the grouped data into individual branches, ensuring each geometry retains its correct material and texture information. These branches are then merged and connected to Custom Preview components, which are responsible for displaying the geometry with the appropriate material properties in the Grasshopper preview.

In this workflow, since Human UI does not natively recognize or display Rhino materials, the backend handles all material assignments and passes the correct material and texture information to the Custom Preview nodes. This setup allows the rendered view in Grasshopper to accurately display the selected materials for each part, reflecting the user's choices made through the interface. By organizing geometry and material data into structured paths and using Stream Filter and Stream Gate components, the system ensures that only the relevant components and their materials are visualized at any given time.

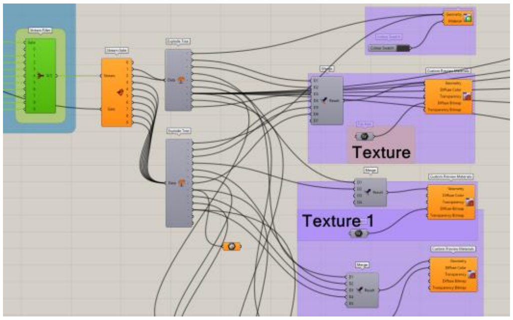


Figure 16: Material Assignment and Visualization Workflow in Grasshopper (by the author)

2.6 User Interface Backend Structure and Section Division

The backend of the configurator's user interface is organized around a main window that manages multiple sections through a tabbed layout. As shown in the image, the configuration begins with a list of tab names, each representing a key area of the workflow: General Overview, Ground Floor, First Floor, Second Floor, Roof, and Facade. These tab names are fed into a Tab Names component, which also allows for the assignment of text size and icon sources for each tab, ensuring clarity and visual consistency.

The main window is created using the Show component, where parameters such as width, height, and font family are defined. Additional styling is handled through theme selection, accent colors, and swatch inputs, allowing for a customizable appearance that can be easily adapted to different preferences or branding requirements. The Boolean toggle controls the visibility or refreshes state of the window, while number sliders are used to dynamically set the window's dimensions.

The "Current tab state" panel tracks which tab is active, providing real-time feedback and enabling the backend to update the displayed content accordingly. All UI elements for each section are bundled and added to the main window using the "Added Elements" input, allowing for modular development where each tab can contain a unique set of controls and visual outputs specific to that phase of the configurator.

This backend structure divides the interface into logical sections, making it straightforward to manage and extend. Each tab serves as a container for related UI elements, supporting a clear workflow from general overview through each floor and building component. This modular approach ensures that as users navigate between tabs, the interface dynamically updates to present the relevant controls and information for the selected section, maintaining both usability and scalability in the design.

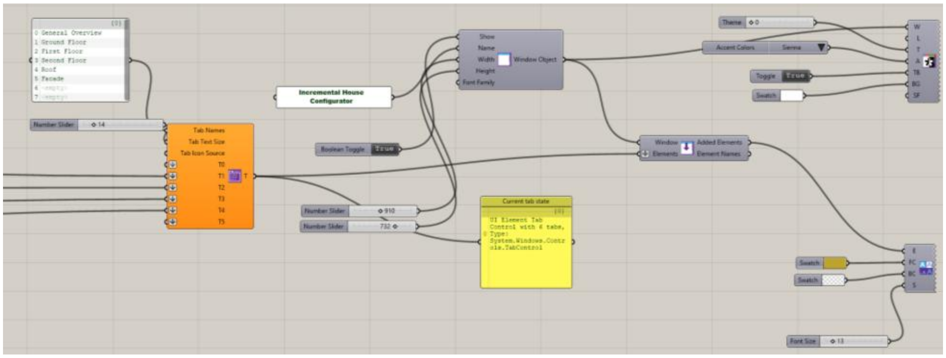


Figure 17: User Interface Backend Structure and Tab Management in Configurator (by the author)

-Image Integration:

Images are brought into the Human UI using the “Image Path” and “Image Source” components, which specify the file location of each image to be displayed (Grasshopper Docs, 2024). The image paths are set for each relevant option, and the images are then configured with width and height parameters before being passed to the “Image” and “Image Setting” components. These are bundled and connected to the UI stack, ensuring that each design option or material preview is visually represented in the interface.

-Sliders and Toggles:

Number sliders are used for continuous parameter adjustments, such as controlling the size of partitions, windows, or shades. Boolean toggles allow users to activate or deactivate specific features or options in real time. Both sliders and toggles are labeled for clarity and are grouped in horizontal or stacked UI layouts for better organization.

-Python Script Component:

A Python script component is included to process more complex logic or data transformations that are not natively handled by Grasshopper components. For example, it can be used to process selection indices, manage data trees, or trigger custom operations based on user input. The script receives input from the radio button and other UI elements, processes the data, and outputs the results to be used by the rest of the definition.

-UI Layout and Data Flow:

All UI elements—images, labels, sliders, toggles, and radio buttons—are organized into horizontal or stacked layouts using "UI Elements Horizontal" and "UI Elements Stack" components. The result is a modular, readable, and user-friendly interface where each control is logically grouped and visually accessible.

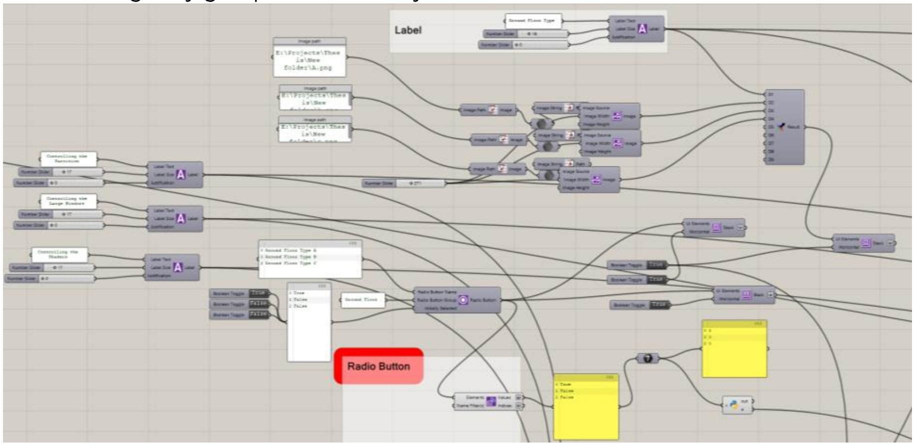


Figure 18: UI Elements in Grasshopper: Image Integration, Sliders, Toggles, and Data Flow (by the author)

2.7 Radio Button Selection Logic for Floor Plan Options

In this section of the backend, user selection between different floor plan options—such as for the first or second floor—is managed through radio button groups in the Human UI interface. Each radio button corresponds to a specific spatial configuration, for example, different layouts for the back part of the first-floor plan. To organize the options visually and improve usability, the available choices are divided into two rows, as shown in the user interface screenshot. Each option is represented not only by a radio button but also by a preview image, allowing users to make informed selections based on both text and visual reference.

The backend logic starts with a list of possible configurations, which are mapped to radio button names and grouped accordingly. When a user selects an option, the index of the selected radio button is captured and processed. This selection index is then passed to a Python component, which manages any additional logic needed—such as combining selections from multiple rows or handling dependencies between options. The output from the Python script is used to filter and activate the correct geometry and material data for visualization and further processing.

By structuring the radio button options in two rows and linking them to preview images, the interface remains clear and intuitive. The backend ensures that the user's selection is accurately reflected in the system, with the Python component and subsequent filtering steps directing the correct data streams for rendering and further operations. This setup supports a flexible and user-friendly workflow for configuring complex floor plan layouts.

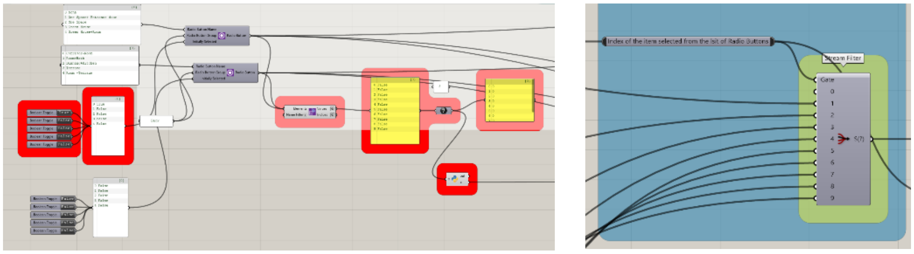


Figure 19: Radio Button Logic for Floor Plan Selection in Configurator (by the author)

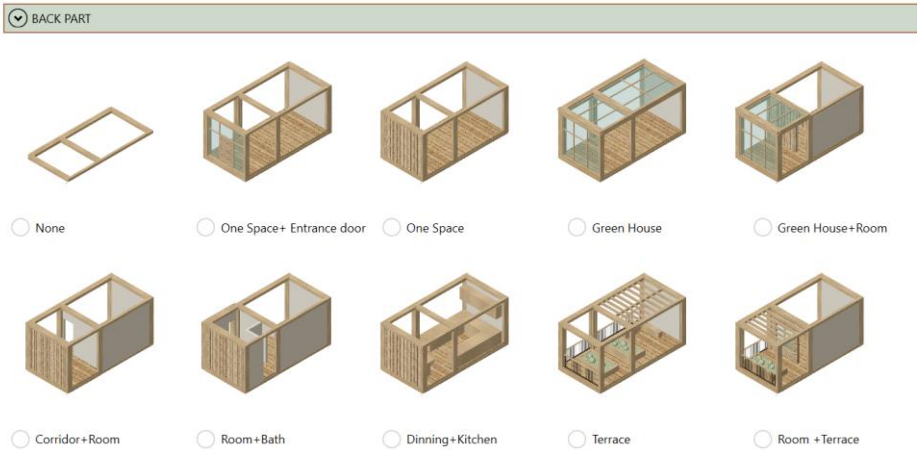


Figure 20: Radio Button Floor Plan Selection: Visual Options and Preview Images (UI by the author)

3. Digital Configurator - User Manual

This user manual guides you through the Incremental Modular House Configurator, a tool designed to help you plan and visualize a modular home that adapts to your changing needs. The manual provides an overview of the system's philosophy, key features, and step-by-step instructions for using the configurator—from initial planning to customizing your home's layout. Use this guide to understand how to select modules, explore design options, and make informed decisions about your project's growth and flexibility.

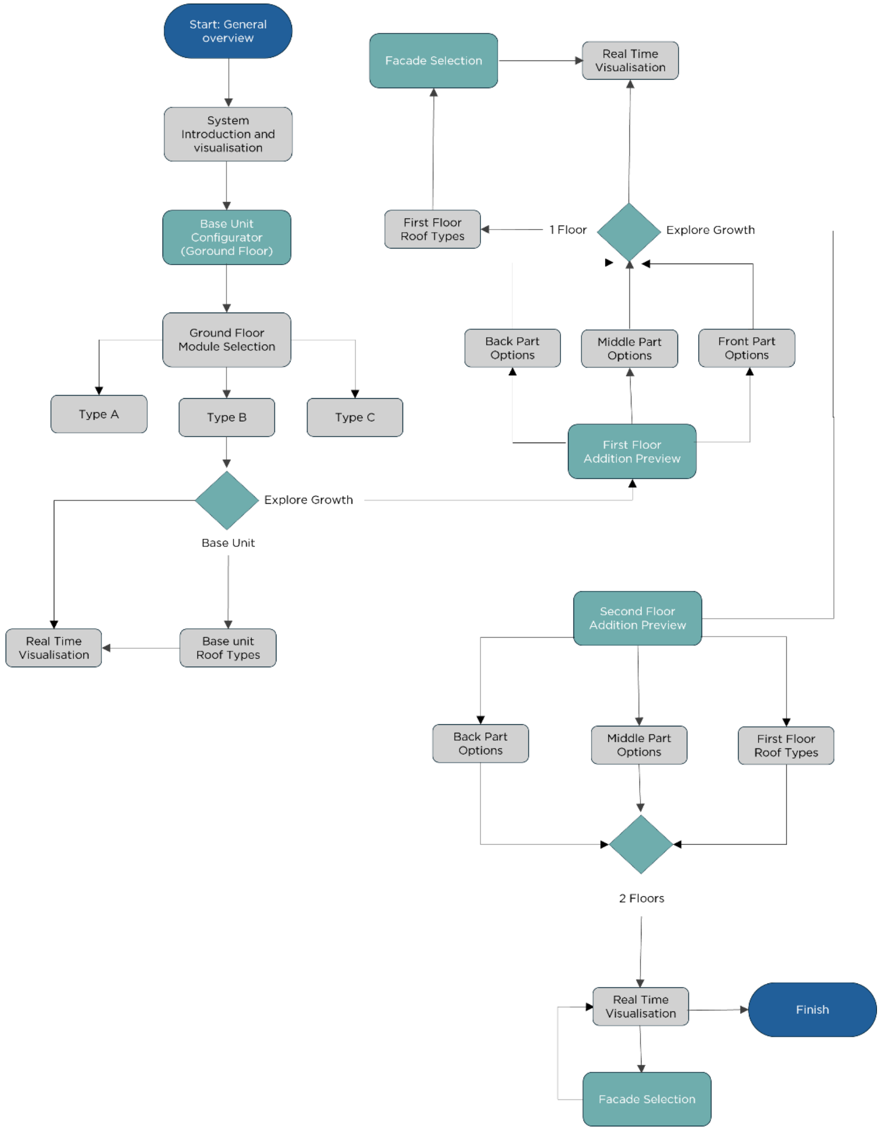


Figure 21: User Manual: Digital Configurator Workflow Overview (by the author)

3.1 System Overview

The Incremental Modular House Configurator helps you plan and visualize a modular home that grows with your needs. Starting with a base ground floor unit, you can explore how your home can expand through phased additions, allowing you to make informed decisions about both immediate and future possibilities.

Key Features:

Phased Growth Planning:

Begin with a base unit and expand over time.

Uniform Module Sizing:

All units share the same size, with different site positions.

Cost-Effective Growth:

Purchase only what you need now, with options for future expansion.

Timeline Visualization:

See your home's evolution across multiple phases.

Real-Time 3D Preview:

Visualize each design in Rhino.

Construction Flexibility:

Build in stages or complete the full plan at once.

Growth Philosophy:

This system recognizes that housing needs change over time. Whether you're a young professional, growing family, or planning for retirement, your home can adapt and expand incrementally rather than requiring a complete rebuild.

Getting Started

Understanding the Growth Concept

Before configuring your modular house, it's important to understand the incremental growth philosophy:

Phase 1 (Base Unit): Your starter home - a complete, livable ground floor module
Phase 2 (First Addition): Vertical expansion when you need more space
User Manual: Step-by-Step guide.

3.2 Getting Started with the Configurator

3.2.1 General Overview

When you open the configurator, you start on the General Overview page. Here, you'll find a brief introduction to the system, the philosophy of incremental modular housing, and visualizations that show how your home can grow and adapt over time. This section helps you understand the possibilities before you begin making choices.

3.2.2 Ground Floor Configuration

Next, move to the Ground Floor tab.

Module Selection

You'll see three base layout options (Type A, B, and C), each with a 3D visualization and floor plan. Select the one that best fits your plot or lifestyle.

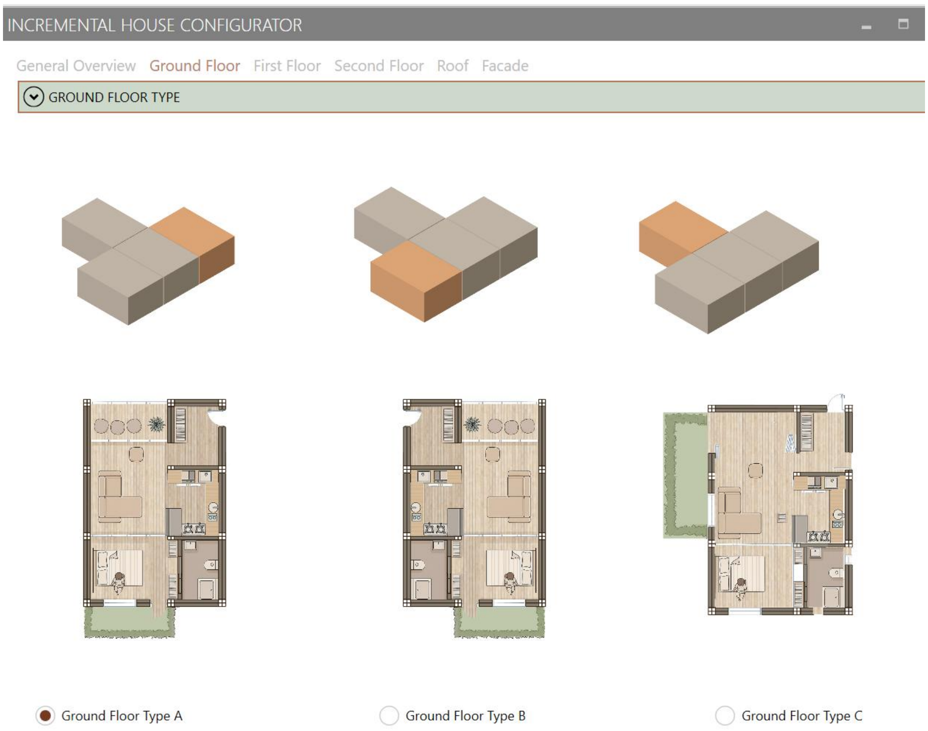


Figure 22: Base Layout Options: Ground Floor Types A, B, and C (by the author)

Partition Control

Use the sliders to rotate and adjust the interior partitions, allowing you to customize the internal layout to your needs. sliders are used for interior customization.

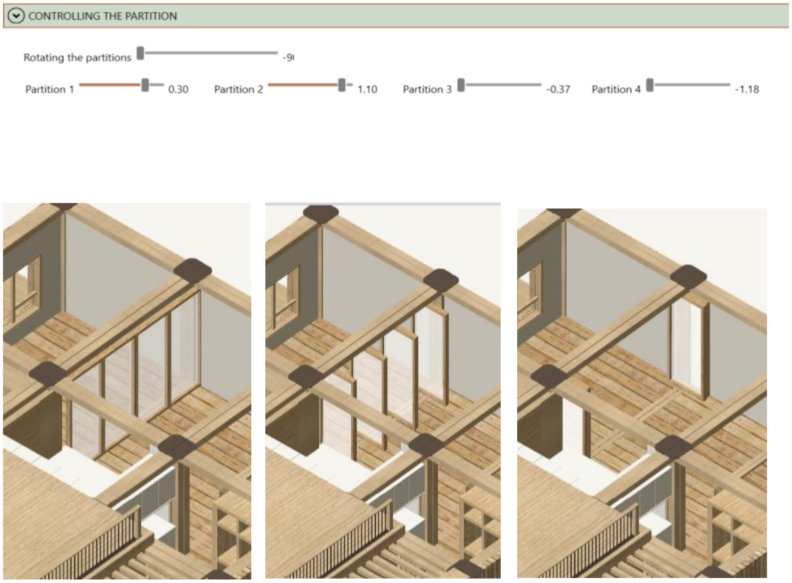


Figure 23:Partition Control: Customizing Interior Layouts with Sliders (diagram and UI screenshot by the author)

Large Window Control

Adjust the opening angle of the large windows for light and ventilation.

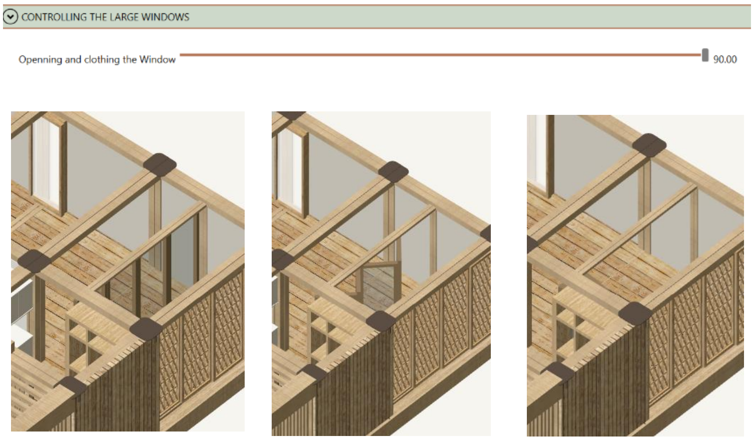
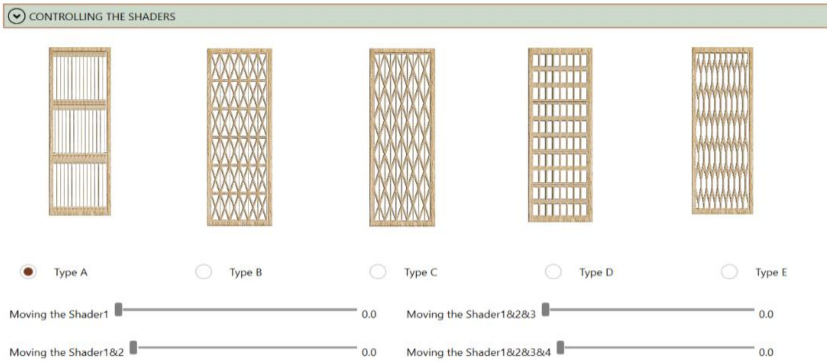


Figure 24: Adjustable Openings for Light and Ventilation (by the author)

Shading Control

Choose from five shading types (A–E) and use the sliders to position them for optimal comfort and privacy.
All changes you make are instantly shown in the Rhino 3D preview window, so you can see the results in real time.



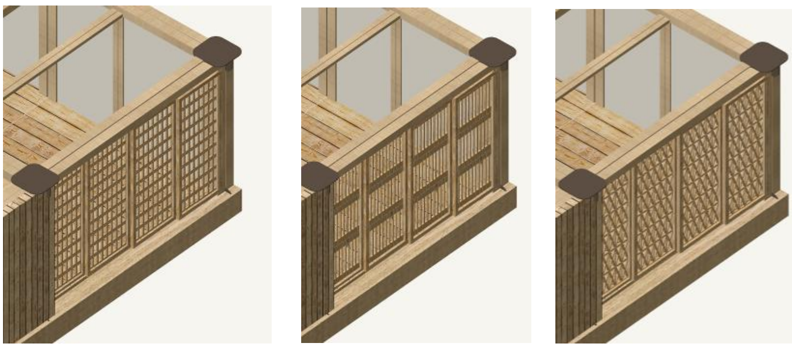


Figure 25: Adjustable Panel Types and Slider-Based Positioning (by the author)

Figure 26: Adjustable Panel Types and Slider-Based Positioning (by the author)

Growth Decision, Expand or Finish

After configuring the ground floor, you decide whether to keep your home as a single-level unit or to plan for future growth:

If you finish here:
You can select a roof type for the base unit and proceed to the facade step.

If you want to expand:
Continue to the first-floor addition.

3.2.3 First Floor Addition

If you choose to add a first floor, the configurator divides it into three parts: Back, Middle, and Front.

For each part, you will see multiple layout options (such as None, One Space, Green House, Room + Bath, Terrace, etc.), each illustrated with a 3D image.

Simply click the radio button under your preferred option for each section.
After configuring all parts, you can preview the combined first floor addition in real time.

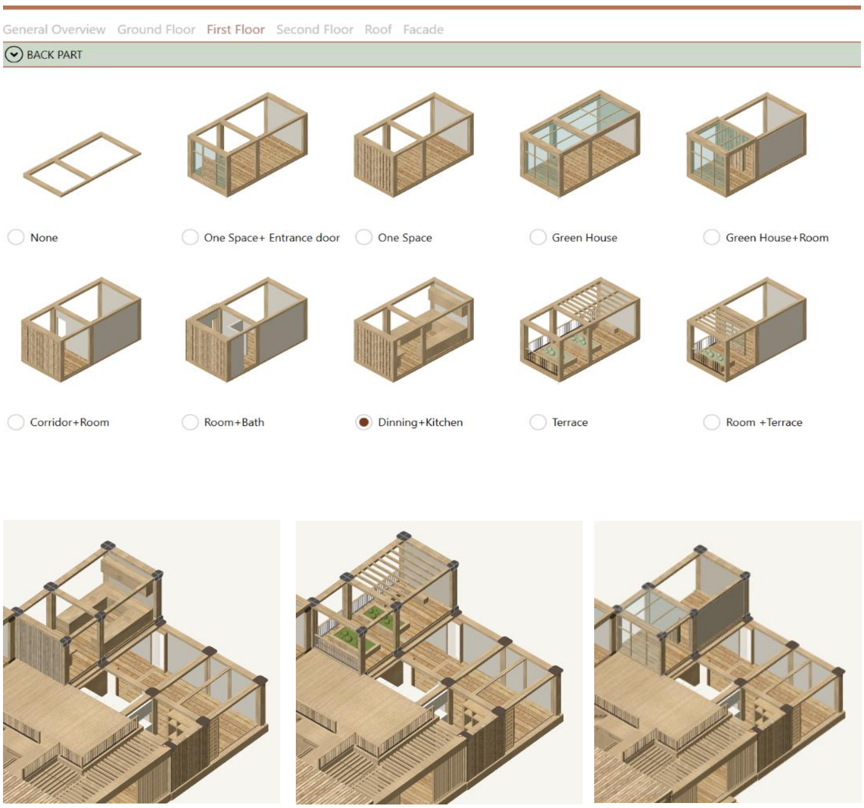


Figure 27: First Floor Addition: Configurator Layout and Section Options(Back Part) (by the author)

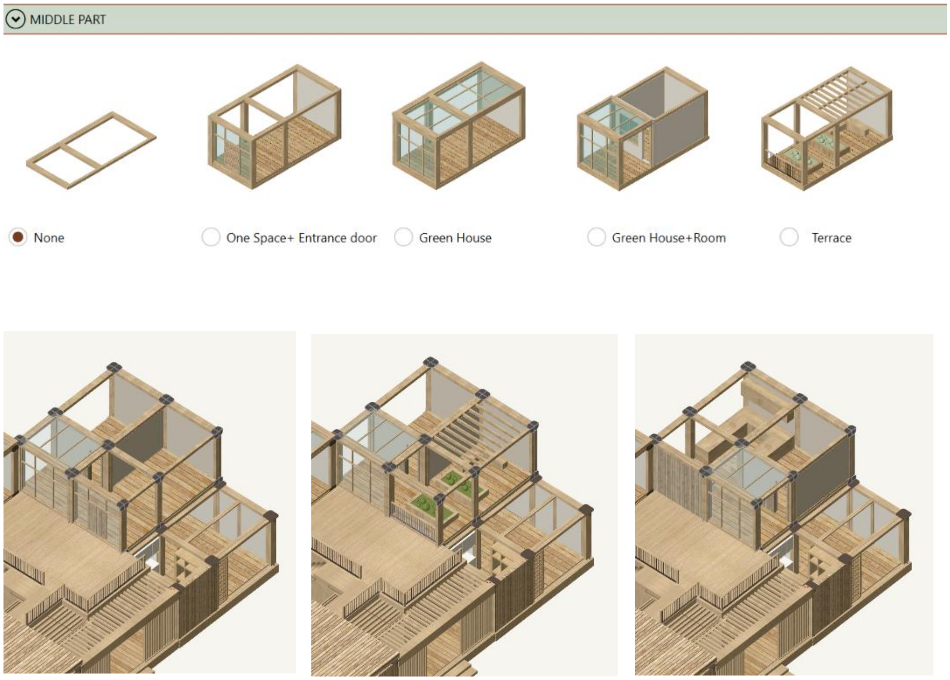


Figure 28: First Floor Addition: Configurator Layout and Section Options (Middle Part) (by the author)

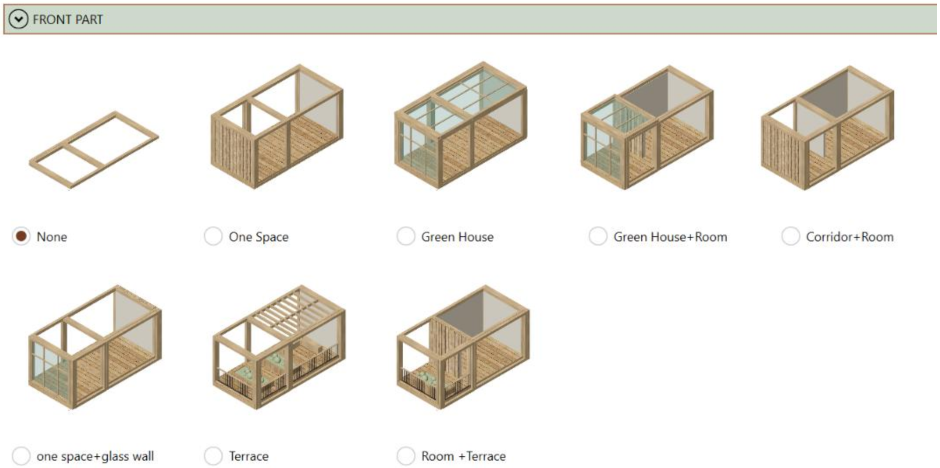


Figure 29: First Floor Addition: Configurator Layout and Section Options (Front Part) (by the author)

3.2.4 Second Floor Addition (Optional)

If you want to add a second floor, the process is similar:

Again, the floor is divided into Back, Middle, and Front parts, each with its own set of layout options.

Your available options may depend on the selections you made for the first floor, ensuring that the design remains structurally and visually consistent.

Once you finish, preview the second-floor addition.

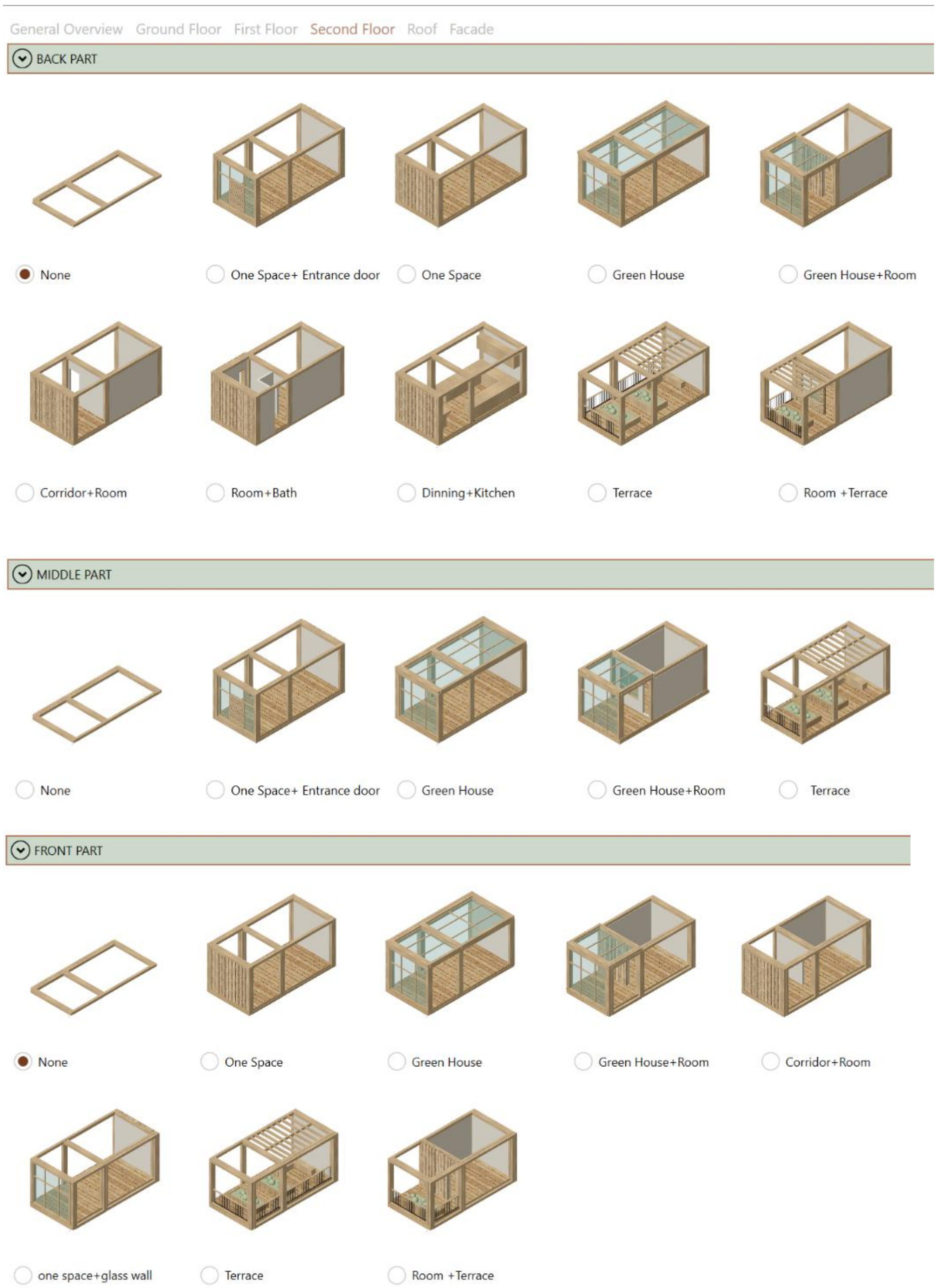


Figure 30: Second Floor Layout Options: Modular Room Selection and Arrangement (by the author)

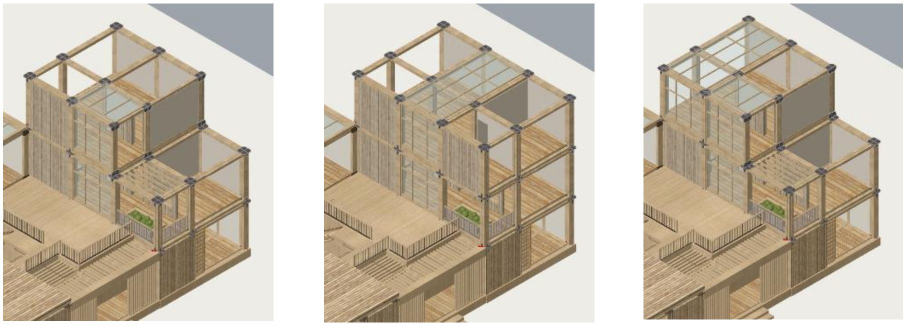


Figure 31: Second Floor Layout Options: Modular Room Selection and Arrangement (by the author)

3.2.5 Roof Selection

Depending on the number of floors and the layouts you've chosen, you'll be presented with compatible roof types.

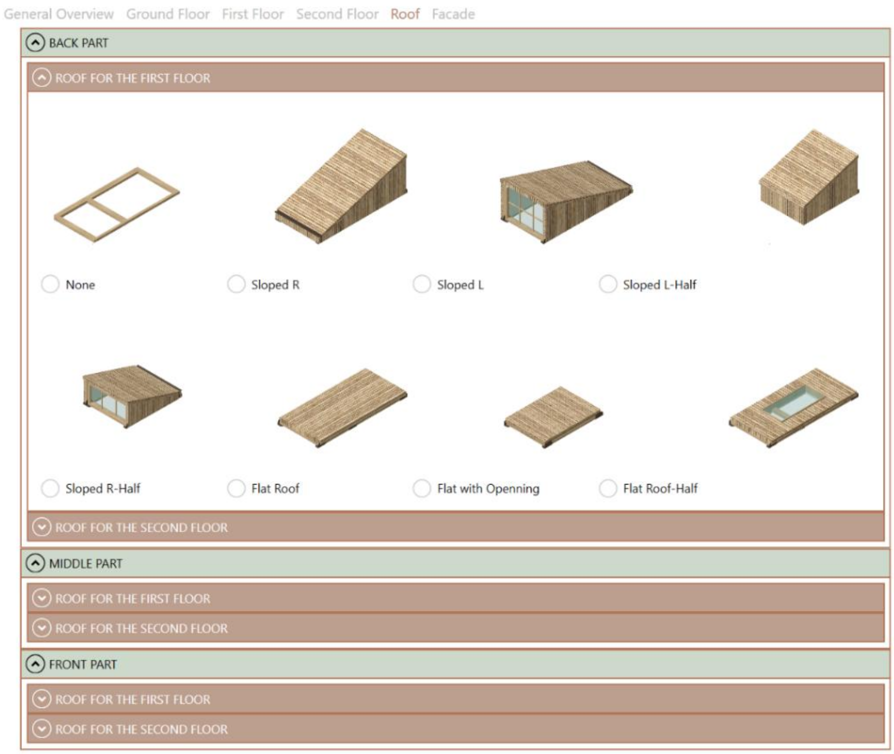


Figure 32: Roof Selection: Configurator Interface (by the author)

Figure 33: Roof Selection: 3D Preview (by the author)

Select your preferred roof style.
The preview updates to show how the roof integrates with your design.

3.2.6 Facade Customization

In the Facade tab, you can select different exterior shading and window configurations.

Dynamic Options

The available facade options depend on the room and space configurations you chose for each part of the building. For example, if you added more windows or terraces, you'll see corresponding facade and shading choices.

Customization

Adjust shading patterns, window positions, and other exterior elements for each facade.

Visualization:
All facade changes are updated in real time in the Rhino preview, so you can assess the appearance and daylighting from every angle.

Figure 34: Roof Selection: Configurator Interface and 3D Preview (by the author)

Figure 35: Facade Customization: Shading and Window Options (by the author)

3.2.7 Real-Time Visualization

Throughout every step, your selections are displayed instantly in the Rhino viewport. This real-time feedback helps you understand the spatial, structural, and aesthetic impact of your choices before finalizing your design.

Figure 36: Real-Time Visualization: Instant Feedback in Rhino Viewport (by the author)

3.2.8 Finish

Once you are satisfied with all your selections, you can review your complete design and export or save your configuration for further development or construction planning.

Tip:

At any point, you can go back to previous steps to adjust your choices. The configurator is designed to be flexible, allowing you to experiment with different layouts and see how your home can evolve over time.

4. Construction User Manual

This manual provides a step-by-step overview of the construction process for your Incremental building system. It highlights the main stages, important considerations, and best practices to ensure a smooth and efficient project. Use this guide as a reference for the overall process, from initial planning and material selection to on-site assembly and final installation. For detailed technical instructions or specific requirements, consult your project's engineering documents or seek professional advice as needed.

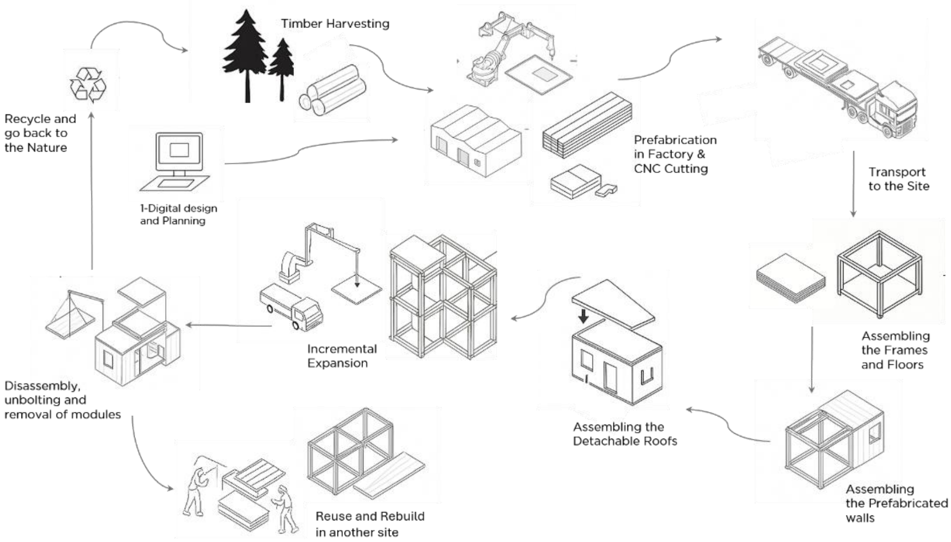


Figure 37: Incremental Construction Workflow: From Digital Design to Reuse and Recycling (by the author)

4.1 Design, Planning, and Preparation

Before any construction, use the digital configurator to finalize your house design. Choose your ground floor layout, plan for future expansion, and select room, facade, and roof options.

Preparation:

- Engage with local professionals for any required site surveys or utility connections.

4.2 Material Selection and Factory Prefabrication

Timber Selection:
- High-quality, sustainably sourced timber (Douglas fir, larch, or ash) is chosen for structure and panels.

CNC Fabrication:
- In a controlled factory, posts, beams, CLT floor panels, and wall/roof panels are cut and drilled to precise dimensions using CNC technology.

Panel Assembly:
- Wall and roof panels are filled with insulation, fitted with durable cladding, and labeled for easy on-site identification.

Steel Connectors:
- Corner plates and brackets from recycled material are manufactured for bolted connections, supporting both quick assembly and future disassembly.

Quality Control:
- Each component is inspected, and any issues are corrected before shipping.

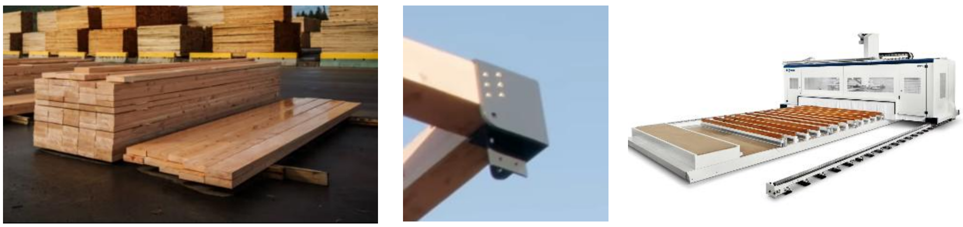


Figure 38: Material Selection and Factory Prefabrication Workflow

4.2.3 Site Preparation

Foundation

- Install screw pile foundations at the planned locations. Make sure all screw piles are set to the correct depth, aligned, and level to provide a stable base for the modules. Screw piles are quick to install, environmentally friendly, and allow for easy removal or relocation of the building in the future.

Figure 39: Screw Pile Foundations: Modular Timber Base Installation (www. building-diy.com)

Utility Preparation:

- Install or prepare connections for water, electricity, and sewage.

Access and Storage:

- Clear space for delivery vehicles and designate a weather-protected area for temporary storage of panels and modules.

4.2.4 Delivery and Inspection

Transport:

- Prefabricated modules and panels are delivered to your site, typically by truck.

Inspection:

- Upon arrival, check all components for damage or missing parts.

Organization:

- Lay out modules and panels close to the assembly area, following the sequence in your assembly manual. Store panels flat, off the ground, and covered if possible.

4.2.5 Frame and Floor Assembly

Frame Erection:

- Position the modular timber post-and-beam frames on the foundation.
- Bolt frames together using labeled steel corner plates and brackets.
- Use a level and measuring tape to ensure frames are plumb, square, and properly spaced.
- Anchor the frames to the foundation as per the engineering drawings.

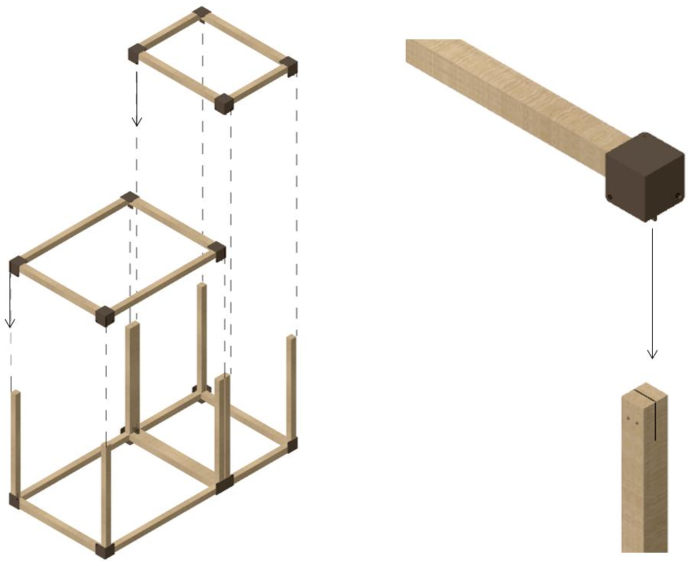


Figure 40: Frame and Floor Assembly: Modular Timber Post-and-Beam Erection Sequence by the author)

CLT Floor Installation:

- Place CLT floor panels onto the frames, ensuring a snug fit.
- Secure panels as specified and integrate insulation beneath as needed.
- Double-check alignment and levelness before proceeding.

Figure 41: CLT Floor Installation: Panel Placement and Alignment (by the author)

4.2.6 Wall Panel Installation

Panel Mounting:

- Attach prefabricated, non-load-bearing wall panels to the frames using bolts or screws.
- Panels are designed for manual handling or light lifting equipment; follow the labeling for placement.

Openings:

- Install windows and doors as indicated in your plan.
- Adjust partitions and interior walls as needed for your chosen layout.

Sealing:

- Seal all joints and corners with weatherproof tape or sealant to ensure airtightness and water resistance.

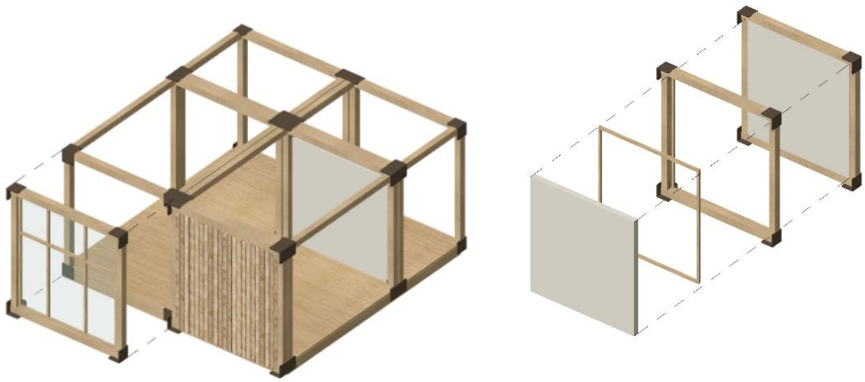


Figure 42: Wall Panel Installation: Prefabricated Panel Mounting, Openings, and Sealing Steps (by the author)

4.2.7 Roof Installation

Panel Placement:

- Prefabricated roof panels are lifted into place and secured.
- For single-story homes, this may be done with light equipment; for multi-story or large roof panels, a crane may be required.

Weatherproofing:

- Overlap membranes, install metal flashing, and check all joints for water resistance.
- Install gutters or drainage systems as designed.

Final Fixing:

- Secure the roof panels with bolts or proprietary connectors, ensuring they can be detached later for vertical expansion.

Figure 43: Roof Panel Installation: Lifting, Securing, and Weatherproofing Steps in Modular Timber Construction (by the author)

4.2.8 Interior Finishing and Services

Interior Walls and Finishes:

- Complete interior partitions, flooring, and wall finishes (paint, plaster, wood panels, etc.).

Utilities:

- Connect plumbing, electrical, and HVAC systems according to your plan.
- Test all systems for leaks and functionality.

Fixtures and Fittings:

- Install kitchen, bathroom, and other built-in elements as desired.

4.2.9 Incremental Expansion

Roof Removal:

- When expanding vertically, detach the existing roof using modular connectors and lifting points (a crane may be needed).

Additional Module:

- Stack new post-and-beam frames on top of the existing structure.
- Install new floor and wall panels, then reattach the roof at the new top level.

Integration:

- Seamlessly connect new modules to the existing structure and services.
- Update insulation, weatherproofing, and finishes as needed.

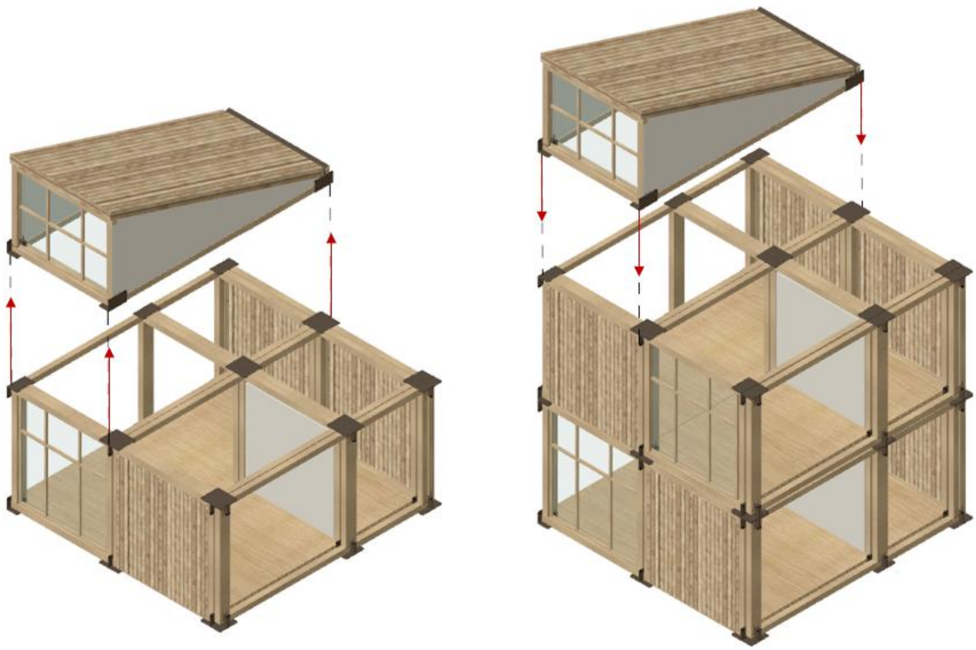


Figure 44: Incremental Expansion: Detachable Roof and Vertical Module Addition (by the author)

4.2.10 Disassembly and Reuse (Optional)

Panel and Module Removal:

- Reverse the assembly process: unbolt steel connectors, remove panels and modules in the recommended sequence.

Reuse:

- All modules and panels are designed for repeated assembly, supporting circular construction and minimizing waste.

- Store or transport components for future use or reconfiguration.

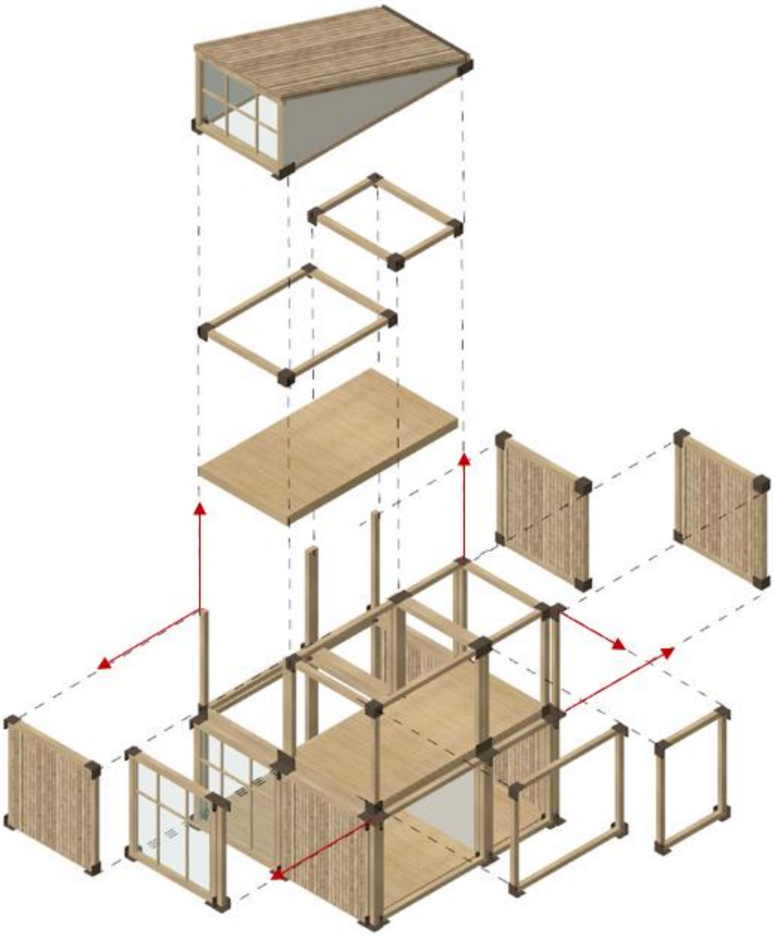


Figure 45: Disassembly and Reuse: Modular Timber System Exploded View (by the author)

4.2.11 Maintenance and Adaptation

Regular Inspection:

- Check timber, joints, and finishes periodically for wear or damage.

Upgrades:

- Replace or upgrade panels, insulation, or finishes as needed.

Reconfiguration:

- Move or replace non-load-bearing walls and adapt facade elements or shading devices to suit changing needs.

4.2.12 Practical Tips and Notes

- Most ground floor and wall panel assembly can be managed manually; cranes are only required for large/heavy elements or vertical expansion.
- Always follow safety guidelines and consult professionals for structural or service connections.
- Keep assembly documentation and labeling for easier future expansion or disassembly.
- The modular system supports both owner-led and contractor-led assembly, and is designed for user-friendly, step-by-step construction.

5. Architectural Design Documentation

This section showcases the architectural design of the project through a series of drawings and visualizations. Included are detailed floor plans, building elevations, and 3D renderings that illustrate the spatial organization, exterior appearance, and overall design intent. These materials provide a comprehensive understanding of the project's architectural concept and layout, serving as a visual reference for both the design team and stakeholders. Review the following pages to explore the key features and qualities of the proposed architecture.

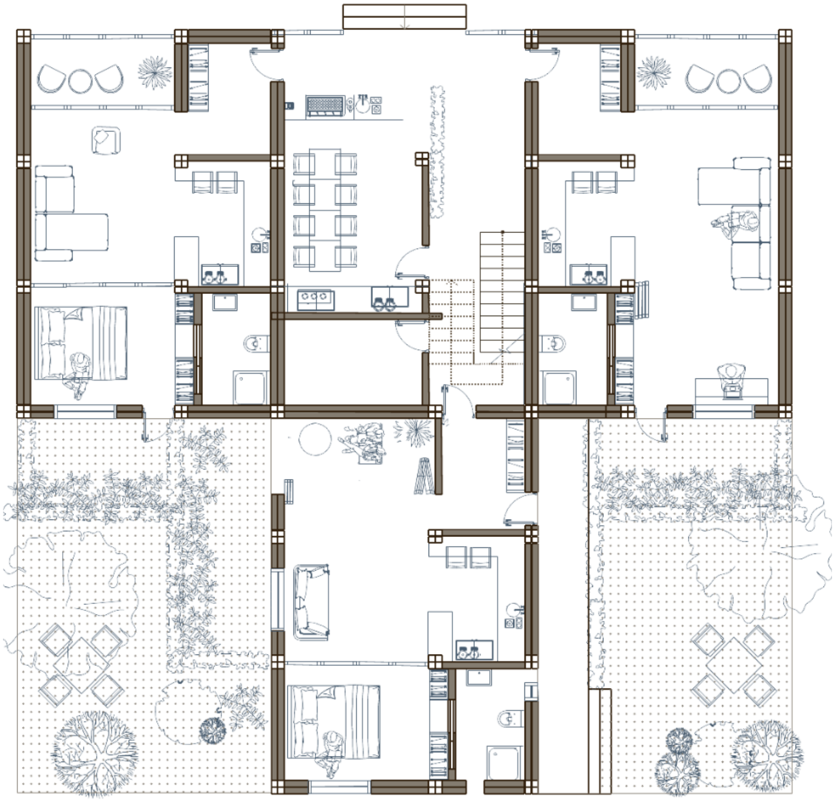


Figure 44. Three distinct residential layouts, each connected to a central shared space, illustrating the integration of private and communal zones within the compound (by the author).

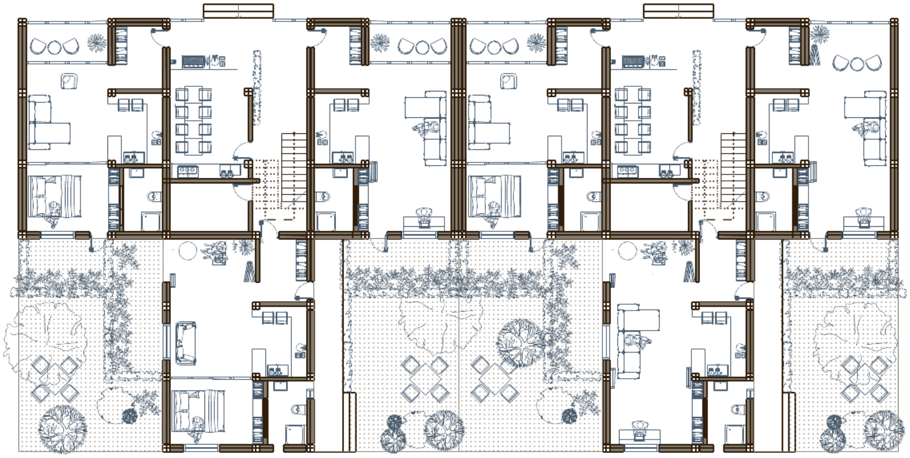


Figure 45. Aggregated floor plan showing the spatial relationship and direct connections between the three unique units and the middle-shared area (by the author).

Figures 46-49. Axonometric, elevation, and top views of the micro-neighborhood, showing three connected units arranged around a central shared space (by the author).

Figure 50. Top view of the micro-neighborhood, showing the arrangement of modular units and shared green spaces (by the author).

Figure 51. Street-facing elevation illustrating the stepped massing and façade articulation of the interconnected units (by the author).

Garden-facing elevation highlighting the integration of greenery and private outdoor areas within the modular complex (by the author).

Figure 53. Axonometric views of the modular neighborhood, illustrating the overall organization and clustering of timber housing units around shared spaces (by the author).

Figure 54. Street-facing elevation highlighting the stepped massing and façade articulation of the modular housing complex (by the author).

Figure 55. Street-facing elevation from a different perspective, showing the variation in unit heights and integration of terraces (by the author).

Figure 56. Upper-level communal terrace, illustrating the connection between private units and shared outdoor spaces (by the author).

Figure 57. View within the upper terraces, highlighting semi-private outdoor spaces adjacent to the living units (by the author).

Figures 58,59,60: Different interior configurations of the modular unit showcasing spatial flexibility—ranging from an open-plan living area to a more enclosed setup with a sliding partition for privacy and adaptability.

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11. Table of Figures