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MOCKUP OF PREFABRICATED CLT MODULES FOR SMALL SOCIAL CONDOS: EVALUATION OF MACHINING, MANUFACTURING, ASSEMBLY, AND PERFORMANCE FOR STANDARDIZATION IN CHILE.

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ABSTRACT: Due to the growing housing deficit, Chile developed an initiative to densify well-located 9x18 meter lots through "small social housing condominiums." So, the question arises: What can we improve from industrialization to make this opportunity more efficient, better, and more massive? This work arises from the observation that the main gaps in the awarding of subsidies in this country are the speed of response from the executors, construction times, insecurity in the neighborhoods, access to qualified labor, quality of construction, and flexibility in design. In response to these gaps, the "Industrialized Building 4 CLT modules" proposes a permanent stock of prefabricated housing, more than 90% prefabrication of the works, zero storage on site, maximum productivity in manufacturing lines, quality control in the factory and flexible modular design.

KEYWORDS: Wooden Buildings, Social Housing, Prefabrication, Modular Construction.

1 – INTRODUCTION

1.1. INDUSTRIALIZATION CHALLENGE

This project stems from the "Industrialized Housing Challenge for Small Condominiums" competition, promoted by public and private entities in Chile. Of the three awarded initiatives, this was the only one featuring a timber structure (Fig. 1). Following the award, a full project was developed, including architecture, structural engineering, technical specifications, and a BIM model with machined elements, connectors, and specialty coordination (Fig. 2)

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The challenge responds to a critical issue: more than 640,000 families in Chile currently lack adequate housing. Of this deficit, 84.4% corresponds to households living in overcrowded, shared, or irrecoverable dwellings. Despite their limitations, shared housing allows many families to maintain support networks and proximity to services, jobs, and urban infrastructure.

In this context, micro-settlement—the use of existing family-owned land for densification—emerges as an alternative to urban sprawl. It excludes land cost from housing prices, contributes to the regeneration of deteriorated neighborhoods, and alleviates pressure on urban peripheries. However, this strategy faces challenges: low effective demand, scarce private sector involvement, complex permitting processes, and a lack of appropriate design typologies.

Figure 1. "Industrialized Housing Challenge for Small Condominiums." Tallwood awarded initiative.

1.2 9X18-METER LOTS: AN OPPORTUNITY.

In the Metropolitan Region, nearly 216,000 plots measuring 9x18 meters were distributed during the 1960s and 1970s under the "Operación Sitio" program. These plots, initially equipped with a basic sanitary unit and subsequently self-built by their occupants, now form a consolidated urban fabric.

If at least 10% of these plots were reused under the small condominium model (assuming 2.5 units per lot), over 50,000 new housing units could be generated without the need for new urban land.

1.3 INTERNATIONAL STATE OF THE ART

On this topic, Fierro et al. present a case study on a large-scale academic timber building, where structural timber systems combined with prefabrication strategies and design flexibility helped address technical challenges such as long spans, fire resistance, and fast construction—factors also relevant to optimizing industrialized social housing [1].

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In their work on modular CLT buildings using Irish timber [2], the authors analyze major design and execution challenges in modular mid-rise construction, emphasizing early specialty coordination and component standardization—central elements also tackled by the prefabricated social housing mockup.

In terms of resource efficiency, particularly relevant to this project's context, research on modular CLT construction using low-grade timber [3] highlights the potential of industrialization to democratize access to timber buildings. It shows that efficient prefabrication techniques can reduce costs and increase availability of sustainable housing solutions—an objective shared by the CLT modules for small condos.

1.4 QUESTION AND HYPOTHESIS.

This context raises a key research question: What can industrialization contribute to make the construction of small condominiums on existing 9x18-meter plots more efficient, viable, and scalable?

From a technical and operational standpoint, the hypothesis is: Industrialization can address critical housing system gaps—such as execution speed, construction quality, labor shortages, and rigid typologies—through a model based on prefabricated CLT modules, with adaptable design, factory quality control, and high productivity.

1.5 OBJECTIVES

The project's objective is to evaluate the technical feasibility and performance of a modular CLT construction system through design and simulation, leading to the construction and testing of a full-scale mockup, as a basis for its standardization within Chile's housing solution catalog.

This paper documents the development process, covering architectural, structural, construction, and performance components, along with preliminary results and scalability projections in the context of Chile's housing crisis.

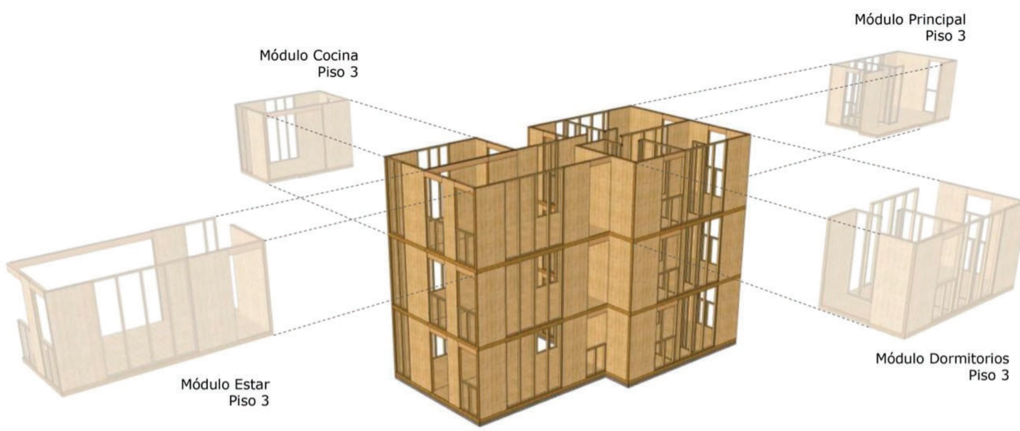

Figure 2.Distribution of the 4 modules per floor.

2 – METHODOLOGY

To validate the proposed system, a methodology was defined based on the future construction and evaluation of a full-scale mockup.

This phase included the participation of researchers, private entities, and graduate students, and encompassed the following stages:

- Finalization of the design, including a BIM model coordinated with structural, plumbing, and electrical specialties.
- Simulation of structural, thermal, and acoustic performance, introducing improvements over the original award-winning design.
- Development of a DFMA (Design for Manufacture and Assembly) model, in collaboration with the manufacturing plant, to maximize production efficiency.

In addition, the following steps are planned for 2025:

- Production of CLT structural components, machined with CNC technology to ensure dimensional precision and repeatability.

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- In-plant assembly, based on a two-stage prefabrication system, with fully assembled and finished off-site structural modules.

- On-site assembly of the mockup, composed of four modules (two on the first floor and two on the second), and a temporary staircase.

- Evaluation of thermal and acoustic performance using standardized measurements to validate the solution as a sustainable and replicable alternative.

- Technical review of connectors and design adjustments based on results and specific site conditions.

- Systematic documentation of the process and coordination of technical visits with authorities, sponsors, and stakeholders from both the public and private sectors.

The mockup (Fig. 3) serves as a functional version of the proposed housing solution, enabling validation of technical, logistical, and regulatory aspects under real application conditions. It represents a key step toward its eventual approval and inclusion in the Chilean Ministry of Housing and Urban Planning's catalog of Industrialized Housing Solutions.

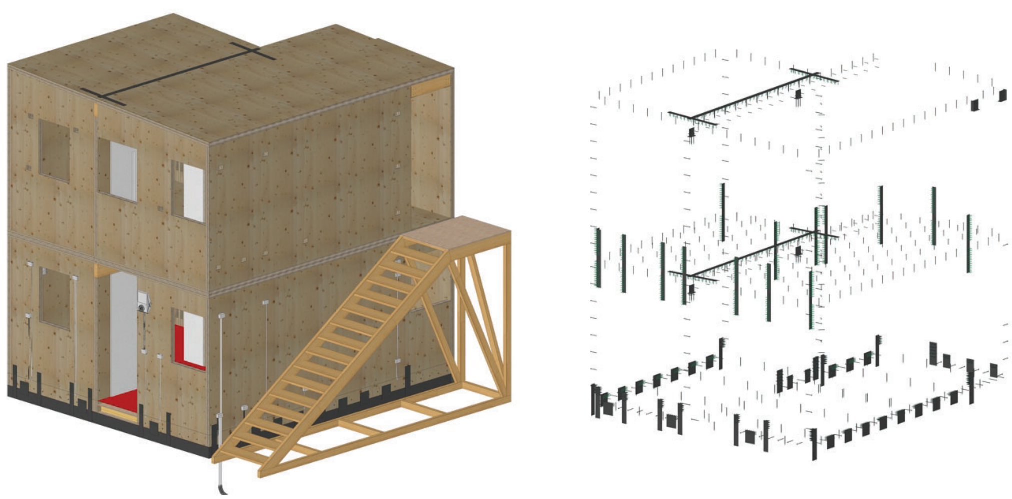

Figure 3. The mockup Model

3 – DESIGN PROCESS: OPTIMIZATION.

3.1. STRUCTURAL ANALYSIS

The building's 3D structural model reports expected seismic displacements of 10.8 mm in the X direction and 5.9 mm in the Y direction, values that remain within acceptable ranges for this type of construction. Maximum inter-story drift was also analyzed to assess lateral load behavior.

The structural system is composed of CLT walls and metal connectors, distributed in a repetitive module along structural axes identified by letters and numbers (e.g., Axis 1, Axis A). The primary connectors used include the TCN200 model and WHT340 and WHT440 joint elements, selected according to location and structural demand. Tables detail the quantity, type, and placement of connectors at each level of the building (floors 1 to 3).

The adjustable LSC connector was recommended for timber stairs, enabling efficient connection between stringer and support without additional framing. Its design allows for left or right installation and is available in galvanized or stainless steel versions for more demanding conditions. Installation must meet specific fastening and positioning requirements to ensure structural resistance.

3.2. THERMAL AND DAYLIGHTING EVALUATION

One of the main contributions of this phase was the ability to conduct parametric simulations using the

Galapagos algorithm to optimize the location and size of windows in bedrooms and living areas, aiming to improve natural lighting and interior visibility. A total of 500 iterations were evaluated, yielding configurations with better Daylight Autonomy (UDI) and geometric visibility indices, without sacrificing visual comfort (Fig. 4).

The continuity of the thermal envelope was also analyzed using solutions such as EIFS (Exterior Insulation and Finish System), SATE, and Volcanboard. The EIFS system reduced annual energy demand by up to 46% compared to the baseline case. Although it requires higher initial investment, it offers superior energy performance and long-term savings.

3.3. ACOUSTIC PERFORMANCE

Using INSUL software, different CLT panel configurations combined with concrete and Acoustiblok membranes were evaluated. One of the main results were:

- Airborne sound insulation (Rw): Up to 53 dB with hybrid configurations (CLT + concrete + Acoustiblok).
- Impact sound insulation (Ln,w): Notable improvement with carpet on resilient base (73 dB), lower performance with laminated floors (81 dB), and poor performance with unfinished hard floors (80–85 dB).

System variants (OpA, OpB, OpBi, etc.) allowed the solution to be tailored to the specific type of insulation required, whether airborne or impact.

3.4. ASSEMBLY SEQUENCE

Prefabricated modules are machined at the plant using CNC technology. They will be assembled in a 3,500 m² factory in Santiago and transported by trucks with controlled dimensions (6 m long x 3 m wide x 2.8 m high). On-site assembly is carried out directly from the truck to the final position using a 4-ton mobile crane.

Each module is installed in three hours by a crew of three workers plus the crane operator. The foundation slab and utilities are pre-installed. The staircase is added on the fifth day.

In the case of the full build, it will be completed in about one month: 2 weeks for demolition and foundations, 1 week for assembly, and 1 week for exterior finishes.

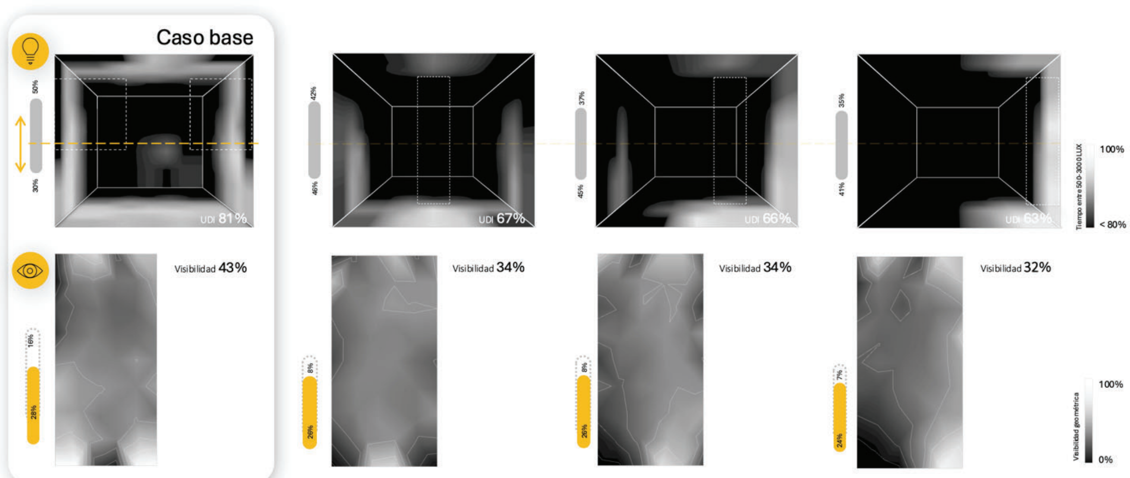

Figure 4. optimization the location and size of windows in bedrooms and living areas.

4 – RESULTS

4.1. PREFABRICATION AND QUALITY CONTROL

The developed system enables over 90% prefabrication of the total construction. By applying the DFMA methodology and detailed BIM modeling from early stages, the project achieves high factory efficiency, minimizes errors, and optimizes material use. All quality control is performed in the plant, ensuring precision in machining, assembly, and finishes.

4.2. ENERGY PERFORMANCE AND SUSTAINABILITY

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The housing units meet the requirements of the Sustainable Housing Certification (CVS) from the Chilean Ministry of Housing (MINVU). An analysis conducted by EBP, considering all possible orientations, showed an energy demand below 57 kWh/m²-year and thermal comfort exceeding 30% across all three levels.

Each condominium captures approximately 24.3 tons of CO_2 equivalent due to the use of structural timber. Additionally, 24% of demolition waste is reused, and 91% of the construction budget incorporates material optimization strategies. Water consumption is five times lower than that of equivalent reinforced concrete solutions.

4.3. TECHNICAL AND ECONOMIC FEASIBILITY

The production of a complete condominium (3 housing units) takes 10 working days in the factory (Fig. 5). On-site assembly requires an additional 10 days. Thus, the full construction cycle is completed in approximately one month. The plant projects a capacity of 500 housing units per year by 2024, scalable to 1,500 between 2025–2028 and 2,000 between 2028–2033.

The standardized system allows for efficient production, cost reduction, and greater control over timelines and quality.

4.4. CONSTRUCTIVE AND LOGISTICAL CONSIDERATIONS

Each condominium can be assembled by a team consisting of one foreman and four workers, supervised by on-site professionals. To deliver 14 condominiums per month, 7 crews and logistical support from the plant are required (Fig. 6).

Construction involves 69.6% off-site costs and 30.4% on-site. The system supports serial production with low on-site labor requirements and minimal urban impact during construction.

4.5. SYNTHESIS

The development of a model and simulation, followed by the construction of a mockup, allowed validation of key aspects of the system: structural design, logistics, thermal and acoustic performance, energy efficiency, and compliance with current regulations.

Through the mockup construction, the technical and operational feasibility of the system will be demonstrated for real-world application, with advantages in sustainability, quality control, speed, and cost. The model represents a scalable industrialized alternative to address the housing deficit in Chile's consolidated urban areas.

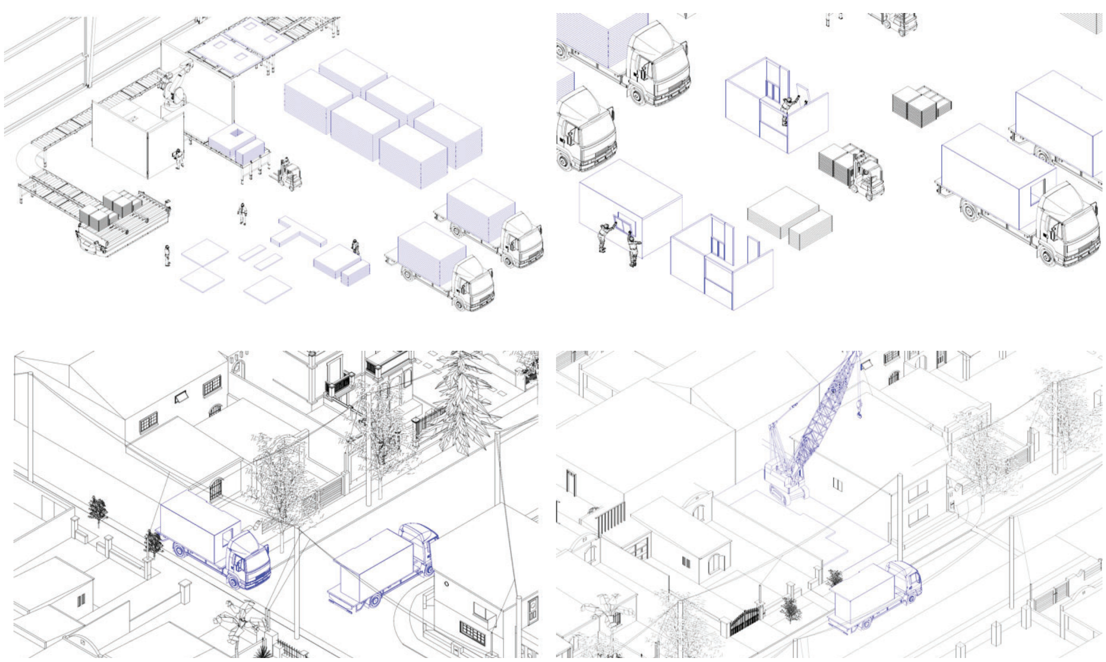

Figure 5. Fabrication and transportation sequence

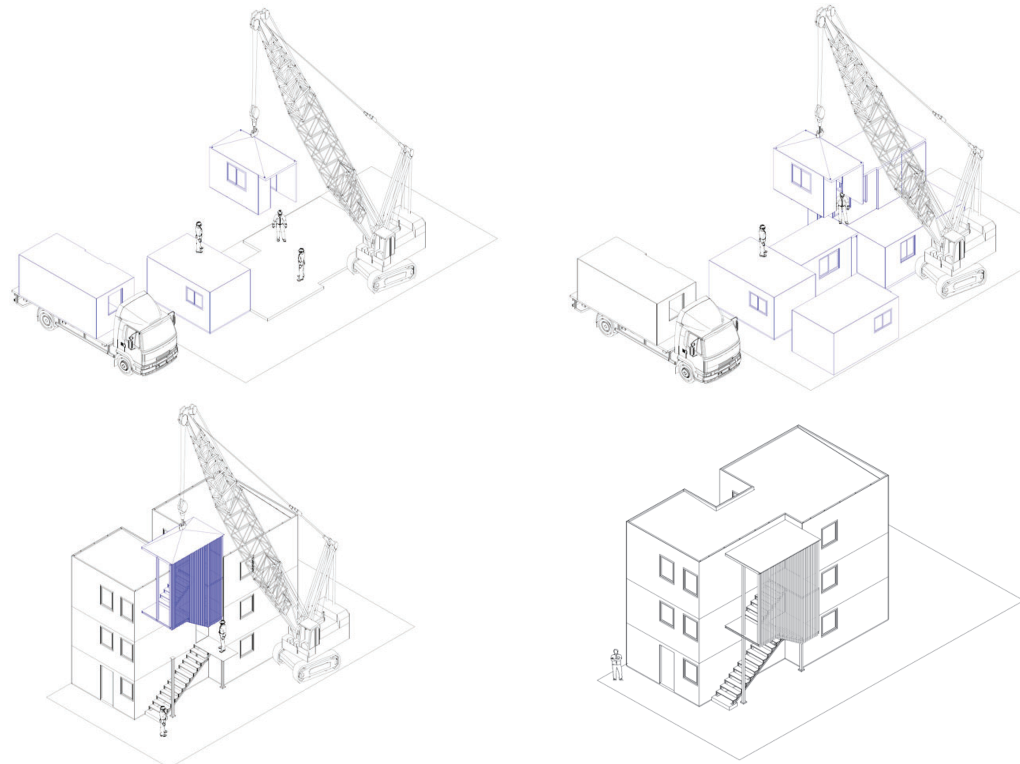

Figure 6. Assembly sequence.

5 – CONCLUSIONS

The project "Industrialized Building: 4 CLT Modules" offers a technically and operationally viable alternative to address Chile’s housing deficit, integrating construction efficiency, sustainability, and replicability in consolidated urban areas.

The construction and evaluation of the mockup will demonstrate that:

- Industrialization significantly reduces execution times, with factory quality control superior to traditional methods.
- The modular CLT system adapts to existing urban plots, such as 9x18-meter lots, without requiring new infrastructure or urban development.
- High standards of thermal, acoustic, and structural performance are met, as required for quality social housing.
- Standardized prefabrication, combined with DFMA methodology and BIM modeling, ensures efficiency in manufacturing, assembly, and resource management.
- The system is scalable in production capacity and adaptable to various geographic, climatic, and regulatory contexts.

Recommendations for implementation and future development:

- Technical certification: Advance the formal incorporation of this solution into the Chilean Ministry of Housing’s Catalog of Industrialized Housing Solutions, enabling its application in subsidized projects.
- Public-private collaboration: Strengthen partnerships among industry, developers, and academia to ensure operational continuity, iterative innovation, and validation in diverse territories.

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- Operational monitoring: Integrate monitoring systems into real projects to evaluate long-term thermal and acoustic performance, providing feedback for design improvement.
- Financial incentives: Promote funding and subsidy mechanisms that recognize the environmental, economic, and social benefits of sustainable prefabricated solutions.

In summary, this project (Fig. 7)represents a concrete and replicable proposal to advance a housing policy based on industrialized timber solutions, with high positive impact in environmental, economic, and social terms, and aligned with Chile's goals for sustainable urban densification.

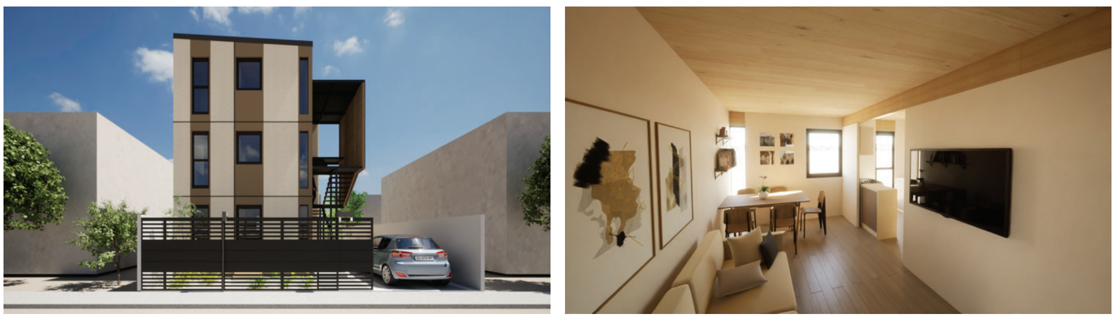

Figure 7. Last version of the Small Condominium.

6 – ACKNOWLEDGEMENTS

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