Modularity in Biobased High-Rise Design: From Structural Systems to Community Building

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Abstract

This paper explores modularity in architectural design through a comparative analysis of case studies in biobased high-rise structures and community-focused modular housing. The research is divided into two parts: the first focuses on structural systems in modular high-rise housing, and the second examines the architectural qualities of modular designs in fostering community interaction. The selected case studies—ranging from Mjøstårnet, Treet, and Stadthaus to HoHo Vienna, Hotel Jakarta, and Habitat 67—highlight various expressions of modularity, from identical unit-based designs to the use of modular components. In examining these projects, the paper addresses how modularity influences both structural integrity and social functionality, with an emphasis on human-centered design. The study uses metrics such as building footprint, structural floor area, and height-to-footprint ratio to compare the efficiency of different systems. By integrating environmental psychology and urban studies, this research contributes to a deeper understanding of modularity as a multifaceted approach in contemporary architecture, emphasizing its potential to shape both the built environment and social dynamics within communities.

Keywords: *Modularity, Biobased high-rise structures, Community building, Spatial configuration, Environmental psychology*

Introduction

Modularity is practiced in various ways across architectural case studies, each revealing unique possibilities for design. This research is structured into two distinct parts. The first part examines case studies focused on modularity in biobased high-rise structures. These case studies provide insight into the application of modularity within the context of sustainable, high-rise building design. The second part expands the scope by including cases where the focus shifts from material to the architectural qualities of modularity, with an emphasis on the concept of community building. This allows for a broader understanding of modular buidling, not limited to a specific material but instead examining its potential in shaping human interaction and shared spaces.

In the selected case studies, different expressions of modularity are observed. In projects such as Treet, Hotel Jakarta, Nakagin Capsule Tower, and Star Apartments, modularity is reflected through the use of identical units. On the other hand, projects like Stadthaus, HoHo Vienna, Mjøstårnet, and Habitat 67 demonstrate modularity through the use of modular building components, where the emphasis is on assembling modules to form a cohesive whole. In Sky Habitat, modularity is expressed in the design of the floor plan, where flexibility and adaptability are central to the spatial arrangement.

This research aims to broaden the understanding of modularity in architecture, showing that it extends beyond merely stacking identical units. Instead, modularity can take on various forms, contributing to both the structural integrity and the social functionality of a space.

The research will be guided by a thematic, comparative case study analysis, divided into two parts: the first focusing on structural systems in modular high-rise housing, and the second on spatial analysis of modular designs. Through this approach, the study will explore the different strategies of modularity and its impact on architecture.

Part1: Structural Systems in Modular High-Rise Housing

Method

The first section of this case study will focus on examining the technical aspects of 3D prefabricated, bio-based modular high-rise housing projects. Examples from three structural systems—volumetric modular, panelized, and column-and-beam—will be analyzed and compared in terms of their stability, load-bearing capacity, and structural flexibility. Within the volumetric modular category, the design and construction of individual modules will be further compared to highlight differences in their structural performance.

Case Studies

The case studies selected for the first part of this research focus on the structural systems of modular high-rise housing. These include Mjøstårnet, Treet, Stadthaus, HoHo Vienna, and Hotel Jakarta. Projects will be chosen based on their use of bio-based modular construction methods and the availability of structural data (e.g., drawings, research papers). A diverse set of examples will be included to capture variations in design, scale, and implementation. The analysis will utilize data sourced from open-access research papers and technical documentation on structural systems.

Metrics such as building footprint, structural floor area, and height of the structure will be calculated for each case to derive key indicators, including the Structural Footprint Ratio (SFR) and the height-to-footprint ratio. By comparing these metrics, insights into the performance, limitations, and efficiency of different structural systems will be drawn. Due to space constraints in this paper, the comprehensive analysis of each case study across various aspects has been placed in the appendix.

Metrics and Their Implications

Structural Floor Area (SFA):
Represents the portion of the building footprint occupied by structural components, such as columns, cores, or shear walls.

Total Floor Area (TFA):
This includes the total floor area of a floor plan.

Structural Footprint Ratio (SFR):
A metric indicating the proportion of the footprint dedicated to structural elements. A higher SFR typically corresponds to greater load-bearing capacity, but it may also suggest overengineering or inefficiencies in space utilization.
Buildings with a low SFR ratio likely have fewer structural components, leaving most interior walls as non-structural and modifiable. This metric reflects the reconfigurability and adaptability of the space because non-load-bearing partitions can be altered without affecting the structural integrity.

Height-to-Footprint Ratio:
Serves as a proxy for the slenderness of a building. Taller buildings with smaller footprints are generally more susceptible to lateral forces, such as wind or seismic activity, necessitating enhanced structural stability measures, including larger cores or bracing systems, to resist overturning.

Structural Footprint Ratio -to-Height Relationship:
Short buildings with high SFR: Likely exhibit over-engineering for vertical load bearing, resulting in high stability against lateral forces. Tall buildings with low SFR: Optimized for structural efficiency but may encounter stability challenges due to increased slenderness, requiring careful consideration of lateral load-resisting systems.

Actual Span
Refers to the average distance between structural supports (e.g., columns, beams, walls). Directly indicates the usable space within a building. Larger spans offer more flexibility for layouts and functions since fewer obstructions are present.

Through these comparisons of metrics, this study highlights the strengths, weaknesses, and height limitations of various structural systems, providing insights into their applicability for modular high-rise housing projects. A consistent methodology was applied across all case studies. To illustrate this process, the following section will present the analysis method using **Mjøstårnet** as a representative example.

The primary structure comprises glulam trusses on the facades, along with internal columns and beams (highlighted in black, Figure 1). The footprint measures 16.3 m x 36.9 m, with larger columns at the four slab corners and progressively smaller inner grid columns as the height increases, reflecting reduced load demands. The secondary load-bearing core (highlighted in green) is made of CLT panels, with wall thicknesses ranging from 220 mm (outer walls) to 140 mm (inner walls). The core is not structurally connected to the columns; instead, LVL floor panels transfer lateral forces from the core to the glulam truss system.

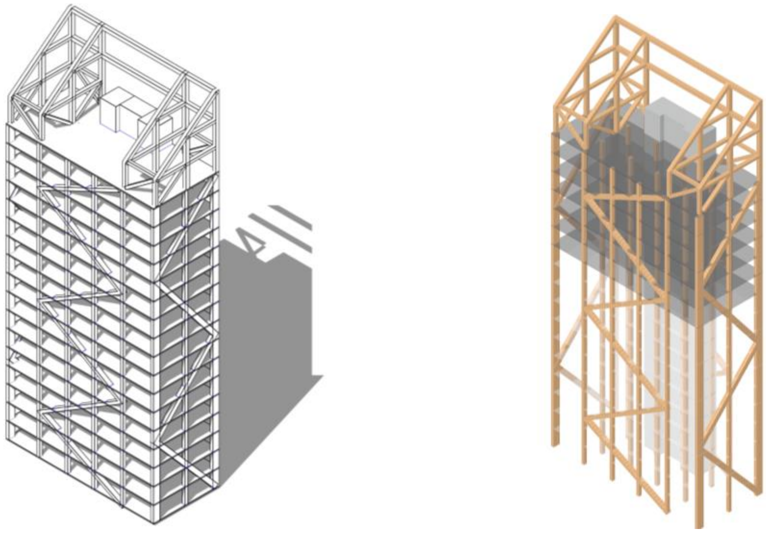

Figure 1. Structural model of Mjøstårnet

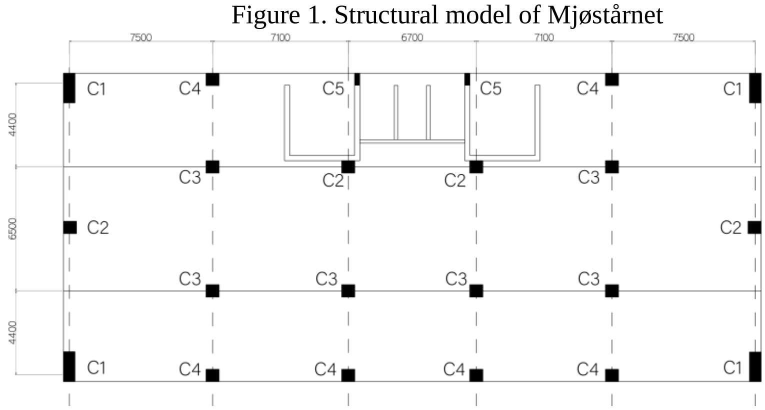

Figure 2. Structural plan of Mjøstårnet

Column dimension and number

Column	Width (mm)	Height (mm)	Number of columns
C1	625	1485	4
C2	625	630	4
C3	725	810	6
C4	625	625	6
C5	215	625	2

a) Calculate Structural Footprint Area (SFA):

- Sum up the cross-sectional areas of all columns, load-bearing walls, and core zones.
- Example: In a 16.3m x 36.9m floor with 22 columns (each lcoation and dimension stated in the table above), the SFA would be:
- $4\times(0.652\times1.485)+4\times(0.652\times0.630)+6\times(0.725\times0.81)+6\times(0.625\times0.625)+2\times(0.215\times0.625) =11.416m2$

b) Calculate Total Floor Area (TFA):

- The **Total Floor Area** is the total footprint of the floor, calculated as: $TFA=Length\times Width$
- Example: For a 10m x 10m floor, the total floor area is: $TFA=16.3\times36.9=$ 601.47 $m2$

c) Determine the Structural Footprint Ratio (SFR):

- Example: Structural SFR=$\frac{SFA}{TFA}$= 0.0189
- This represents the proportion of the floor area consumed by structural elements.

d) Determine the Height-to-Footprint Ratio (HFR):

- HFR=$\frac{Footprint\ Area\ of\ Building}{Height\ of\ Building}$
- Example: For Mjøstårnet with a height of 85.4m and a footprint area of 601.47 m²:
- $HFR = \frac{85.4m}{601.47m2}$= 0.142 $m-1$
- This means that for every meter of footprint area, the building rises 0.142 meters.

Result

The table presents the Structural Footprint Ratio (SFR) for each case, calculated by comparing the structural footprint to the actual building footprint. This ratio provides insights into the efficiency of space utilization within each structural system.

Structural Footprint Ratio

Building	**Structural Footprint Area (m^2)**	**Footprint (m^2)**	**Structural Footprint Ratio**
Mjøstårnet	11.4	601.47	0.0189
Treet	7.7	483	0.0159
Stadthaus	11.9	289	0.0412
HoHo Vienna	26.5	518.1 (Part)	0.0511
Hotel Jakarta	79.14	784.2 (Part)	0.101

1. **Land Use and structural Efficiency**:

   The structural footprint ratio reveals significant differences in land use and structural efficiency across the buildings. Mjøstårnet and Treet exhibit the lowest ratios (0.0189 and 0.0159, respectively), demonstrating highly efficient structural systems that occupy minimal ground area relative to their total footprint. In contrast, Hotel Jakarta has the highest ratio (0.101), could reflect design considerations such as modularity or lower vertical load-bearing efficiency.

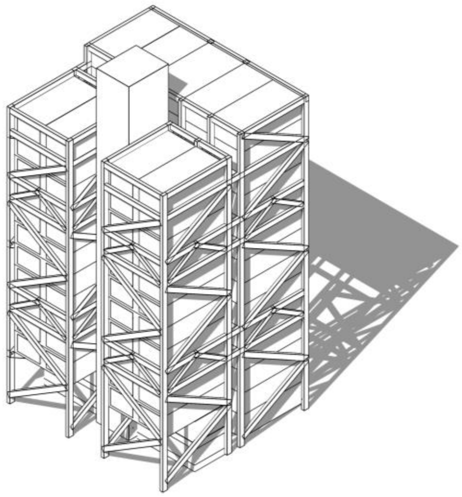

Figure 3. Structural model of Treet

With a structural footprint ratio of 0.0189, slightly higher than Treet, Mjøstårnet achieves significantly greater height (85.4 m). The increased structural footprint is reasonable to ensure stability at this scale, especially given its slender design and higher height-to-footprint ratio (0.142). While Hotel Jakarta's higher ratio suggests a trade-off between design modularity and land use efficiency.

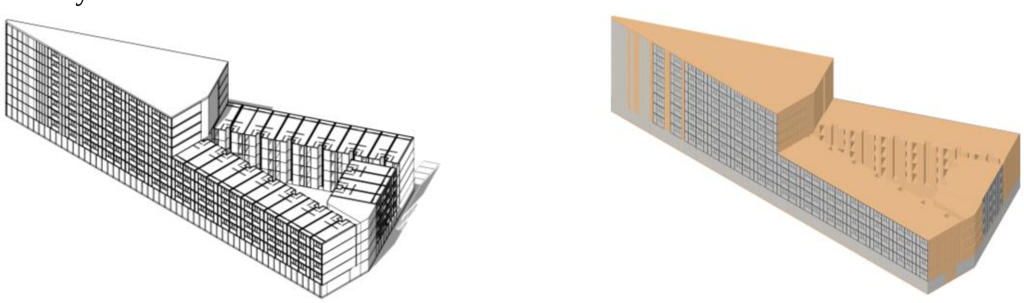

Figure 4. Structural model of Hotel Jakarta

The table illustrates the Height-to-Floor Area Ratio for each case, calculated by comparing the total height of the building to its structural floor area. This ratio offers a measure of vertical efficiency, reflecting how much height is achieved relative to the building's footprint.

Height-to-Floor Area Ratio

Building	**Height (m)**	**Footprint (m²)**	**Height-to- Footprint Ratio**
Mjøstårnet	85.4	601.47	0.142
Treet	45	483	0.093
Stadthaus	29	289	0.103
HoHo Vienna	84	518.1 (Part)	0.162
Hotel Jakarta	34	784.2 (Part)	0.043

2. **Slenderness**:

The height-to-footprint ratio highlights notable differences in the verticality and compactness of the buildings. HoHo Vienna has the highest ratio (0.162), reflecting its tall and compact design, maximizing vertical efficiency relative to its footprint. In contrast, Hotel Jakarta has the lowest ratio (0.043), showcasing its emphasis on a wider, low-rise layout. While Treet and Stadthaus have similar ratios (0.093 and 0.103, respectively), their lower values suggest designs that are shorter and more grounded compared to the taller structures.

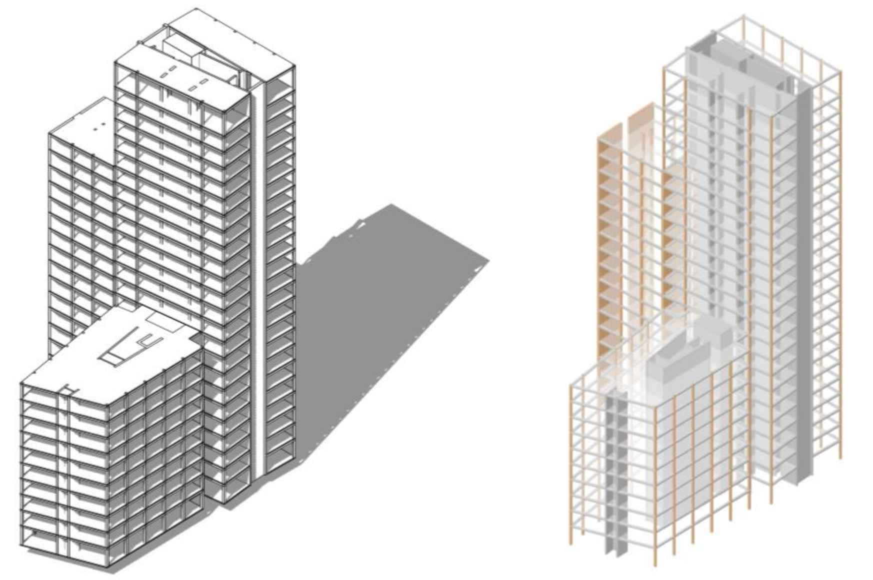

Figure 5. Structural model of HoHo Vienna

It is worth noting that Mjøstårnet utilizes a glulam truss system, while HoHo Vienna employs a hybrid system with a concrete core and CLT horizontal members. The hybrid approach in HoHo allows it to achieve a higher height-to-footprint ratio (0.162) compared to Mjøstårnet (0.142), demonstrating the advantages of integrating concrete for vertical load-bearing capacity. However, this comes at the cost of a higher structural footprint ratio (0.0511 for HoHo versus 0.0189 for Mjøstårnet).

The following table shows the maximum and minimum span dimensions for different buildings, along with the structural system used. This data helps to compare the span capabilities of various structural systems and provides insight into the flexibility and efficiency of each building design. The span dimensions directly influence the layout, floor plan flexibility, and overall spatial performance of the buildings.

Actual Span

Building	Actual Maximum Span (m)	Actual Minimum Span (m)	Footprint (m^2)	System	Note

Mjøstårnet	7.5	4.4	601.47	Column-and-Beam	Best span with good flexibility.
Treet	8.7	1.6	483	Column-and-Beam	Large max span, but small min span limits layout.
Stadthaus	9.4	1.08	289	Panelized	Large max span, very small min span.
HoHo Vienna	7	4.8	518.1 (Part)	Column-and-Beam	Good max span with decent min span.
Hotel Jakarta	10.4	3.3	784.2 (Part)	Volumetric Modular	Large max span, but small min span.

1. High Maximum Spans with Limited Flexibility in Modular and Panelized Systems

   Both Stadthaus (9.4 m max span) and Hotel Jakarta (10.4 m max span) have impressive maximum spans, showcasing the potential for open spaces in these systems. However, their small minimum spans (1.08 m for Stadthaus and 3.3 m for Hotel Jakarta) significantly limit their flexibility. This is a recurring issue with modular and panelized systems, where the layout flexibility is often constrained by the fixed size of the modules or the structural walls. For modular systems, this limitation is particularly tied to the modular unit sizes, which can't be easily adjusted or reconfigured, reducing overall flexibility.

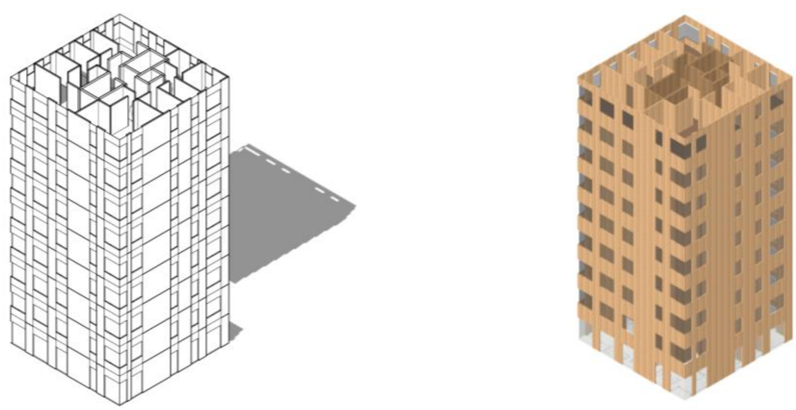

Figure 6. Structural model of Stadthaus

The Stadthaus case, which utilizes a panelized system. This system's compact design and structural walls contribute to very low reconfiguration flexibility. Since all the walls are structural, the possibility for adjusting the interior layout is minimal.

2. Column-and-Beam Systems Offer the Greatest Layout Flexibility:

   Mjøstårnet and HoHo Vienna demonstrate well-balanced spans, with maximum spans of 7.5 m and 7 m, and minimum spans of 4.4 m and 4.8 m, respectively. Both rely on column-and-beam systems, which offer greater flexibility by minimizing obstructions within the building layout. This structural approach supports adaptable floor plans and larger open spaces, enabling easy reconfiguration as needed. The column-and-beam system is particularly effective in providing layout versatility and accommodating open floor plans with minimal structural limitations.

In HoHo Vienna, the columns are integrated with the façade panels, significantly speeding up the installation of prefabricated components. However, this integration introduces limitations, as it makes the façade structural, complicating future amendments or disassembly. A more optimal design would separate the structural system from the façade, allowing for easier modifications or disassembly in the future.

Conclusion

There are inherent limitations due to the lack of complete documentation for some case studies. Consequently, approximations were made based on the available architectural drawings, scaled diagrams or average values reported in the sources. Calculations followed standardized formulas for each metric to ensure consistency across all systems.

This research focused on analyzing the slenderness and vertical height-to-footprint ratio of modular high-rise buildings, primarily concentrating on the tower portions of each structure. For most cases, where the design consisted solely of a tower, this approach allowed for a clear evaluation of vertical performance and efficiency. However, in cases with composite designs, such as HOHO Vienna and Hotel Jakarta, adjustments were necessary. In HOHO Vienna, where the building includes both 3 towers with differing heights, the analysis was limited to the tallest tower alone to maintain consistency and focus on vertical performance metrics. Similarly, for Hotel Jakarta, which features a central courtyard surrounded by the building, only the structural footprint of the built portions was considered in calculations. These simplifications were necessary to ensure consistent comparisons across diverse cases.

While this methodology facilitated a focused study on vertical structural efficiency, it inherently excluded other significant components, such as podiums or open spaces, which contribute to the overall spatial and structural performance of the designs. Future research could expand to include these additional building elements, providing a more comprehensive evaluation of how modular high-rise buildings balance structural efficiency with spatial and programmatic integration.

The glulam column and beam system stands out as the most efficient choice, offering the highest flexibility, slenderness, and structural efficiency. Its ability to provide large spans while minimizing structural footprint makes it ideal for designs that prioritize open, flexible floor plans and overall space optimization. This system also allows for greater adaptability and potential for sustainability, especially if diagonal bracing is incorporated to enhance stability without significantly increasing the structural footprint.

In contrast, hybrid systems, such as those combining concrete cores with CLT horizontal members, are effective in achieving taller structures. However, they still tend to occupy more footprint compared to glulam systems, making them less efficient in terms of space utilization. On the other hand, stacked modular units and panelized systems are highly limiting in terms of flexibility and efficiency. These systems are constrained by the fixed dimensions of their modules or panels, resulting in lower adaptability for reconfiguration. The footprint to structural efficiency ratio is low, and such systems should be avoided unless there is a specific need for standardization or rapid construction with limited design flexibility.

This research provides a comparative analysis of various structural systems, serving as a design advisory guide for modular high-rise buildings to optimize efficiency, slenderness, and structural flexibility. However, as a theoretical study, it is intentionally developed without a specific context. When applied in practice, the findings should be adapted to the unique requirements and conditions of the design context rather than implemented directly.

Part 2: Spatial analysis in relation to Community Formation

Method

The second part of this research investigates the historical development of modular housing design and its architectural qualities within communities, focusing on spatial configuration, massing, and layout. The analysis integrates theoretical insights from environmental psychology and urban studies to assess how modular housing fosters or inhibits community building.

Theoretical Framework

This study draws on Edward Hall's concept of proxemics and Jane Jacobs' observations on urban dynamics to provide a foundation for evaluating the social impacts of modular housing design.

Edward Hall's studies define informal, or personal spaces surrounding individuals, categorizing them into three distinct zones. Intimate space refers to the closest "bubble" of space surrounding a person, which is only accessible to the closest friends and intimates. Social and consultative spaces are areas where individuals feel comfortable conducting routine social interactions with acquaintances or even strangers. Lastly, public space is the area beyond which interactions become impersonal and individuals perceive a sense of detachment. Hall's theory suggests that people living in high-density environments often withdraw socially to maintain a sense of personal space and privacy. Overcrowded shared amenities or poorly designed communal spaces can create feelings of exposure or overwhelm, thus reducing the willingness of residents to engage with others. Based on this, it is essential to design social and consultative spaces that enable meaningful interactions while still respecting the privacy needs of individuals.

In addition, the work of Jane Jacobs in *The Death and Life of Great American Cities* emphasizes the importance of smaller, close-knit environments in fostering casual interactions and trust. Jacobs argued that appropriately scaled spaces encourage familiarity, ownership, and responsibility among residents, which, in turn, supports social cohesion. According to Jacobs, when residents feel a sense of belonging and accountability to their community, they are more likely to engage with others and contribute to the well-being of the shared environment.

These two theoretical perspectives—Hall's proxemics and Jacobs' principles—provide the framework for evaluating how well modular housing designs address the balance between privacy and communal living.

Framework for Analysis

The analysis integrates the theoretical framework with three core categories that will guide the examination of how modular housing supports community dynamics. The first category, massing and layout, focuses on the arrangement and proportions of modular units or buildings, with particular attention to the distribution of shared versus private spaces. This category aims to explore how spatial configurations facilitate individual privacy while also creating opportunities for communal interaction.

The second category, spatial hierarchy, evaluates the organization of public spaces, circulation pathways, and the relationship between private and communal areas. The goal is to determine if circulation or transitional spaces are appropriately scaled and positioned to foster casual social interactions, as suggested by Jacobs' principles. An examination of how spaces are organized within a building or community will reveal whether the spatial hierarchy encourages engagement and connectivity among residents.

The third category, degree of co-living, assesses the balance between private living arrangements and co-living environments. This category focuses on how shared amenities and spaces shape social behaviors and community dynamics. Smaller, more intimate group settings are considered for their ability to create a sense of safety and belonging, which in turn fosters trust and collaboration among residents.

Case Studies

The selected case studies include global examples of modular housing designs that vary in scale and context. These case studies are as follows: Nakagin Capsule Tower, Star Apartments, Sky Habitat (2012), and Habitat 67. In addition, the evolution of Hong Kong public housing typologies from 1950 to 1990 will be examined, as this provides a local perspective on the response to socio-economic conditions and the role of modularity in addressing housing challenges. The plans that will be referenced in this study are sourced from the official website of the Housing Authority.

Evaluation Approach

The case studies will be compared based on the spatial configurations and how they address key questions derived from the theoretical framework. These questions include: How do massing and layout strategies balance private and shared spaces to support community dynamics? Are public and communal spaces organized in a way that fosters natural interactions while maintaining individual privacy? Do shared amenities promote a sense of ownership and responsibility among residents? And finally, how effectively do the designs address challenges of high-density living, such as overcrowding and social withdrawal?

By combining theoretical insights with architectural analysis, this study aims to clarify how modular housing can strike a balance between individual needs and communal living. The findings will inform recommendations for enhancing community-building through modular housing design, especially in high-density environments like Hong Kong. This research will also highlight key strategies for creating more sustainable, cohesive communities through modularity, considering both global and local perspectives.

Result

Nakagin Capsule Tower, Star Apartments, Sky Habitat (2012), and Habitat 67 are notable modular housing examples, with distinct differences. Nakagin Capsule and Star Apartments focus on individual living, offering smaller units, while Sky Habitat and Habitat 67 cater to families, providing larger, more luxurious spaces.

Massing and layout

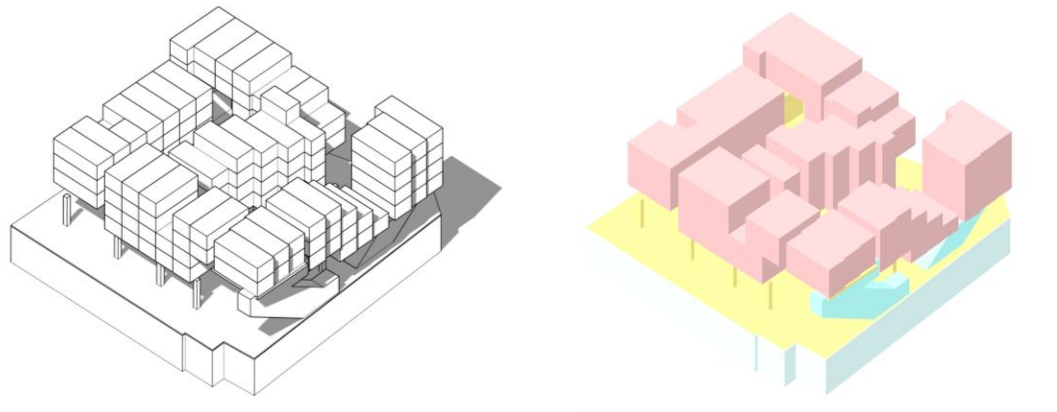

Figure 7. Massing model and program massing model of Star Apartment

In the case of the Star Apartments, the lower ground level is an existing structure repurposed to serve as a community rehabilitation and medication center, targeting vulnerable populations, including the chronically ill and homeless. Above this, a massive concrete structure elevates and supports the residential units. Between the existing podium and the stacked residential units, a dedicated communal floor bridges these elements. This floor hosts various shared programs, including a community room, community kitchen, exercise facilities, and an art room, fostering interaction and support among residents.

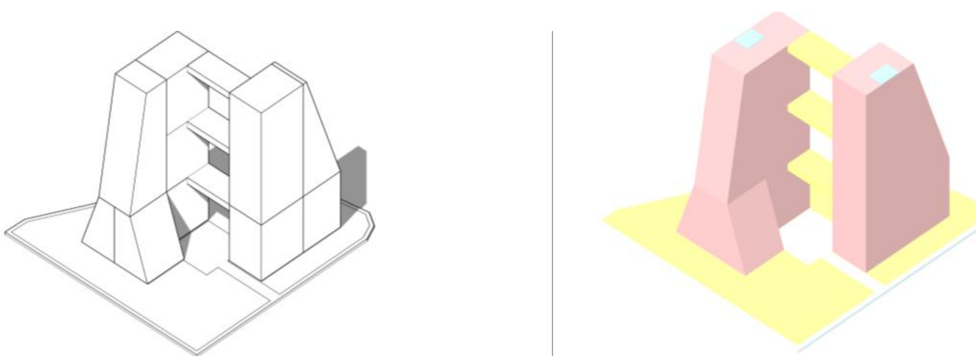

Figure 8. Massing model and program massing model of Star Apartment

In sky habitat, The development consists of 38-story, 140-meter twin towers connected by three expansive sky bridges, which house features such as swimming pools and gardens. The stepping and splayed design of the block responds to the specific regulation in Singapore, with principles that indoor and outdoor living must be provided and provide windows that will no look at neighbours. When comparing the scale of Sky Habitat and Star Apartments, Sky Habitat is significantly larger. Star Apartments provide 102 single-person units, each approximately 30 sqm, while Sky Habitat offers over 500 apartments ranging from 63 to 279 sqm. To foster community within its large-scale development, Sky Habitat incorporates three communal sky bridges at intervals between the towers. These bridges encourage localized interactions by allowing users to gravitate towards the nearest sky bridge, creating smaller communities within the expansive complex. In contrast, Star Apartments cater to more isolated and vulnerable individuals who benefit from a small, intimate community. This approach aligns with the specific needs of its target users, prioritizing support and connection over large-scale shared spaces. This thoughtful integration of communal spaces reflects the building's mission to balance individual living needs with a strong sense of community, catering to its unique target users.

Figure 8. Photo showing terraces of Habitat 67

Figure 9. Photo showing in between space of Habitat 67

Habitat 67 is a pioneering example of modular prefabricated concrete construction, offering different unit sizes through various configurations of modular components. By combining one to four 600-square-foot boxes, the building achieves a "Lego-like" stacking and alternating form. This arrangement creates small pocket spaces, terraces and intersections that function as intimate transitional areas for neighborly encounters. Although there are no large designated spaces for community use, the unique configurations foster connections between immediate neighbors, creating a more localized design with shared and communal spaces.

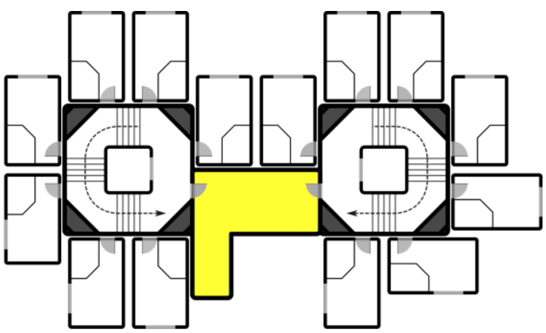

Figure 10. Floor plan at bridge deck levels of Nakagin Tower

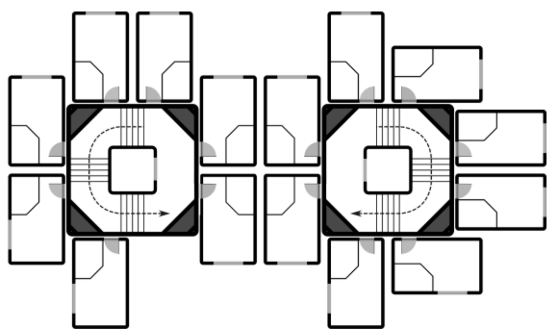

Figure 11. Typical floor plan of Nakagin Tower

Nakagin Capsule Tower consists of two interconnected concrete towers, 11 and 13 stories tall, housing 140 self-contained prefabricated capsules. The towers are connected by three bridge decks (on the 6th, 9th, and 12th floors), each featuring an external balcony. Each capsule is designed as a small, individual living or office space, measuring 2.5 meters by 4.0 meters (approximately 10 square meters). These units are intended for single occupancy, with each resident having only 10 square meters of personal space. The 140 residents share the three bridge decks, which serve as communal circulation spaces, totaling 39.75 square meters (0.284 square meters per person). This type of space can become overcrowded with higher user numbers and does not encourage community formation due to the lack of sufficient communal space.

Consequently, it may lead to social withdrawal, as residents feel disconnected and are unlikely to utilize these spaces.

Circulation and spatial heirachy

The site of Sky Habitat measures 154 by 150 meters, offering ample landscaping and communal spaces strategically placed along the access route. These spaces extend from the entrance to the entry court, where centralized circulation connects the ground floor to the living units. Vertical circulation is facilitated by dedicated cores, each equipped with four elevators and two staircases per tower. Additional communal spaces are integrated into the design through three sky bridges, further enhancing connectivity and social interaction. Unlike in Star apartment, where communal spaces are more intertwined with circulation, the design here ensures a clearer distinction between circulation paths and communal areas.

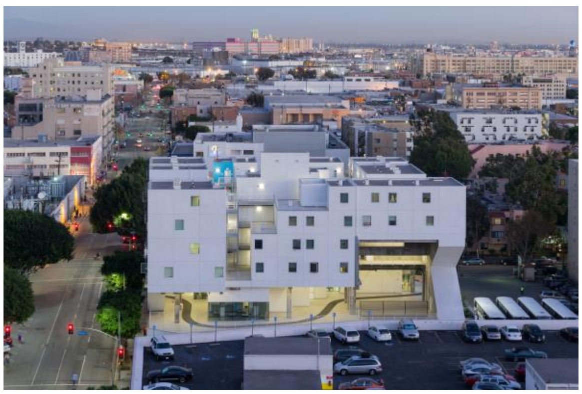

Figure 12. Photo showing terraces of Star apartment

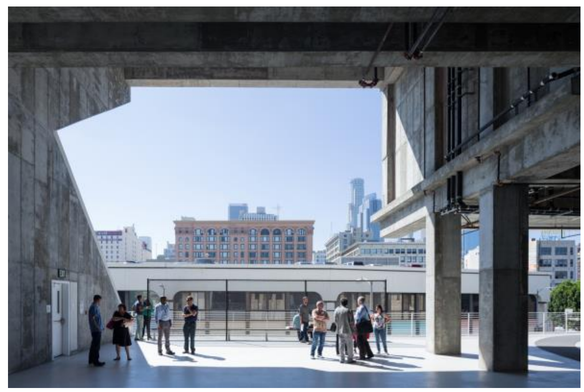

Figure 13. Photo showing in between space of Star apartment

In contrast, Star Apartments and Sky Habitat feature dedicated floors for community use. Star Apartments require residents to pass through a communal level to access their units, with a gallery connecting units to the communal atrium, fostering a high degree of engagement in shared spaces and circulation design. Communal space are placed between the circulation

The floor plans of Nakagin Tower and Habitat 67 consist mostly of residential units, with communal space limited to circulation corridors.

Degree of co living

Figure 14. Communal floor plan of Star apartment   Figure 15. Typical floor plan of Star apartment (Michael Maltzan Architecture. (n.d.). Star Apartments. Retrieved January 12, 2025, from https://www.mmaltzan.com/projects/star-apartments/)

In the Star Apartments, each residential unit is equipped with its own kitchen, bathroom, and living room, making the unit self-sufficient for individual living. At the same time, shared spaces such as community kitchens and common rooms strike a balance between privacy and community. Facilities for exercise and entertainment, including spaces for reading and art-making, foster neighborly connections while also serving therapeutic purposes. Without compromising privacy, the Star Apartments offer residents the flexibility to choose their level of participation in co-living arrangements. The communal level has a total area of 1,977 square meters, distributed as follows: A total of 260 square meters is designated for circulation (such as corridors and pathways) and essential services. 424.6 square meters is allocated for communal programs, such as shared facilities or activity zones. The remaining 1,292.4 square meters is flexible, unprogrammed space available for residential use. This could include open lounges, adaptable areas, or other uses by residents. The platform accommodates 102 people, the total free space of 1,292.4 square meters provides approximately 12.67 square meters per person. The total designated program space of 424.6 square meters offers 4.16 square meters per person.

In contrast, the Nakagin Capsule Tower lacks any concept of co-living. Designed primarily for single professionals, the building's primary purpose was to provide compact, efficient, and self-contained living spaces in Tokyo’s dense Ginza district. These capsules were marketed to young urban professionals, such as "salarymen," and frequent business travelers seeking affordable, centrally located, and functional accommodations. The absence of communal spaces reflects the tower’s focus on individual and transient use rather than fostering a sense of community. While the Nakagin Capsule Tower stands as an extreme example of compact living in an urban environment, its design leaves little room for enhancements to living or cooking areas within each unit. However, improvements could be made by introducing shared communal spaces, such as a communal kitchen or lounge, to enhance living experiences without increasing the size of the individual capsules.

Sky Habitat adopts a private and exclusive approach, targeting primarily upper-middle-class families. Its design fosters a sense of community among families through shared events and amenities. However, the emphasis on family-oriented spaces means that community-building for solo residents is not a primary design consideration. The communal spaces, while well-designed for families, do not cater to the needs of individuals or smaller households. In contrast, Habitat 67 also targets families but lacks communal or shared amenities altogether. While the building's design was not explicitly intended to promote community living or co-living, the absence of shared spaces significantly limits opportunities for community formation among residents.

Hong Kong's public housing

In the 1920s-1930s, a housing shortage in Hong Kong arose due to an influx of Mainland Chinese immigrants. Although the 1935 Housing Committee proposed low-cost housing, economic downturns stalled implementation. After the 1953 Shek Kip Mei fire left over 50,000 homeless, Governor Alexander Grantham initiated a public housing program, introducing multi-story buildings to provide affordable homes for low-income immigrants. Public housing in Hong Kong is a set of mass housing programmes through which the Government of Hong Kong provides affordable housing for lower-income residents. It is a major component of housing in Hong Kong, with nearly half of the population now residing in some form of public housing. , to ensure consistent housing outcomes, most public housing in Hong Kong was built using standard block types starting in the 1950s until the 2000s and, more recently, by adopting the modular flat design (MFD) approach.

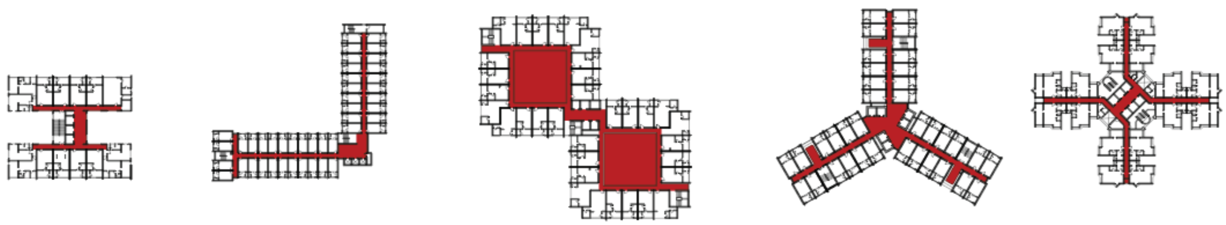

Figure 16. Typical floor plan of Hong Kong public housing model

Layout and circulation

A chronological progression of typical public housing models from the 1950s to the 1990s reveals evolving design principles. From left to right, these include the Mark I resettlement block (1950s), slab type (1960s), twin tower type (1970s), trident type (1980s), and harmony type (1990s), plans are Circulation and shared space are highlighted in red. All models prioritize land-use efficiency, featuring stacked, repetitive units connected by long double-loaded corridors, with no designated communal spaces.

The twin tower type of the 1970s introduces a unique "sky well" design, allowing natural light and ventilation into the towers. However, the high population density results in buildings of at least 25 stories, creating a "well-like" sensation for residents on lower floors. Despite this, the sky well fosters interaction by increasing visibility and auditory connections between neighbors. However, the ground floor of the sky well design lacks assigned programs and functions merely as an open area for residents. From personal observation, many of these spaces are now inaccessible, as entry has been restricted due to safety concerns over potential hazards, such as residents throwing objects from above.

By the 1990s, the harmony type demonstrates an improvement in living conditions. A typical floor accommodates 16 units with 6 elevators, compared to the trident type of the 1980s, where 36 units share the same number of elevators. This progression reflects a shift toward smaller, less overcrowded housing blocks, enhancing resident comfort and accessibility.

Degree of co living

In the early generation of Mark 1 H-blocks resettlement housing, water standpipes, communal latrines, and bathrooms were centralized in the crossbars of the structures. However, these arrangements faced significant safety and security issues, highlighting the inadequacy of shared amenities in addressing residents' needs. For example, in the resettlement blocks, a single level of 30 units, each housing approximately five people, shared only 12 latrine cubicles, annotated in light blue,12 bath cubicles, annotated in dark blue, and the wash area annotated in light red. This insufficient ratio of amenities to users resulted in poor living conditions and growing dissatisfaction.

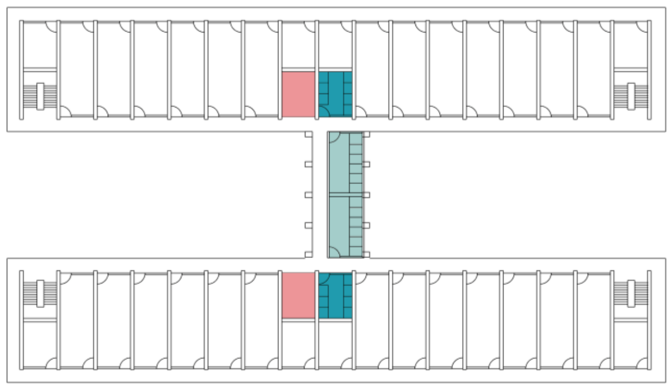

Figure 17. Mark I typical resettlement block plan. Source: Commissioner for Resettlement, Annual Departmental Report, financial year 1954–55. Hong Kong: Government Printer.

Acknowledging these shortcomings, the government conducted a review in 1964 on squatter control and living conditions. This led to a mandate requiring all dwelling units to include private bathrooms and balconies, marking a departure from shared facilities. This shift demonstrated the failure of communal amenities in ensuring adequate living standards and established the standard for comprehensively equipped private units.

While the government attempted to incorporate the concept of community into housing design, it did so primarily through external provisions. Clinics, shops, primary schools, and post offices were introduced as shared functions within larger housing estates comprising multiple residential buildings. However, within individual buildings, the absence of social and consultative spaces hindered meaningful community interaction and limited opportunities for interpersonal engagement among residents.

Conclusion

This study identifies a significant gap in modular housing case studies targeting solo dwellers, particularly regarding how such designs influence community-building strategies. The results indicate that while the early failures of co-living in resettlement housing highlight implementation challenges, they do not undermine the inherent viability of co-living as a concept. Instead, these failures underscore the importance of comprehensive design considerations, adequate funding, and contextual sensitivity to ensure success.

The findings suggest that key amenities such as toilets and bathrooms require focused attention to ensure privacy and safety—elements critical to resident comfort and security. Shared functions like kitchens and living areas, on the other hand, present substantial potential for fostering interaction and building community. Thoughtfully designed communal spaces with balanced ratios of private and shared areas can create environments that address both the practical needs of residents and the social dynamics of co-living.

The method of comparing modular housing metrics has proven appropriate for analyzing structural flexibility, layout efficiency, and community potential. However, the method’s limitations include its reliance on secondary case study data and its inability to fully capture the lived experiences of residents. Future studies could enhance this approach by incorporating user feedback or conducting ethnographic research to better understand the social impact of these designs.

While the findings of this study provide valuable insights, the generalizability of the results is limited by the specific focus on modular housing for solo dwellers and the geographic and cultural contexts of the analyzed cases. Comparing these results with other studies on co-housing and communal spaces reveals that smaller, localized shared spaces, such as lounges or gardens, are more effective at fostering interactions by creating human-scale environments conducive to casual socialization.

Further research should explore innovative approaches to integrating modular housing with co-living principles, particularly in creating adaptable, human-centered communal spaces. Investigating the long-term performance of these designs in fostering community cohesion, resident satisfaction, and environmental sustainability would provide deeper insights into their effectiveness and inform future housing developments.

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Appendix

Stadthaus

Modularity by component

CLT panel

Applications	Offsite construction, Multi-storey buildings
Country	Norway
Type	Residential buildings, Office building
Location	Brumunddal, Norway
Client	Arthur and Anders Buchardt, AB Invest AS
Building year	2019
Architectural design	Voll Arkitekter
Structural design	Sweco
Constructor	Hent AS, Moelven Limtre AS

Load bearing capacity

The Stadthaus at Murray Grove is a nine-storey residential building completed in 2008, notable for being the tallest all-timber residential building in the world at the time. It occupies a site measuring 17 m x 17 m and houses twenty-nine apartments.

The structure employs cross-laminated timber (CLT) panels as load-bearing elements, functioning as both walls and floor slabs. Their tight honeycomb arrangement ensures every wall contributes to stability and efficient pressure distribution, eliminating the need for beams or columns. Both interior and exterior walls are 128mm. The walls at the core are composed of a regular interior wall with a thickness of 128 mm, a 40 mm layer of insulation, and an additional panel measuring 117 mm in thickness, creating a composite structure that contributes to the building's stability and thermal performance.

Stability

For maximum stability,all vertical elements are utilized as shear walls, ensuring ample capacity to resist both vertical loads and wind forces. A timber core enhances the building's overall stability, while inset balconies with structural balustrades provide additional reinforcement to the outer structural walls.

Flexibility

The building's flexibility is extremely limited due to the reliance on load-bearing walls throughout the structure. Openings are fixed and cannot be modified, resulting in no adaptability for layout changes.

On the other hand, there is potential for flexibility in exterior attachments, even if the interior layout is inflexible. The use of cross-laminated timber (CLT) panels and the structural honeycomb design allow for certain adaptations on the exterior. For example, elements such as cladding, balconies, or shading devices could be added or modified without compromising the structural integrity of the load-bearing walls, provided they do not impose significant additional loads.

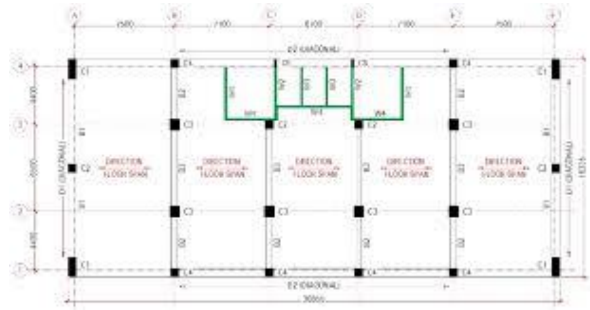
Mjøstårnet

Modularity by component

GLT column and beam

Applications	Offsite construction, Multi-storey buildings
Country	Norway
Type	Residential buildings, Office building
Location	Brumunddal, Norway
Client	Arthur and Anders Buchardt, AB Invest AS
Building year	2019
Architectural design	Voll Arkitekter
Structural design	Sweco
Constructor	Hent AS, Moelven Limtre AS

Load bearing capacity



The primary structure of Mjøstårnet consists of glulam trusses on the facades, as well as columns and beams located within the building. These elements are highlighted in **Figure 1** in black. The footprint of the structure is 16,3 m x 36,9 m

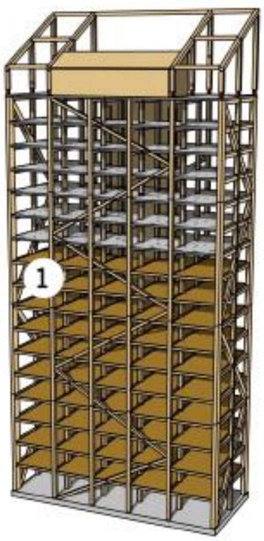
Structure	Width (mm)	Height (mm)
C1	625	1485
C2	625	630
C3 (bottom)	725	810
C3 (top)	625	630
C4	625	625
C5	215	625

According to the Proceedings of the 13th World Conference on Timber Engineering (2023), structural data for Mjøstårnet was provided by the structural designers at Moelven Limtre AS. The column grid system includes the largest columns placed at the four corners of the slab plate. The columns in the inner grid are larger on the lower levels and progressively smaller on the upper levels. This variation is due to the decreasing load demands as the height of the building increases.

The core, which serves as the secondary load-bearing element (highlighted in green), is constructed from CLT. The width of the CLT panels in the core ranges from 220mm on the outer walls to 140mm on the inner walls.

The cores are not structurally connected to the columns. Instead, the floor panels made of LVL (laminated veneer lumber) play a crucial role in transferring lateral forces from the core to the glulam truss system

Stability



Mjøstårnet stands at a height of 85.4 meters with a total of 18 floors. The building's considerable height increases its exposure to lateral forces, such as wind and seismic activity, which must be effectively resisted to prevent excessive swaying. The height plays a critical role in the structural design and directly influences the materials and systems used for stability.

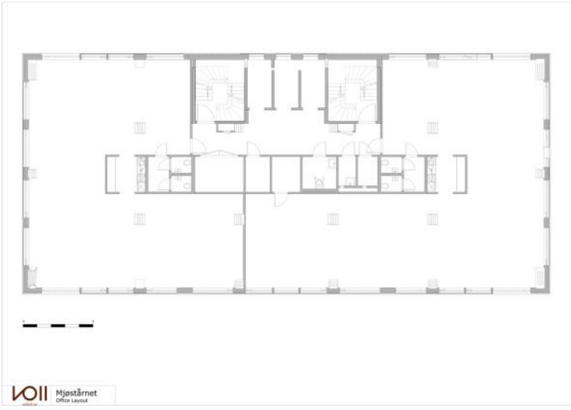
To minimize the degree of swaying in this 85.4-meter high structure, concrete slabs are used on the upper floors (11th to 18th), which add additional mass and help counteract wind-induced movement. The rest of the structure, including the first 10 floors, is made from lightweight wood, which offers sufficient structural integrity for lower levels but lacks the mass required for higher levels.

Lateral stability is primarily provided by diagonal bracing. while the CLT core does not contribute significantly to lateral stabilization due to its lower stiffness compared to the more rigid glulam trusses and bracing system.

Flexibility

The building has a footprint of 16.335m x 36.855m, covering an area of 602.7 m². The distance between the columns averages 7.180m on the x-axis and 5.100m on the y-axis. This spacing provides a flexible layout, allowing for customization and modifications after construction. Additionally, the partitions, interior walls and non-structural elements within the floor plans can be adjusted, as seen in the different level plans. The design allows the floor plans to be tailored based on the specific program requirements of each floor. The building's design supports potential future modifications or changes in function, which could enhance its long-term adaptability.

Hotel room



Meeting room level

Sustainability

Material	Share (%)
Wood	34
Insulation	33
Concrete	26
Steel	1
Other materials	6

HoHo Vienna

Modularity by component

GLT column and concrete beam

Applications	Offsite construction, Multi-storey buildings
Country	Austria
Type	Hotel buildings, business
Location	Vienna, Austria
Client	Günter Kerbler
Building year	2018
Architectural design	RLP Rüdiger Lainer + Partner
Structural design	Woschitz Group

Tyson Infanti, Business Development & Projects Manager at HESS TIMBER GmbH, the key supplier of prefabricated timber structural elements for the HOHO Vienna project, shared valuable insights and details about the construction during a webinar hosted by Wood Solutions.

Load bearing capacity

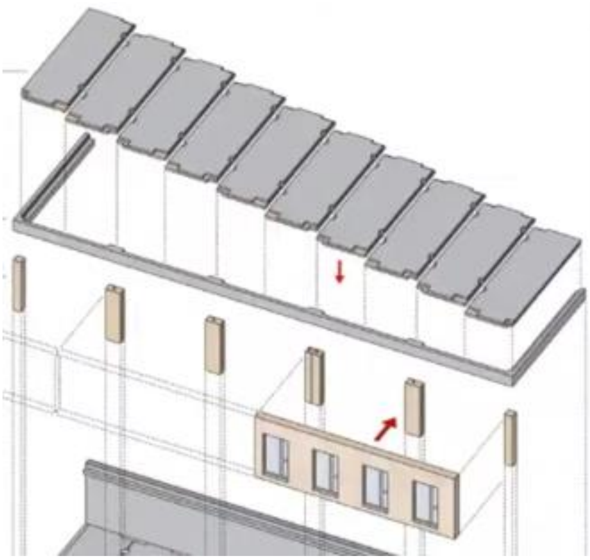
The building uses glulam (glued laminated timber) columns with dimensions ranging from 0.4m x 0.4m to 0.4m x 1.08m. The structure is erected on a concrete podium, which serves as a stable base for the timber components and helps distribute loads evenly.

Timber elements of both wall panel and slabs are horizontally docked to the sides of the concrete core. Timber bears vertical loads, such as the self-weight of the structure and live loads (e.g., occupants, furnishings).

Stability

The HOHO Vienna building stands at 24 storeys and reaches a height of 84 meters, is just 1 meter shorter than the Mjøstårnet in Norway.

The core of the building is constructed using reinforced concrete, containing shafts for elevators and stairways. This core provides the primary lateral resistance to forces, ensuring overall stability.



Key Stabilizing Features also include the precast concrete ring beam measuring 0.4m x 0.6m, is used to tie the timber elements together, including the structural glulam (GLT) columns and the cross-laminated timber (CLT) wall panels. This structural integration enhances lateral stability and ensures that the building can withstand horizontal forces.

The concrete core provides lateral resistance, acting as the primary stabilizing system against horizontal forces.

Flexibility

Low flexibility for exterior adaptability

The cross-laminated timber (CLT) exterior wall panels are prefabricated and attached to additional load-bearing columns made of glued laminated timber (glulam). These columns not only support the floor slabs but are also connected to the precast concrete ring beam.

The integration of exterior wall panels with the load-bearing columns creates a tighter facade system, which could improve thermal and acoustic insulation but reduce design flexibility for future modifications or reconfigurations of the building envelope.

Flexible Interior Layouts

The hybrid floor elements, which combine prefabricated CLT with a concrete plate are prefabricated in modular sizes of 2.4m x 7m. The distance from the core to the facade is covered by a single 7-meter floor element, allowing for an uninterrupted span across the entire floor, providing flexibility and minimizing structural interruptions. The distance between each column is 4.8 meters, which is the span of two hybrid floor elements.

The absence of shear walls within the interior space allows for uninterrupted floor plans, providing high levels of flexibility in the interior layouts. This enables the building to adapt more easily to different functions or tenant requirements over time.

Material choice

The HOHO Vienna building is constructed with 75% wood, showcasing an innovative approach to hybrid construction. During the webinar, Tyson Infanti highlighted that the use of concrete in the core was an economical choice rather than a technical necessity. He admitted that the building could have been realized entirely in timber, demonstrating the feasibility of a fully timber structure.

This acknowledgment underscores the potential to eliminate concrete in similar projects, which could significantly enhance the sustainability of building designs. A fully timber structure would further reduce the carbon footprint and environmental impact, aligning with the design goals for sustainability.

Hotel Jakarta

Volumetric modular

Country	NL
Type	Hotel buildings, business
Location	Amsterdam (NL)
Client	WestCord Hotels
Building year	2018
Architectural design	SeARCH
Structural design	PBT

Load bearing capacity

The building's load-bearing system consists of two main components: the reinforced concrete skeleton structure and the modular room units. These systems work together to support the vertical and lateral loads of the nine-storey hotel.

The building is divided into three distinct sections, each structurally independent and load bearing. The room modules are designed to be self-supporting, with vertical loads managed within each section.

Reinforced Concrete Skeleton Structure

Staggered Base: The modular units are placed on a staggered reinforced concrete base, ensuring even load distribution and stability.

Foundation: All vertical loads are ultimately transferred to the reinforced concrete foundation, which anchors the building securely.

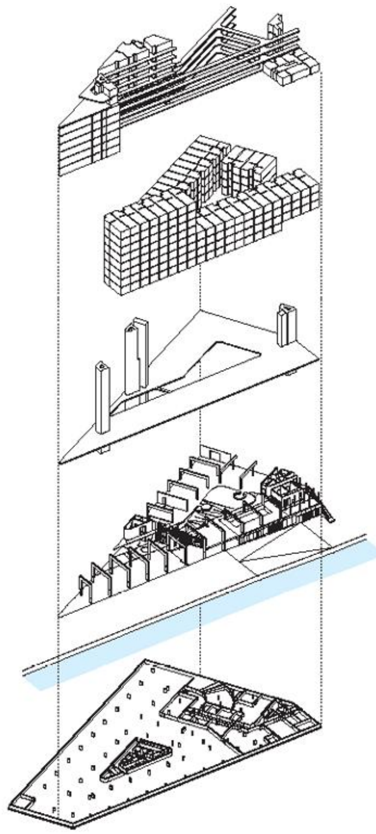
Modular Room Units

Each prefabricated modular room unit measures 30m² and is enclosed by 14cm-thick, five-layer cross-laminated timber (CLT) walls that function as bearing walls, supporting up to 8 stacked layers.

When placed side by side, the walls are doubled. Doubling of partition walls between units increases the structural wall thickness to 28cm, providing enhanced load-bearing capacity at 3.3m intervals (the width of each unit). The room modules are 10 m long, 3.70 m wide and 2.70 m high.

Stability

The building includes **three reinforced concrete cores as** access tower, which provide the main lateral stability.



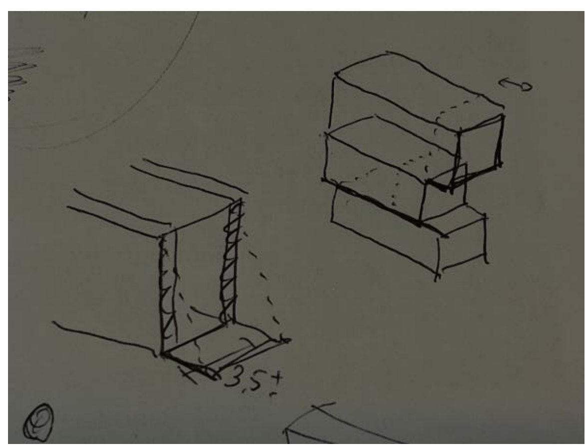
The wooden gallery, encircling the courtyard, serves as a critical structural element by connecting the three separate parts of the building: the modular units and the reinforced concrete tower. This gallery functions as a stabilizing ring, tying these components together and ensuring the building behaves as a cohesive structure under lateral forces. By linking the modules and the core, the gallery efficiently redistributes lateral loads—such as those caused by wind—across the interconnected system.

Flexibility

Of the hotel's 201 rooms, 176 were prefabricated using modular construction, while the remaining rooms were built on-site to fit the constraints of the challenging site.

Due to the load-bearing nature of the prefabricated modules, the flexibility of the structure is extremely low in terms of internal layout. It is not feasible to change the size of the hotel rooms or repurpose entire floors in the future, as the load-bearing walls and module dimensions are fixed.

However, the installation of the gallery introduces the potential for exterior attachments to the stacked modules. The small intervals between the load-bearing walls—3.3 meters—allow for the possibility of attaching lightweight structures, such as balconies, to the modules. Additionally, variations in the stacking arrangement could be explored to introduce irregularities in the façade design, as the primary load-bearing walls remain aligned, enabling such modifications without compromising structural integrity.



Material choice

According to Kathrin Hanf, project manager at SeARCH, the reinforced concrete floor slab was chosen for its multiple advantages.

She explained that "only the thin concrete slab made it possible to actually accommodate 200 rooms located on the facades on the relatively small plot with ideal lighting." A wooden floor construction would have required greater module height, potentially reducing the number of floors to remain within the development plan’s boundaries.

This highlights the trade-off between timber and concrete and the potential for a 100% timber module in a different context.

Additionally, concrete's superior acoustic performance made it an ideal choice for the hotel. The heavier floor slab effectively controlled impact sound insulation, reducing sound transmission between floors. Combined with the doubling of partition walls and rock wool-filled gaps (4 cm thick), the design met the high acoustic standards required for hotel operations, ensuring minimal noise transmission between rooms.

Wood can provide decent sound insulation if appropriately designed, but it generally requires additional layers or materials to meet high acoustic standards.

Treet

Volumetric modular

Country	NL
Type	Hotel buildings, business
Location	Amsterdam (NL)
Client	WestCord Hotels
Building year	2018
Architectural design	SeARCH
Structural design	PBT

Load bearing capacity

All primary load-bearing structures in the building utilize timber. Glulam is employed for the trusses, cross-laminated timber (CLT) for elevator shafts, staircases, and internal walls, and timber frameworks for the prefabricated modules.

The structural system of the building is characterized by a hybrid assembly of glulam trusses, prefabricated modules with timber framework, and concrete slabs. The glulam trusses provide the primary horizontal stiffness and support for the building. These trusses, located along the façades, are the main load-bearing elements, with typical column cross-sections measuring 405x650 mm or 495x495 mm, and diagonals measuring 405x405 mm.

Prefabricated residential modules make up the main building volume. These modules are stacked in sets of four storeys, with levels 1-4 resting on a concrete garage deck, separated from the surrounding load-bearing structure. Above this, level 5 acts as a "power storey," constructed with strengthened glulam elements and connected directly to the trusses. The power storey supports a prefabricated concrete slab, which serves as the foundation for the next four stacked levels (6-9). These upper levels, like the lower ones, are independent of the load-bearing truss structure except at their base connection to the concrete slab.

The CLT shaft is not part of the load bearing system and is installed separately from the trusses.

The base of the building is a rectangle with length of baselines equal to 23 x 21 m.

Stability

The building, with a height of approximately 45 meters and 14 storeys, relies on glulam trusses as the primary system for lateral stability. These trusses effectively transfer lateral forces, such as those caused by wind loading, to the reinforced concrete foundation through anchored joints, ensuring overall structural stability (**refer to Figure 6**).

To accommodate construction tolerances and allow for potential horizontal movement, there is a theoretical clearance of 34 mm between the building modules and the glulam trusses. This clearance prevents interference between these components. The roof comprises a prefabricated concrete slab, designed to interconnect the trusses and enhance the building’s mass and minimize swaying

The external cladding and glazing of the building are fixed directly to the load-bearing trusses and balconies, rather than the residential modules. This design ensures that wind loads do not act directly on the prefabricated modules, further protecting their structural integrity and contributing to the building's stability under dynamic forces.

Flexibility

The base of the building is a rectangle with dimensions of 23 x 21 m, incorporating three types of modules: Type A and B, which measure 4 m x 8.7 m, and Type C, which measures 5.3 m x 8.7 m. Since the modules are not directly connected to the primary truss structure, the building demonstrates a high level of structural flexibility. The truss system, responsible for bearing all lateral and vertical loads, operates independently of the modules, allowing for potential modifications to exterior elements without compromising stability.

However, the prefabricated modular units impose significant constraints on interior flexibility. The fixed dimensions of the modules make it unfeasible to alter the internal floor plan, change apartment sizes, or repurpose entire floors in the future. This limitation restricts user customization within the interior.

Despite this, the installation of facades and balconies introduces the potential for exterior attachments to the truss structure, independent of the modules. As the truss system and modules are theoretically separated, lightweight exterior elements, such as balconies, can be added without impacting the prefabricated units.

Star Apartment

Hybrid- concrete superstructure and timber framed modules

Country	NL
Type	Hotel buildings, business
Location	Amsterdam (NL)
Client	WestCord Hotels
Building year	2018
Architectural design	SeARCH
Structural design	PBT

Load bearing capacity

Load-Bearing Capacity:

The load-bearing capacity of the Star Apartments primarily relies on the concrete superstructure, which includes a large podium and three circulation cores providing vertical support, while the timber-framed units, stacked up to four levels, function as load-bearing components. Each unit carries not only its own weight but also the weight of the units above it. The wooden frame, with vertical members (40x90mm) and ceiling members (65x300mm), is designed to support vertical loads from the stacked units, residents, and furnishings. The concrete superstructure provides additional stability, but the timber units are integral to distributing the load vertically through the building's stacked design.

Stability:

The stability of the Star Apartments is primarily provided by the concrete superstructure, which anchors the stacked timber units and ensures the overall structure remains resistant to lateral forces. The concrete podium, along with the circulation cores, offers vertical and horizontal stability. The timber units, while load bearing, are more susceptible to lateral movement, especially since there is no exterior bracing. The internal concrete galleries or corridors, connecting the timber modules, likely provide lateral stability by adding rigidity to the vertical stacking system. Despite the lack of external bracing, the stacking of the units provides some inherent stability through the distribution of loads across multiple levels. The internal concrete elements play a key role in ensuring stability, reducing the ability to modify the exterior or layout easily.

Flexibility:

The flexibility of the Star Apartments is constrained by the fixed nature of the modular units and the concrete superstructure. While the timber frame units themselves can offer some internal flexibility in terms of layout (e.g., the interior configuration of rooms), the overall design is rigid due to the stacking arrangement. The units are connected and supported by the concrete superstructure, limiting the possibility of changes in unit placement or layout.