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LIGHT FRAME TIMBER TOWER: INTERDISCIPLINARY DESIGN OF PREFABRICATED AND ANTI- SEISMIC 5- STORY EXPERIMENTAL BUILDING

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ABSTRACT: Currently, the 100 percent of the buildings over four stories in Chile are built on reinforced concrete. This paper presents the first modern mid-high rise anti-seismic timber structure built in the country based on the light frame construction system. With 5-story high and a 6th-floor terrace, it satisfies the strict seismic regulation and becomes a referent for future timber constructions in our country. It was designed collaboratively by an interdisciplinary group of architects, engineers and members of the industry responsible for the construction. The result is an experimental tower -made of prefabricated stackable modules- which optimize its prefabrication, transport and subsequent assembly. It is expected to monitor its energy performance, seismic behavior and measures its construction cost-efficiency while market surveys of perception to potential end users and developers are conducted.

KEYWORDS: Light frame timber tower, Interdisciplinary design, Prefabrication, Modularization

1 INTRODUCTION[1]

Chile is one of the most seismically active countries in the world, so the infrastructures must comply with high structural standards. The actual seismic regulation was designed for reinforced concrete buildings, and there is no particular normalization for mid-rise high buildings in timber yet. That is why there are almost no over 3 - story high wood structures and no information about their construction costs [1]. On the other side, although wood is an abundant natural resource in Chile, there is a lack of knowledge and technical professional capacity in all areas of timber construction. The country has the industrial capacities, but there is a need to develop and share the technical know-how to promote the mid-high rise timber construction.

This paper aims to analyse the interdisciplinary collaboration methodology and the participants involved in the process of design of a six-story experimental timber building based on industrialized construction systems in Chile (Figure 1). This construction project has an academic and educational purpose, so the actors involved are not necessarily the same as in real habitable projects. The institution in charge of the design is the Timber Innovation Center, a joint venture between the Catholic University of Chile (UC) and the Chilean Wood Corporation (CORMA). Its board is formed by representatives of the faculties of engineering, architecture, civil construction, and agronomy, as well as the representatives of the leading timber construction industries in the country. The mandates of this project comes from the Secretary of Housing of Chile, and it is financed by members of the timber construction industry and public institutions which are interested in the development of sustainable constructive systems in Chile. Therefore, the project needs to respond and account for academic, private and public interests simultaneously.

The forest companies in Chile are among the biggest in the world due to the abundant forest resources in the country. The economy around this resource is based mainly on the extraction and exportation of the commodities. In this context, the Chilean State wishes to promote the local manufacture of timber-based products to increase the timber building construction with more efficiency and better technology. Nevertheless, timber has been used mainly for temporary and emergency housing based on inferior quality materials, resulting in a low valuation of the material for permanent housing solutions by Chilean society. The latter led to a low demand for wood-based buildings.

For these reasons, the Chilean State has been over the past years partially funding several initiatives related to the development of the manufacture of timber engineering products and research associated with the development of timber construction systems for low and high rise structures. In this context, the project presented in this text emerged as the first mid-rise timber structure in Latin America based on a light-frame construction system viable to be manufactured by most of the local building industry.

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Figure 1: *Light Frame Timber Tower render*
Source: Developed by the Timber Innovation Center Interdisciplinary Team.

1.1 DESCRIPTION

The project consists of the design, prefabrication, transportation, and assembly of a six-story experimental timber building based on a light-frame timber construction system. The building was designed to be erected using prefabricated modules to be manufactured within less than a month and assembled in less than a week (Figure 2).

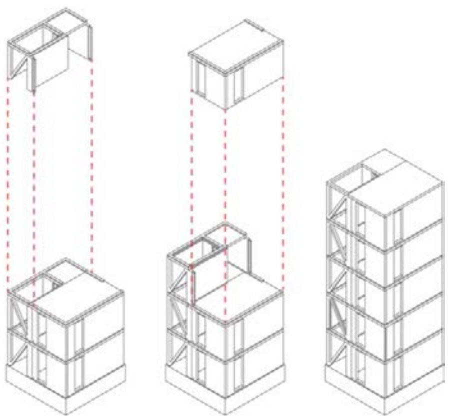

Figure 2: *Modules assembly process.*
Source: Author. Developed by the Timber Innovation Center Interdisciplinary Team.

The system considers the utilization of ATS (Anchor Tiedown System) technology, which is frequently used for these types of buildings in seismic areas in North America and New Zealand. This technology consists in the installation of a continuous rod inside the wall frame; with the purpose of transferring the seismic solicitations of the structure to the foundation to prevent shear wall overturning. This technology is viable to make a structural design and fulfil the seismic regulations for medium and high rise buildings in Chile.

This project is the first to use this technology in Latin America. Considering the inexperience of high rise timber structures in the region, the primary purpose of the project is experimental, to understand its physical performance and structural behavior before using the system for other purposes. Therefore, the primary participants involved in the project have had no previous experience, and the design has been based mainly on the literature available and consultancy of experts from associated foreign institutions.

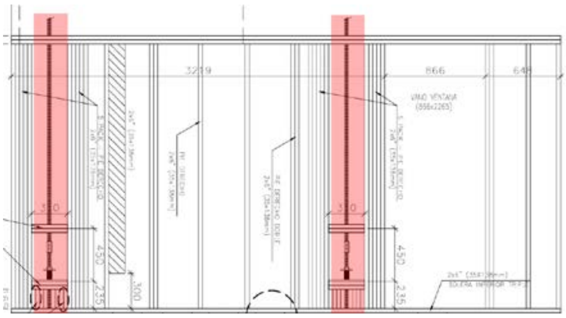

Figure 3: *Diagram of ATS installed in the light frame structure.*
Source: Author. Developed by the Timber Innovation Center Interdisciplinary Team.

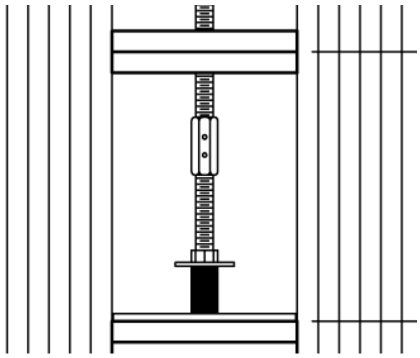

Figure 4: *Detail of the ATS installed in the light frame structure.*
Source: Author. Developed by the Timber Innovation Center Interdisciplinary Team.

Besides, the project considers a ventilated façade which will be tested in different thicknesses. Therefore, it will be possible to measure the speed of the air inside the ventilated cavity in several configurations to determine the most efficient. After concluding the ideal thickness of the cavity for each orientation, the whole building will be refurbished following these parameters. The energetic performance will be measured every day for twelve months, and it will be compared with the performance of another prototype of one storey high, emplaced in the same site and conditions.

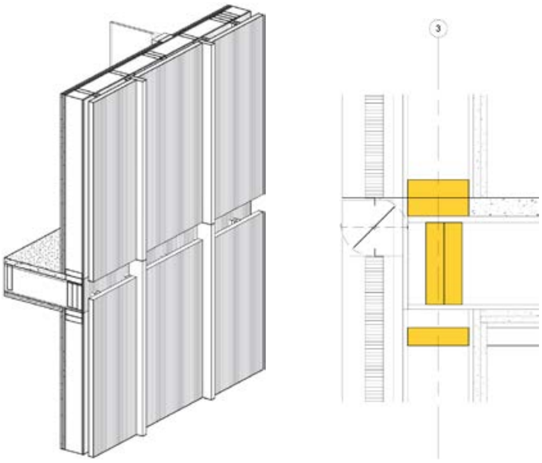

Figure 5: *Illustrations of the ventilated façade.*
Source: Author. Developed by the Timber Innovation Center Interdisciplinary Team.

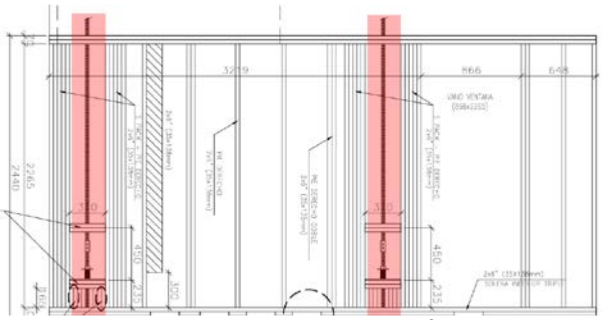

Figure 6: *ATS installed in a generic timber frame wall.*
Source: Author. Developed by the Timber Innovation Center Interdisciplinary Team.

2 DESIGN METHODOLOGY

2.1 OBJECTIVES

The project's objectives are five and pursuing diverse results:

First, this project seeks to calculate the costs of manufacture, transportation, and assembly according to the actual development of the technology in Chile to evaluate its economic viability when compared with other construction systems based on concrete and steel, which are used by the Chilean construction industry for high-rise buildings.

Second, it seeks to measure its performance through the installation of equipment and sensors which will gather the following data of the building: (1) energy demands, (2) thermal transmittance, (2) thermal bridges, (4) water tightness, (5)air tightness, (6) water vapur permeability, (7)higrotermic behavior and, (8)acoustic properties. These variables will be measured every day for eighteen months, and it will be compared with the performance of other one-story prototypes, but with not ventilated façade instaled. These data will allow the researchers to extrapolate the information and determine the most energy-efficient configuration (height-façade-materiality) in different locations and climates.

Third, several accelerometers will be installed in the building in order to obtain data regarding its seismic behaviour. This information will be later used to design habitable buildings in different seismic zones of the country using the same construction system.

Fourth, market surveys of perception to potential end users and developers will be conducted. This project seeks to counteract the fact Chileans do not accept wood as a high-quality construction material in general. The prototype will be open to the building industry –real state and construction companies-, educational institutions and the general public during the measurement period to demonstrate the quality and structural stability to the visitors.

Also, the first floor will be showing the results of the measurements and the process of manufacture and assembly, while the fifth level will be equipped like a real high-quality apartment with the purpose of changing the perception of timber construction for housing. The others floors will only be accessed by researchers who will oversee the measurements of the performance of the building (Figure 3). Also, solar panels installed at the terrace will provide energy for the building.

Figure 7: *Section of the building.*
Source: Author. Developed by the Timber Innovation Center Interdisciplinary Team.

Furthermore, considering that the project will be emplaced in a National Park -where many native timber species have disappeared due to the introduction of foreign species over decades- the immediate context where the project will be emplaced considers a research project which aims to develop and study strategies of re-growing native species. This way the project will not only pursue the demonstration of the viability of high rise timber structure in seismic areas and its performance but also illustrate that wooden-based structures can coexist with responsible forest management.

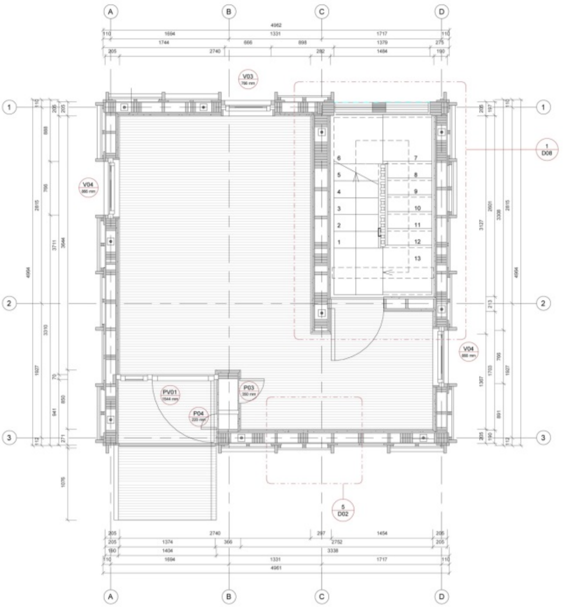

Figure 8: *Plan view of the second floor*
Source: Author. Developed by the Timber Innovation Center Interdisciplinary Team.

Figure 9: *Image of the project emplaced on the real site.*
Source: Author. Developed by the Timber Innovation Center Interdisciplinary Team.

2.2 PARTICIPANTS

Given the number of activities developed and the amount of data collected and analyzed, many participants and institutions have been involved since the beginning of the process, until the current stage of development of the project. First, there is an architectural team in charge of designing the general layout of the project seeking to represent an actual type-apartment configuration, integrating other field experts in the design layout. Second, an engineering team in charge of reviewing international research projects and literature related to the ATS construction system, to develop the structural design according to the current building regulations in Chile. Third, an energy efficiency evaluation team to oversee the simulations of the physical-performance parameters using software analysis, comparing simulations to previous measurements in other projects. The project will use this information to calibrate the software consequently and adequately can measure more accurately the energy behavior of the ATS construction system. Fourth, the construction company team as a critical actor in the design process. An evaluation of the design was carried out to inform the architects and engineers about the industrial capacity of the company, and the viability to be manufactured in a cost-efficient way. Fifth, the "clients" represented by the funding partners of the project, which are private and public institutions have supervised the process interests and have indirectly influenced the design process. This situation has conditioned the project positively, making the technology more viable to be manufactured by private institutions and to be executed in public projects in a short-term period.

These participants and collaborators have had different modes of action and have influenced the project in various ways, fulfilling an essential role in the design process. Since the beginning, all of them had collaborated in the process of design, affecting the project from simultaneous –and sometimes conflicting– points of view.

3 TECHNICAL ASPECTS

3.1 SEISMIC CONSIDERATIONS

Currently, there are no seismic regulations explicitly directed to timber structures up to six floors. The regulation was conceived for concrete structures, so to meet these requirements, the timber structure needs to be over-structured. Timber is more flexible than concrete and does not collapse –as concrete does– when the horizontal deformation of seismic loads rises above 0.2 percent of the story high, a parameter defined by the current Chilean regulation. In seismic countries, such as Canada, United States, and New Zealand, there is a specific regulation for light-frame timber structures, and this value reaches 0.5 percent of the stories high. Hence, these international regulations recognize the properties and characteristics of the wood, making make it a competitive economic alternative. Since the project is a prototype and it has been conceived as an academic exercise in Chile, the engineering project is based on the current regulation designed for concrete structures, the primary material used to build in Chile. Notwithstanding, the Center's team of engineers is currently developing new seismic regulations for the Chilean reality, which will not be issued before the experimental tower is built. These conditions will modify the values for timber structures, avoiding the over-structuring of timber constructions in the future.

3.2 FIRE RESISTANCE

There are no constructive timber solutions tested in any laboratory in Chile which can resist the amount of time required by the fire regulation for structures up to five or six stories. Therefore, the participation of experts in the field of fire resistance for timber structures has been needed to design a project which could be viable in actual habitable buildings. The architectural assumptions used in the design of the prototype, to abide by fire regulations, were based on tests of constructive solutions executed in Europe and United States.

In this case, the structure should resist 90 or 120 minutes before collapsing if a fire occurs. To achieve the performance required the walls are protected by fire resistance panels on both sides of the structural walls. These extra layers are fixed off-site. Therefore the structure is not under risk of fire during the assembly process.

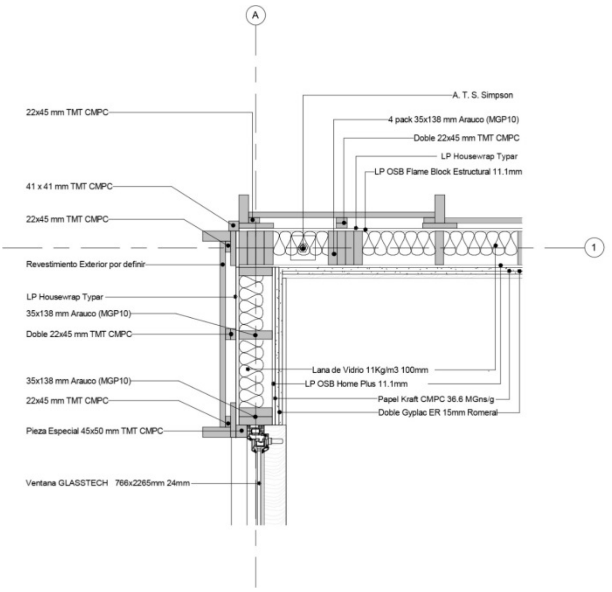

Figure 10: *Construction detail*
Source: Author. Developed by the Timber Innovation Center Interdisciplinary Team.

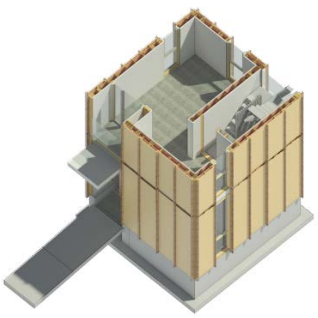

Figure 11: *Axonometric View*
Source: Author. Developed by the Timber Innovation Center Interdisciplinary Team.

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3.3 CONSTRUCTION CONSIDERATIONS

The Light Frame Timber Tower is a 6-story building that shows a cost-efficient way to build through the stacking of prefabricated modules. The term prefabrication refers to “any part of a building that has been fabricated at a place other than its final location.” This achieves greater control over execution, increases the efficiency, precision and productivity, by reducing the time frames, costs and construction waste [2]. The tower was divided into a few repetitive modules that could be prefabricated in the plant, transport and stacked on- site. The stacked modular construction used not to be cost-efficient, because of the usual floor, roof and walls duplication after the module assembly. To avoid this, the tower modules consist of three walls and a single roof/floor element, reducing unnecessary construction material and production time. The construction of modular buildings has a controlled process, which generates less waste, creates fewer mistakes and could be reused, through the disassembled and the modules relocation. Compared to traditional construction, the projects can be completed 30% to 50% sooner [3].

To accomplish the optimization of the construction system, it was required a collaborative design between architects, engineers and the industry responsible for the construction. That obtained complex design solutions by developing a multifaceted understanding of opportunities and problems [4], and it was needed the constant communication between all the actors involved in the project development.

3.3.1 Prefabrication

Each tower floor consists of two prefabricated modules assembled and stacked on- site. The modules are prefabricated almost in their 100% in the industry plant. They are made of the structural light- frame system walls, the upper roof/floor component, installations and part of the terminations, including the interior plasterboard coating and the exterior façade. The structure of the walls is made of 2x6” (35x138mm) radiata pine studs covered each side by and 11, 1 mm oriented strand board. The floor/roof components consist of 2x8” (41x185mm) radiata pine beams and chains with an 11,1mm oriented strand board lower cover and a 15mm structural plywood upper cover.

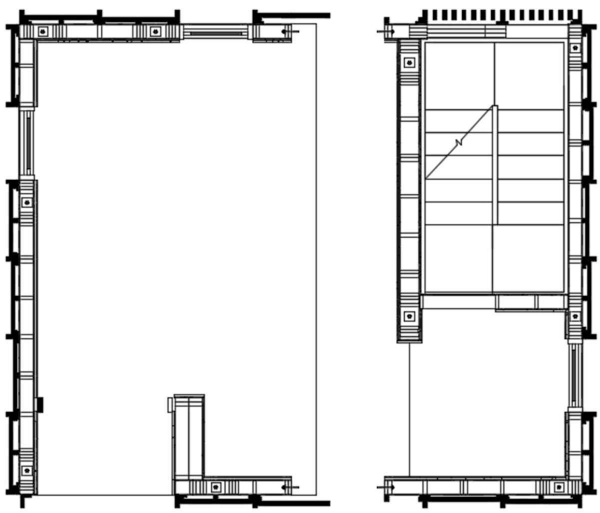

Figure 12: *Plan view of the two modules to be assembled on-site.*
Source: Author. Developed by the Timber Innovation Center Interdisciplinary Team.

3.3.1 Transportation

To optimize the transportation, the module dimensions could not be wider than the truck capacitance. That is why the modules do not exceed the 3,6 meters width.
Also, there are temporary elements considered to avoid the possible breaking during transportation of the modules in the truck and their later assembly.

3.3.1 Assembly

The first two modules are settled on a reinforced concrete foundation and the next ones are stacked on them by using a jib crane.
The stacked modules are hold in place through the “Anchor Tie Down System” (ATS). This counteracts the walls shearing forces and avoids the shrinking effect usually seen in these types of structures.

4 CONCLUSIONS

The structural engineering area made a state of art research to achieve the optimization of the prefabrication and modules assembly through the standardization of the components. The role of the architects was to design a spatial configuration based on a possible housing type by constantly incorporating the responsible industry and engineering recommendations. They consisted mostly in dimension limits from the market products, production of components and their transportation and construction complexities. There were regular meetings with the industry area, to show them the project and discuss its feasibility of production in their plant.
The Light Frame Timber Tower was designed to be prefabricated in three weeks and assembly in five days, with a total construction time that didn´t exceed a month of work. Besides, the removal of the duplicated roof/floor/ and wall/wall element, obtains a 30% of material reduction decreasing the construction times and costs.
On the other hand, the interdisciplinary collaboration and smart design got the maximum of prefabrication that allows the installation and fixing of the ATS and, therefore, the structural stability of the tower.
All these characteristics resulted in a cost-efficient building that makes the tower a referent in Chile and Latin America.

The building was designed through the continued dialogue in between the three named disciplines: architecture, engineering and the construction company. The good communication between members is essential in a collaborative design methodology, for achieving group cohesiveness, ideas transmission and the shared understanding [5].

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