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TAMANGO BUILDING: TYPOLOGICAL EXPLORATION FOR A 12-STOREY WOODEN APARTMENT BUILDING IN A SEISMIC AREA.

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ABSTRACT: In 2020, Tallwood was commissioned to build a 12-story building with a mixed commercial and residential program in Coyhaique, the gateway to Chilean Patagonia and one of the most virgin territories in the world, but also a city that has one of the worst pollution rates in Latin America and is part of one of the countries with the highest seismicity in the world.

This article explains the process and methodology behind the architectural and structural solution for the "Tamango" building, which today has a construction permit and is in the final phase of economic studies to start the construction of its 12-story tower and 21,112m2, which includes 2,806m2 for offices and commerce on a reinforced concrete plate and 9,528m2 for 68 apartments distributed in a hybrid structure of LVL columns and beams, CLT and reinforced concrete composite slabs, and vertical cores of reinforced concrete.

KEYWORDS: Wooden High-rise Buildings, Wooden Architecture, Hybrid Concrete and Wood Structures, Structures in Seismic Zones.

1 INTRODUCTION

1.1 THE PLACE

Coyhaique is one of the southernmost cities in the world. According to the 2017 census [1], it has approximately 57,818 inhabitants within the Aysén Region, where 103,158 people live in 109,024km2, resulting in a density of less than one inhabit/km2, being one of the least populated and most pristine areas on the planet.

However, Coyhaique is also among the most polluted cities in America [2]. In June 2018, the city reached an index of 166.8 PM2.5, considered a very unhealthy category, mainly due to the burning of wet firewood for heating.

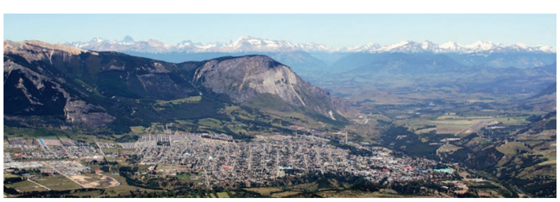

Figure 1: Aerial view of Coyhaique without air pollution. Source: Rakela.

1.2 THE CLIENT

Considering the context described above, Tallwood was contacted by two families from the area interested in leaving a legacy in the area and doing it through a sustainable real estate project and efficient construction, also considering the problematic access to materials and skilled labor in the area.

Thus, the building takes the name of "Tamango," a traditional boot worn by Patagonian gauchos, as a symbol of the mixture between simplicity and comfort sought after the inclement Patagonian climate.

This is how it was decided to develop a structure in which the latest technologies for high-rise timber construction were put into practice, with mechanized elements of CLT, GLULAM or MLE, LVL engineered timber, and certified sawn timber with different structural grades. All of the construction systems, proven in other parts of the world, meet the requirements of the clients by coming from renewable sources and having, at the same time, advantages of prefabrication, such as shorter assembly times, dry and silent works, low emissions of particulate matter, and greater quality control in construction.

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The characteristics of these materials also greatly facilitate reaching efficient energy solutions for heating, and their hygroscopic quality of retaining and releasing moisture gives that feeling of comfort that has long been studied as beneficial for living.

Figure 2: *Landscape of "Cerro Castillo" in Aysen region, Chile and a original "Tamango" (traditional boot worn by Patagonian gauchos). Source: Corsilver and Guillermo Helo..*

1.3 THE LAND

The land where the project will be located is challenging since it is central -it is located three blocks from the main square of the city -will become an urban landmark- but it is also a boundary condition looking towards the nature of the "pampas" and the Coyhaique River.

Planning laws explain some architectural design decisions; local regulations require a continuous façade at least eight meters high. In addition, the height of the building is also obtained from the local rules, which indicates maximum constructability and height.

Figure 3: *In red, the future location of the building. Three blocks from the main square in a border condition facing the Coyhaique River. Source: Google Earth.*

1.4 THE LOCAL CONTEXT

Chile has a strong forestry vocation, 22.3% of the country's surface, equivalent to 16.9 million hectares, is covered by forests -14.6 million hectares are native forests, and 2.3 million hectares are forest plantations- [3]. However, the country is also part of the current challenges that the world of construction is experiencing, such as:

1. How to achieve, from the construction sector respond to the demanding environmental goals? Chile committed to being carbon neutral by 2050, but when this building was designed, it emitted 111 million TCO2, although it also captured 65 million tons through the forests. Thus, it is possible to contribute to the reduction of the so-called "30/30/30" of construction -36% of the final use of energy, 35% of solid waste, and 39% of emissions of CO2 [4]- through wooden structures.

2. How can we increase the productivity of the construction sector? For example, Chile is capable of building 0.24m2/person/day, in contrast with developed countries where are capable to build 0.37/m2/person/day are made, that is, ten floors versus fifteen in the same amount of time [5], which indicates the need for a profound change in the way of building.

However, currently it has been seen that between 2012 and 2020 progress was made from having 14% of homes with wood as the predominant material to 20% in 2020, having the realistic goal of reaching 30% by 2030.

Currently, proposing tall wooden buildings in Chile represents a great challenge and innovation, because in that country there are almost no buildings higher than four floors and all the buildings from 7 stories upwards are made in concrete and steel [6].

The phenomenon described above is aligned with the Chilean seismic code, which limits "inelastic drift" to 0.2%, one of the most restrictive seismic regulations worldwide.

1.5 THE MATERIAL

The idea of using engineered wood was, from the beginning, having to achieve competitive structural values but also using the advantages of wood in terms of: the use of a renewable resource and sustainability, its greater precision in manufacturing, its lower weight (470kg/m3 vs. 2500kg/m3) that would help to have fewer operations, faster assembly in a town located in the far south, and better-quality finishes.

For this, in parallel with the design of the building, a management process was carried out since in January 2020, when nine engineered wood suppliers from around the world were contacted, selecting the final supplier in March 2021, after an exhaustive evaluation that considered the following parameters: price; technical support during design; technical support during assembly; availability, type and quality of material; experience; and interest in the project.

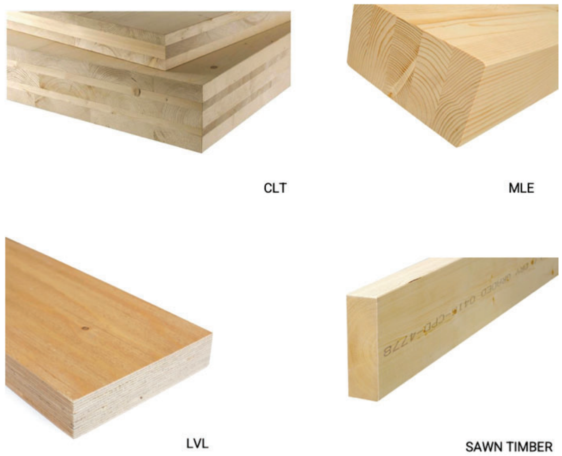

Figure 4: *Wooden elements to be used in the project.*

1.6 THE ASSIGNMENT

The offer, with residential apartments with eight apartments per floor, is mainly addressed to two types of clients: families from Coyhaique who travel permanently and prefer to have an apartment in the city as their residence, and young families who are emigrating from the center to the south of Chile searching for new job opportunities, a better quality of life, or more significant contact with nature.

Thus, due to the conditions of the place, the client's interest, the land regulations, and the local context of the construction industry previously mentioned, the project also requested -among other parameters and requirements- that part of these structural elements of Engineered-Wood will be exposed, generating the following questions and challenges for the team of architects and structural engineers in charge of the design:

According to the order and the maximum height allowed on the land: How should a 12-story building in Coyhaique be designed with wooden structures?

According to the architectural program: Should the plinth or "podium" be designed in reinforced concrete or wood?

Considering the height and the architectural program: What structural typology is ideal for this type of building, which will have apartments between floors 3 and 12 and is located in a seismic country?

In the case of using composite or hybrid structures: How to solve the aerial floors making concrete and wood compatible, considering the seismic regulations of Chile?

One of the main conditions that were considered was the seismic recurrence of Coyhaique, with an average of 7 grade 7 earthquakes every 40 years, which is why the challenge of the Tamango building was unique in the combination of: Pre-existing real estate requirements of engineered-wood structures for tall buildings, and an area of high seismic risk.

2 METHODOLOGY

For the development of the architecture design, engineering, and management of the building, an interdisciplinary team of professionals with extensive experience in wooden projects -as well as in the development of public policies, academic activities, and industries- was formed, bringing together authors of pioneering works in wood in Chile -neighborhoods for 360 homes, 6-story light-framed towers and architecture with high-performance standards- and also, called the support of world-class international advisors from Finland, Slovakia, Poland, Germany, and Canada.

The initial design considered programmatic, regulatory, and economic requirements, coming from a previous study and pre-design developed by the real estate company -the client-, which was necessary to maintain:

Table 1: *Programmatic, regulatory, and economic requirements, from a previous study and pre-design developed by the real estate company -the client-which it was necessary to maintain.*

Nº	Requirement
1.	Three basements, with residential and rental parking capacity, warehouses, and technical rooms.
2.	Continuous façade of at least 8 meters high (by regulatory requirement) with approximately 2,000 m2 for commercial premises, equipment, and offices.
3.	Approximately 8,000m2 with apartments between 90 and 140 m2 in a maximum of 12 floors.
4.	Final sales values of approximately €3,200/m2, being competitive with the local market.
5..	Demonstrate compliance with all local structural engineering, fire resistance, and acoustic performance standards and regulations.
6.	Check the characteristics of sustainability and energy efficiency of the building.
7.	Leave some structural wood exposed.

Before the iteration with different models that would help to answer the questions posed by the project, basic design parameters were established, both from architecture and engineering, which served as a basis.

2.1 ARCHITECTURE PARAMETERS

After determining the theoretical volume using local regulations that establish plinth, constructability, and maximum height, initially, we had an elongated tower, with only four corners, on a 2-story shopping plaza.

2.1.1 Double deck plate

One of the first design decisions was to use a regulatory instance that allows 30% of the continuous façade to be transferred to the public space, creating a public access courtyard that connects with galleries and interior public terraces. One of the project's main goals was to make the

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first-floor program responsive to the urgent needs of the city and open it to the public.

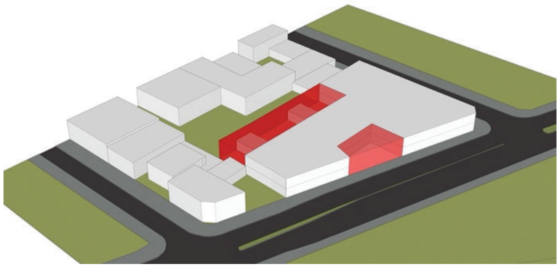

Figure 5: *Architectural design decisions for the two-story commercial plate.*

2.1.2 Six-cornered tower

A second significant move was to divide the building's block in two, in such a way as to make better use of the geometry of the terrain providing six corners with good views, ventilation, and sunlight instead of the initial four corners, which would eventually allow both towers to function, independently, when dilated.

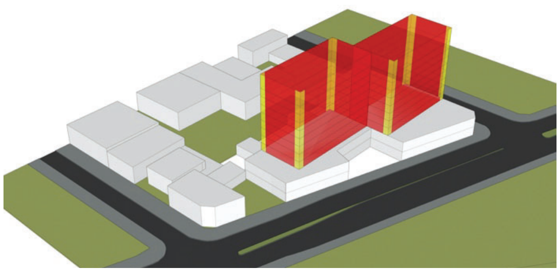

Figure 6: *Architectural design decisions for the six-cornered tower.*

2.1.3 Inclined upper faces

A third important design decision was to use the municipal requirement for roof slopes to generate "duplex" -two-story- and "triplex" -three-story- apartments on the upper level, with more commercial value, better views, and a more flexible architectural program.

Thus, due to the geometric characteristics of the site, the residential building was conceived as two independent volumes connected by circulations, making maximum use of views and sunlight.

From the beginning, all of these design decisions were accompanied with the engineering team, making models and testing different combinations and structural typologies until meeting the high standards required by both the team of professionals involved and international standards, as required by current seismic regulations.

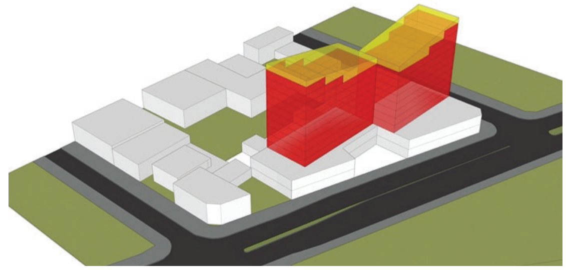

Figure 7: *Architectural design decisions for roof slope and top floors with two and three-story apartments on the upper level.*

2.2 ENGINEERING PARAMETERS

Considering the requirements indicated in the Chilean seismic standard, based on the different constructive and structural typologies [7] that have been part of the growth of this type of building globally [8], as well as consulting other design manuals, the following general criteria were adopted:

2.2.1 First two floors of reinforced concrete

The podium configuring the continuous façade and containing the commercial places and offices was designed from the beginning in concrete. Coyhaique is a city with a lot of precipitation and sporadic accumulation of snow, which is why, in any case, the design required protection for the wooden structures in contact with the natural terrain.

In addition, due to multiple environmental benefits, such as evapotranspiration for cooling, retention, and drainage of rainwater and a contribution to biodiversity through native flora, green roofs were included over the slabs, which added loads to the large slabs already projected.

2.2.2 Vertical cores of reinforced concrete

To provide stability for the seismic design, comply with the Chilean Standard, which allows a maximum relative displacement between two consecutive floors, measured at the center of mass in each of the directions of the analysis, which must not be greater than the height of mezzanine multiplied by 0.002 [9], makes it practically impossible for tall wooden buildings in Chile to comply with the deformations of the standard without having a reinforced concrete core that is capable of absorbing dynamic stresses.

Also, as well as based on similar experiences, such as the Brock Commons building, by Acton Ostry located in Vancouver [10], the project incorporated from the beginning the idea of using vertical cores of reinforced concrete, which were capable of stiffening the tower.

Preliminary analyzes suggested a maximum distance of approximately 12 meters from the edges of the wooden structure to the Reinforced Concrete cores. Therefore, in the first instance, it was decided to include two cores.

2.2.3 Aerial floors of wooden posts and beams and CLT composite slabs - reinforced concrete.

Also, was defined from the beginning to use a mixed slab. In this case, of 170mm CLT. and reinforced concrete of 100mm.

Thus, metal reinforcements would connect these slabs to the concrete cores, generating the necessary solidarity between both structural elements.

2.3 PARAMETERS OF OTHER SPECIALTIES

Among the more than 30 specialties involved, the following criteria were used for fire resistance, acoustic performance, and thermal performance, which directly affected the architecture and structure of the building:

2.3.1 Fire Resistance

According to the General Urban Planning and Construction Ordinance of Chile (OGUC), due to its size and use, the structure of the Tamango building must have a fire resistance of 120 minutes [11]. Bearing this in mind, engineers specialized in the field considered three main criteria:

Table 2: *Three main criteria for calculating fire resistance.*

Nº	Criteria
1.	Projected real fire (Burnout) using local regulations, Eurocode 5, and other technical texts.
2.	Carbonization and delamination analysis for exposed structural members.
3.	Carbonization and delamination analysis for protected structural elements.

The analysis with these criteria determined sections of structural elements and the necessary conditions to achieve "exposed wood" inside the apartments.

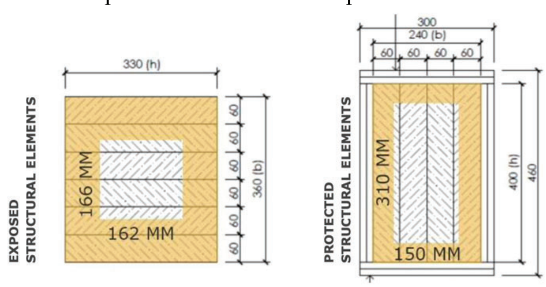

Figure 8: *Exposed and protected structural elements fire resistance analysis. The traditional carbonization factor of 0,7mm/min., modified according to delamination calculation.*

2.3.2 Acoustic performance

The acoustic performance of the dividing elements was analyzed to comply with the requirements for airborne noise and impact noise.

In Chile, for slabs, according to the General Urban Planning and Construction Ordinance of Chile (OGUC), a normalized impact sound pressure level (Ln,w) less than or equal to 75 dB is required. And for walls and floors, an acoustic reduction index (Rw+C) greater than or equal to 45 dB. Compliance with these requirements can be demonstrated by belonging to the List of Constructive Solutions for Acoustic Insulation of the Ministry of Housing and Urban Planning (MINVU) or by carrying out Test Reports or Inspection Reports issued by a laboratory with current registration.

Table 3: *According to the General Urban Planning and Construction Ordinance of Chile (OGUC), permissible decibels for airborne noise and impact noise.*

Noise Type	Requirement
Impact noise	Normalized impact sound pressure level (Ln,w) less than or equal to 75dB
Airborne noise	Acoustic reduction index (Rw+C) greater than or equal to 45dB.

This affected the sizes and stamps of the dividing elements. Not only local regulations considered but also international standards, assuming that the new inhabitant of the apartments, when faced with new materials and construction systems, can be more demanding than usual, even if it is comfortably complying with acoustic requirements established in the Chilean regulation.

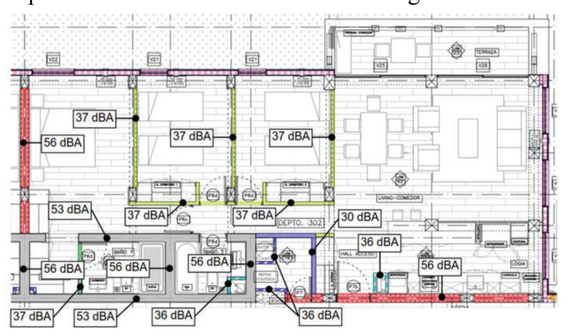

Figure 9: *Acoustic performance of elements in a typical department of the Tamango building.*

2.3.3 Sustainability and Energy Efficiency

Another fundamental specialty to integrate from the outset was Sustainability and Energy Efficiency, which had two fronts: the carbon footprint, which helps to explain, to a certain extent, the use of this amount of wood, and the performance during its use, that in addition to complying with the requirements of the "Coyhaique Atmospheric Decontamination Plan (PDA)" -a measure established to help reduce particulate material emissions that have Coyhaique as one of the most polluted cities of America- explains, to a certain extent, the design of the envelopes and the percentage of windows in the building.

Table 4: *Maximum allowable thermal transmittance [W/m2K]*

Thermal Zone	Roofs W/m2K	Walls W/m2K	Ventilated floors W/m2K	Doors W/m2K
Coyhaique	0,25	0,35	0,32	1,70

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Regarding the carbon footprint, the building has 1,870m3 of wooden structure, which captures 1,230 tons of CO2 equivalent, discounting what is emitted in its manufacture and transport from Finland and Austria.

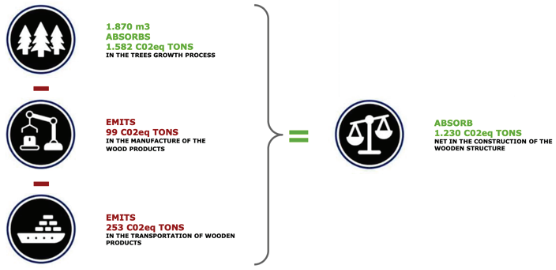

Figure 10: *Carbon footprint of the wooden structural elements of the building*.

Regarding the performance during use, five available heating systems were analyzed, resulting in the best evaluation of the "electric heat pumps" that heat the water for underfloor heating, reaching a 67% reduction in emissions according to a "base case" that It was used for the study and a 75% savings in monthly expenses by department.

This was also achieved thanks to an envelope designed with insulation, ventilated facades, and mechanical ventilation, which achieves a 60% saving in energy demand compared to a typical home with an equivalent classification from the Chilean Ministry of Housing and Urbanism (MINVU).

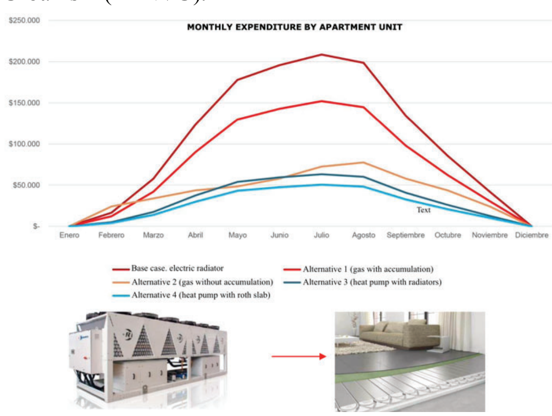

Figure 11: *Monthly expenditure by apartment unit, comparing five alternatives: Base case (electric radiator); Alternative 1 (gas with accumulation); Alternative 2 (gas without accumulation); Alternative 3 (heat pump with radiators); Alternative 4 (heat pump with roth slab).*

3 STAGES AND RESULTS

Once the essential criteria described above were agreed upon and having carried out a series of preliminary economic evaluations complying with precise real estate requirements, the design phase began, incorporating all the new needs.

Thus, different iterations of the architectural program and the structural elements were made during the project's development. In general, there were three main iterations:

3.1 CLT WALLS AND TWO REINFORCED CONCRETE CORES

The residential building, comprised of two independent volumes linked by circulations, was initially conceived with two reinforced concrete cores containing elevators and stairs. The preliminary analysis suggested a maximum distance of 12 meters from the edges of the wooden structure to these cores, so the architectural design was oriented under this premise at this stage.

The housing programs -unlike others, such as commercial premises and offices- are characterized by having a more significant number of enclosures and linear meters of wall. This, added to the client's requirement to leave the wood in sight, initially determined the decision to structure the apartments with CLT walls.

Following modeling and structural study, the projected CLT walls experienced significant stress, resulting in the modification factor being adjusted to reflect the system mentioned above accurately. This adjustment caused an increase in the base shear, causing a drift that more than doubled the permissible limit established in the Chilean code.

Figure 12: *Plan with CLT walls and two reinforced concrete cores*.

The CLT walls received a considerable amount of the total seismic cut, implying that the reduction factor used for the seismic analysis was associated with CLT. Although some studies suggest it may be higher, the consensus is to use R=2. This resulted in high seismic demand and a much higher than allowable drift.

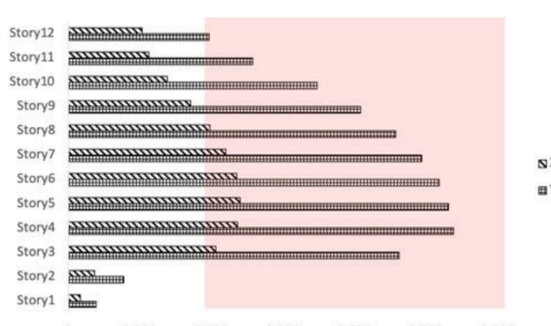

Figure 13: *Graph showing CLT walls received a considerable amount of the total seismic cut*.

Due to the lack of characterization of the CLT in the regulations, for the calculation of the structural model, a seismic reduction factor R=2 was used for the CLT compared to R=7 for reinforced concrete. The modeling results showed displacements greater than the 0.002*h allowed in the Chilean standard since it was considered during the calculation analysis that the CLT walls took the horizontal forces to a large extent, causing the earthquake to increase since most of the structures assumed R=2. Therefore, for the building to comply with the drift required by the standard, it would have been necessary to add a considerable amount of CLT walls, which was not viable from the habitability or commercial point of view.

Seeing the great distance that still existed for the viability of the proposed structure, it was decided to carry out a typological study of all the buildings with wooden structures of similar characteristics with the available information.

At the end of this stage, it was also decided to test a new model in which the concrete cores would mainly absorb the movements between floors. This test determined that the distance from the edges of the timber structure to the concrete cores needed to be reduced from 12 to 8 meters.

3.2 LVL COLUMNS AND BEAMS, FACADE WITH DIAGONALS AND TWO REINFORCED CONCRETE CORES

In this intermediate stage, the CLT walls were downsized to give the building rigidity and reduce previous deformations, and wooden bracing was installed on the facades. LVL columns and beams -material proposed because it achieves smaller sections than GLULAM to resist the same loads- replaced practically all of the CLT walls, leaving only a few, mainly in the living rooms, to expose the wood structure. These walls of the room continued towards the terrace - exterior balcony, which would later bring consequences after the criteria of wood protection from the design.

Programmatically, wet areas were left in the concrete cores to reduce eventual water infiltration problems in areas with wooden structures. In addition, during this stage, a third central core of CLT was configured, which contained the vertical circulations -elevator and stairs of the security area-.

Figure 14: *Plan with LVL pillars and beams, facade with diagonals and two reinforced concrete cores.*

The models of the previous stage had presented more significant deformations at the ends of the tower, so at this stage, it was decided to incorporate diagonals in the short façades of the building. But, a milestone marked a change in this process: it was found that there is no consolidated criteria in Chilean regulations to determine what percentage of the shear, in the event of an earthquake, each element takes in hybrid structures.

Therefore, it was impossible to determine how much was assumed by a seismic reduction factor of R=2 for CLT walls or how much of R=7 for reinforced concrete core walls. Therefore, it was agreed, between the engineering team and the independent calculation reviewers, that only the R=7 of the reinforced concrete cores would be considered for calculating the cut. Therefore, it was necessary to eliminate all the wooden structural elements that would absorb lateral forces during earthquakes and eliminate from the design all the CLT walls and the LVL diagonals of the facades.

The bracing elements also experienced significant axial forces, resulting in the reduction factor being applied to the timber bracing system, the same as that used for the CLT walls in the previous iteration per Chilean code. This ultimately led to a similar level of deformation.

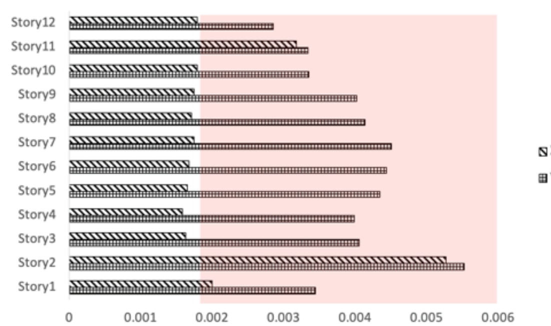

Figure 15: *Graph showing that the reduction factor being applied to the bracing timber system, which is the same as the one used for CLT walls, led to a similar level of deformation.*

3.3 LVL PILLARS AND BEAMS, THREE REINFORCED CONCRETE CORES AND EXPANSION JOINT

The third and final stage began with removing all CLT walls and LVL diagonals, which were replaced by a grid of LVL pillars at 3-4 meters connected by LVL beams.

One of the essential architectural requirements was to achieve large spaces without interference in the living areas, whose maximum spans of 5 meters dominated the design of the thicknesses of the CLT slabs.

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Figure 16: *Plan with LVL pillars and beams, three reinforced concrete cores and expansion joint.*

In this stage, a detailed analysis of the fire resistance for 120 minutes of the structural elements was carried out, as required by the Chilean standard for buildings with more than five floors for exposed and protected wooden structural components. Also, a detailed architectural evaluation accompanied this analysis to meet the requirements for element dimensions, concealed connector design, and the amount of exposed wood to meet the client's needs.

Various construction solutions certified and cataloged by the Ministry of Housing and Urbanism of Chile (MINVU) were used for the dividing walls. In the case of using unlisted construction solutions, they were tested and approved.

Another requirement -difficult for structural calculation and wood durability- was maintaining the usual Chilean standard for balconies or terraces. In this case, to avoid thermal and humidity conflicts caused by the continuity of the exterior-interior CLT slabs, it was decided to design the prefabricated metal balconies independently, with a fixing system using cranes to the load-bearing wooden structure. All the facades were designed to be prefabricated and assembled with cranes without scaffolding.

By not including additional lateral resistant elements to the concrete core, the modification factor was based solely on the reinforced concrete (RC) system. This resulted in the deformation of the building being within the permissible range established in the Chilean code.

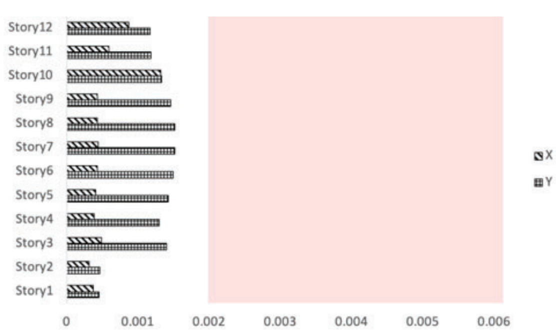

Figure 17: *Graph showing that not including additional lateral resistant elements other than the concrete core, resulted in the building's deformation within the permissible range stated in the Chilean code.*

Already having new structural models with positive results, complying with NCH 433, a consultancy was carried out to review the criteria with the Canadian structural engineering consultancy Timber Engineering Inc., which endorsed the results, suggesting adding a third central core of concrete for elevator. Subsequently, the independent calculation review, asked to include an expansion joint at the meeting of the two volumes of the residential tower.

4 CONCLUSIONS

The design of a hybrid high-rise structure of wood and reinforced concrete -in an area of high seismicity- was a complex process that forced innovation and required coordination and joint work, from its beginnings, between architecture, engineering and the more than 30 specialties that participated. Each of these stages required long study processes and iterations to arrive at these solutions, which are shown here in a simplified way.

The Tamango building now has a construction permit and a competitive budget. The main conclusion after this two-year work is that this experience shows that it is possible to build hybrid structures in wood and reinforced concrete in areas of high seismicity, complying with the highest standards. Also, the spatial conditions required for habitability, commercial requirements, and the requirements of Chilean law and international standards are met.

Figure 18: *Renderings with exterior views of the building.*

After this typological exploration process, a final design was reached with three vertically reinforced concrete cores, LVL beams and columns, and CLT - reinforced concrete composite slabs, where the maximum distance between the edges of the structure and the concrete supports is 8 meters, requiring an expansion joint in the intermediate area.

For a 12-story building of these characteristics and in this location, a design of composite reinforced concrete structures is necessary to absorb shear forces and engineered-wood (LVL posts and beams + CLT slabs) for gravitational forces, being an viable option with the current technologies, economic conditions, and regulations.

The mixed slab of CLT + reinforced concrete, connected and solidary with concrete supports is a viable alternative to transfer the shear force to the reinforced concrete cores. A distance of 8 meters between the edge of the wooden structure and the concrete cores is feasible. Therefore, it is possible to comply with the Chilean regulation of fire resistance of 120 min with exposed and protected wooden structures. It is recommended that the balcony structures be independent of the main load-bearing wooden structure.

To arrive at the information required for the assembly of prefabricated structures, developing the so-called "Digital Twin" was critical, from which the data for manufacturing, machining, and all on-site assembly plans are obtained.

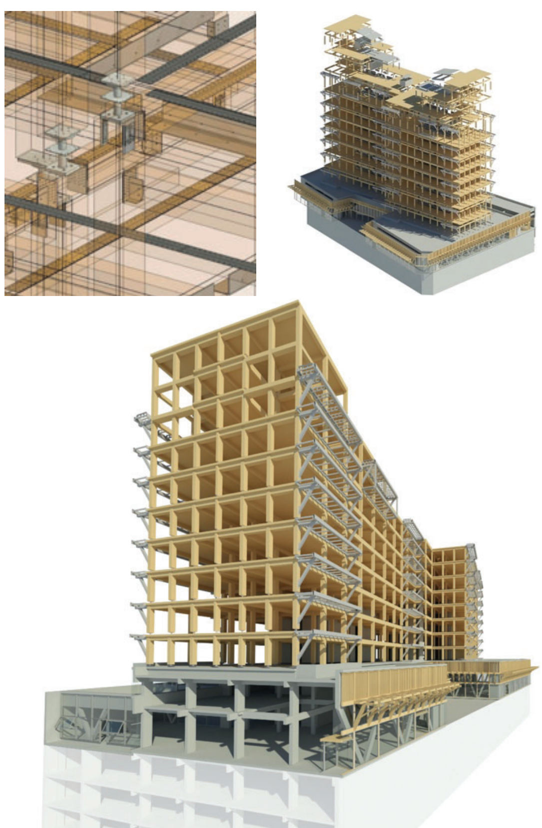

Figure 19: *Images of the BIM model with all the necessary information, so-called "Digital Twin".*

This digital model with the structure's detailing in BIM format allows the concept of "Build before Building," which produces the efficiency and quality of the on-site assembly, and also in this case, a "storyboard" or illustrative assembly sequence, which allows the constructor to be guided in the general evaluation of the project. Thus, an assembly speed of 200 m2/day is calculated, including facades. The wooden structure is assembled in 45 days, estimating a saving of 3 months of work.

According to the version delivered for bidding to construction companies, as well as for obtaining the Building Permit granted by the Coyhaique Municipal Works Directorate, Tamango building, has the following areas:

Table 5: *Architectural program and areas of the Tamango building*

Architectural program	Area
The total area of the project, with a mixed program and structure.	21.112 m2
Three underground floors, with 220 parking spaces, 95 warehouses, and the building's technical team.	8.778 m2
Two-story platform, with shops and offices.	2.806m2
Ten-story tower -between 3rd and 12th floor-, with 68 apartments, between 90 and 140m2 each.	9.528m2

Considered from the ground level, the wooden structure has also the following characteristics:

Table 6: *Characteristics of the building, related to the topic of this article.*

Structure Material	Area
The Total area of the project (100% from the ground level).	12.334m2
Wood Structure -CLT, LVL- (60%)	7.272m2
Reinforced Concrete Structure (35%)	4.370m2
Steel Structure -terraces- (5%)	692m2
Elements	**Quantity**
LVL elements -beams and columns-	2.446
CLT elements -slabs-	624
Metal connectors	6.141
Screws	339.417

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Figure 20: *Rendering with interior view of the building.*

Finally, Tamango's experience also leaves many possibilities for improvement for new construction solutions and, at the same time, it can help to improve local regulations, incorporating new materials for Chile.

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Figure 21: *Rendering with a view of the landscape project in the interior plaza of the building.*

REFERENCES

[1] National Statistics Institute (INE): Final results of Census, Santiago de Chile, 2017.IQ

[2] Air: New air quality data, 2019.

[3] Forestry Institute (INFOR): Forestry Yearbook 2021 Area of Forestry Information and Economics. Government of Chile, 2021.

[4] Global Alliance for Buildings and Construction: Global Status Report for Building and Construction Sector: Towards a zero-emissions, efficient and resilient buildings and construction sector. International Energy Agency, United Nations Environment Programme. 2019.

[5] de Solminihac, H., Dagá, J.: Labor Productivity in construction in Chile. Clapes UC, Santiago de Chile, 2018.

[6] Terraza, H., Donoso, R., Victorero, F., Ibáñez, D.: The construction of wooden houses in Chile: A pillar for sustainable development and the reactivation agenda. The World Bank, Washington DC, 2020.

[7] Foster, R., Reynolds, T., and Ramage, M: Proposal for Defining a Tall Timber Building. *Journal of Structural Engineering*, 2016.

[8] Wiegand, E., Ramage M.: The impact of policy instruments on the first generation of Tall Wood Buildings, *Building Research & Information*, 50:3, 255-275, 2022.

[9] National Institute of Statistics (INE): Chilean Standard NCh 433 Seismic Design of Buildings, Santiago de Chile, 2012.

[10] Fallahi, A.: Innovation in Hybrid Mass Timber High-rise Construction: A Case Study of UBC's Brock Commons Project. University of British Columbia, 2017.

[11] Ministry of Housing and Urban Planning (MINVU). General Urban Planning and Construction Ordinance. Government of Chile, Santiago de Chile, 2020.