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PROFESSIONAL WORKSHOP IN WOOD: STRUCTURAL EFFICIENCY INDEX, FOR ARCHITECTURE STUDENTS.

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ABSTRACT: The Professional Wood Workshop, developed within the School of Architecture of the Pontifical Catholic University of Chile, proposes to students in the final stage of their careers the analysis of different case studies with various architectural programs, such as houses, buildings, schools, and factories, auditoriums, gyms, and warehouses, before the design of their projects, through a quantitative index of the efficiency of the structures that compares the volume (m3) of wood used per surface (m2) of construction.

With the objective that architecture students can identify and understand what criteria and strategies are behind a wooden design, it is that, through tools such as 3D modeling of the referents, they obtain exact parameters of the volume of the foundations, of the primary structure and the secondary structure, managing to comparatively systematize several historical and contemporary examples of good wooden architecture, before beginning to design their projects. The results obtained, quantitative (index) and qualitative (what and how the designer thinks), motivate permanent realization of the workshop, participation in national competitions for students, and a book as a permanent contribution to knowledge in this area.

KEYWORDS: Wooden Architecture, Teaching of Wood Technologies, Educational Theory, Architectural Education.

1 INTRODUCTION

During the professional performance of architects (especially those specialized in wooden constructions), each project is determined by efficiency parameters since the needs are too many, while the resources are limited.

Typically, the design process establishes a maximum expected cost per floor area (USD/m2). This parameter determines many of the decisions of the project, even before deciding its physical form and its materiality since it is a "reality criterion" that conditions the development of the form. We are interested in including and transmitting this concept in the academic context of the last year of undergraduate architecture.

For this, it is necessary to understand the origin and history of these principles, shape a methodology that fits the curriculum for the training of architects in Chile (which comes from the world of Fine Arts) and transmit those results from a quantitative and qualitative.

1.1 THE CRAFT

The craft is an accumulation of knowledge created in a slow process of trial and error: what will I do, how will I do it, and who it will be for.

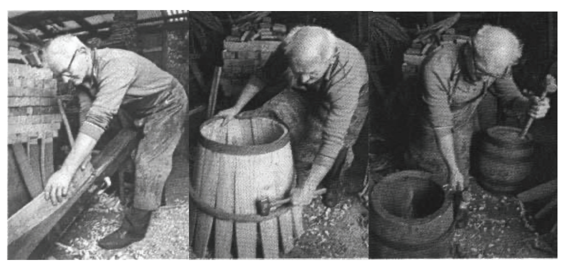

Figure 1: *Wine barrel cooper.*

Every construction system is based on a trade, which usually brings together three elements: (a) The availability of resources or "site material"; (b) The uses and customs associated with the climate, topography, and landscape, which result in what we know as "local culture" as a material good; (c) A heritage that we want to preserve, which we call "culture of origin."

Seen this way, the way of building each place says a lot about the nature of the site; their customs, ways of life, food, clothing, festivals, rituals, and shelter needs that force local builders to seek simple and common solutions so that anyone can carry them out, what we call "Vernacular Culture."

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Figure 2: *Pewenche Ancestral Refuge.*

In recent years, wood construction has once again positioned itself as a valid option to respond to the many building needs due, among other factors, to good environmental indices, being a renewable, recyclable, low-cost, and flexible, added to its exemplary environmental behavior and lower carbon footprint, the possibility of being industrialized, and its flexibility and warmth properties in the finishes.

1.2 THE TRAINING OF THE ARCHITECT

Architects learn, above all, by studying reference projects, which serve as a guide to see how others have solved a project in similar conditions. Although technical construction manuals are helpful in many cases, helping to clarify how a detail is designed, they do not solve the fundamental questions of any project, which are related to the totality of the problem: What to do and how to do it.

As the Chilean architect Cristian Valdés says, "more important than thinking about the 'form' that I am going to give to a project, the central thing is to think about the 'attitude' that I am going to take towards it" [1]. Thus, for example, if it is determined that the main thing will be to build with local materials and technology, the range of possibilities is limited, probably rescuing a trade related to the degree of technical precision that can be chosen.

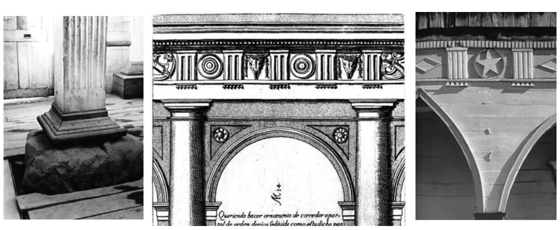

Figure 3: *J. Vignola and his translation on Chiloe wood.*

This apprenticeship method does not prevent the necessary questioning that architects must undertake to "move the border of the possible." Still, it makes the difference between the virtuosity of someone who, mastering a trade, explores new possibilities. Conversely, someone seduced by novelty risks the resources of others by trying untested solutions that usually result in construction defects that jeopardize the stability and durability of the building.

We study, for example, the "Churches of Chiloé," a series of Catholic temples built in the archipelago of that name, located in the wooded area of southern Chile, where, since the 17th century, more than 20 prominent temples were built in wood. Declared a World Heritage Site by Unesco, based on the manual by Jacopo Vignola brought by the Jesuits, are examples of the adaptation of classical architecture thought of stone to a language built of wood. The local carpentry trade, highly developed for constructing wooden houses and boats, allowed us to produce these marvelous temples. It seemed to us a critical case study since it let us know the amount of wood used based only on knowledge of the trade of the local carpenters and compare these data with buildings of similar characteristics currently developed, with all the support of the current structural modeling and calculation. That is to say, to contrast carpenters' and engineers' logic.

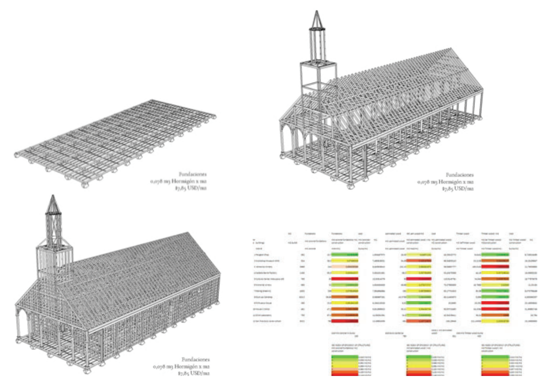

Figure 4: *"Achao Church" index of efficiency of structures.*

We did the same with a series of 25 historical and current works in wood to contract the data that quantifies its structure with the constructed surface area and thereby provide quantitative reference information associated with specific projects that students can know and ponder based on whether or not they can serve as reference models for your project.

Knowing this information at the beginning of the development of a project, even before its formal composition, makes a difference since, in wooden buildings, the adequate modulation of the structure is the fundamental basis to ensure optimal performance.

The trade of good wood construction involves the associated technical solutions and, very exceptionally, considers the architectural variables that are usually not named and therefore forgotten. The questions discussed during the course are: What happens with the concepts in large part of architecture treatises, such as proportion, scale, rhythm, order, and, ultimately, the harmony of the whole? How can you safeguard the constructive wisdom and, at the same time, the beauty of any well-designed wooden structure?

We call this "The aesthetics of logic" or, in other words, the wise way of arranging the pieces and parts that make up the supporting structure of a built body that always result in a harmonious and beautiful skeleton.

Figure 5: *San Francisco Javier School, in Puerto Montt.*

An example of the above is the natural structure that makes up the skeletons of vertebrate animals. So fair, precise, and efficient to support the demanding loads and, at the same time, respond during its life.

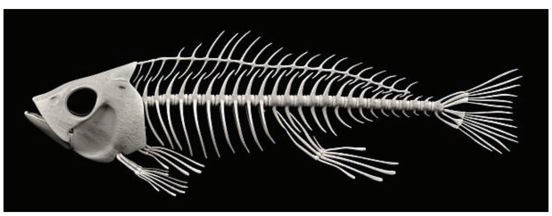

Figure 6: *Animal structure*

1.3 EXPECTED RESULTS

The course intends to discuss the questions posed by rescuing examples of the construction trade present in different wooden buildings, taking both historical and current cases, and measuring them under the same parameter, a structural efficiency index, which quantifies the volume (m3) of wood used in the supporting structure of the building and relates it to the surface (m2) built, allowing reflection and knowing in a single data, in a figure, the amount of wood required for its structure.

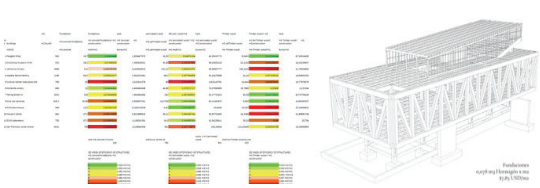

Figure 7: *IEE Comparative table 25 cases.*

This index makes it possible to understand the process behind designing a wood system and allows obtaining a parameter that can be used as a comparison and help make decisions about how the most efficient supporting skeleton of a new building in this material should be.

2 EFFICIENT WOODEN STRUCTURES

In this academic activity, the criteria used to measure and compare the efficiency of the structure of the different wooden buildings were cost, proportion, and language.

2.1 COST

The "cost" is always a priority in any actual project, not only the monetary cost but also the cost of technical and physical resources.

For example, to build the Sewell mining camp - a group of light-framed wooden buildings located in the high mountains of central Chile - at the beginning of the 20th century, North American engineers from the Braden Cooper company determined that all the construction material had to be loaded by "oxen yoke," given the problematic accessibility on steep slopes. This condition decided that the primary construction material for the structures and finishes would be wood due to its characteristics, such as being light, resistant, malleable, and workable by hand.

Figure 8: *Sewell housing building, Chile, 1920.*

Hundreds of carpenters could build large warehouses, bridges, pipelines, levees, retaining walls, offices, restaurants, and accommodations for all staff. The low cost and the availability of abundant wood brought by ships as ballast on their return voyages from North America were the starting point for determining that everything built-in mining operations would be made with this wood.

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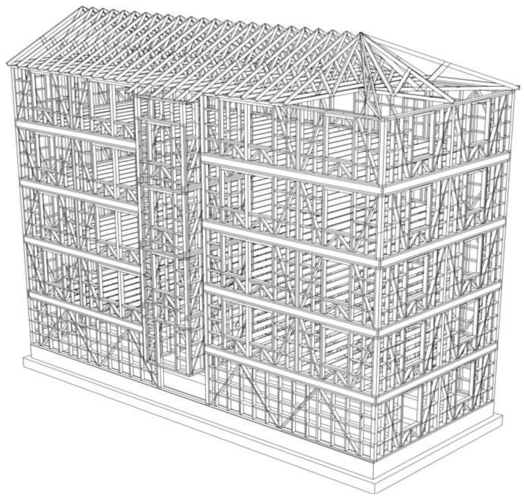

Figure 9: *Sewell bedrooms light-frame structure, Chile, 1920.*

The low weight of wood implied low transportation costs and the possibility of building with only hand tools, taking advantage of hermetic enclosures in extreme climates, and even constructing ponds and wooden pipes to store and transport water with high corrosion resistance.

Students are taught that every project is determined by the conditions of the environment where it will be built. Thus, deciding what material to build with always derives from a chain of implicit consequences, which go beyond the physical form of the project. It is not just an aesthetic problem; it is integral.

In summary, the cost of a structure is a variable that involves the value per m3 of the material plus the cost of the resources necessary to build with the chosen material and sizes in a specific place.

2.2 PROPORTION

Any building built based on a reticular structural system must combine these variables: "Architectural Module" and "Structural Module."

The architectural modulation provides the minimum dimensions necessary to house the activities required by a project, depending on the acts it hosts, which results in different sizes of enclosures.

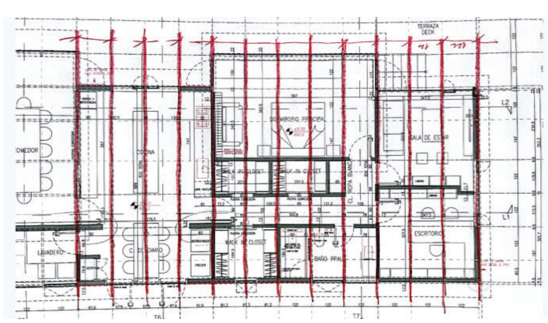

Figure 10: Architectural Module vs. Structural Module.

Structural modulation provides a system of columns, beams, or walls to cover the minimum free spans necessary to house the program's activities, generally determined by the dimensions of the construction materials used.

The students are taught that the first thing is to make a detailed analysis of the program and verify the dimensions of the "free span" necessary for the room with the most significant demand in size, and with this, decide the system of pillars and beams to use, in the "simple, most economical and best way".

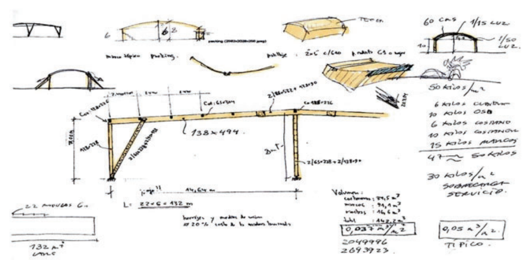

Figure 11: *Calculations of the Greenvic Packing structure.*

Then, we ask the students to analyze from evaluating the different materials to use the modulation or primary grid of dimensions that best suits the program's requirements.

In these cases, a grid's initial design allows the program's different parts to be organized in a simple matrix. However, care must be taken that this matrix is accessible enough for the base module to adapt to the size of the rooms necessary for the program. The smaller the dimension of the modules, the more freedom to adjust the program to the exact needs and not oversize or undersize an enclosure.

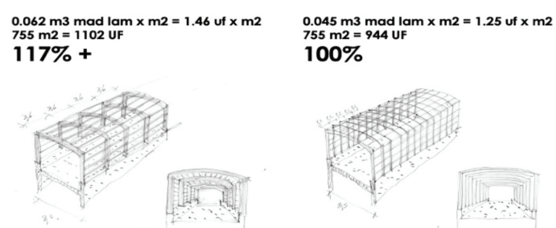

Figure 12: *Venue-Scale Rhythm and Efficient Modulation.*

After that, the "rhythm" determines the expression of the constructive skeleton matrix. In general, the timing of the grid is appropriate to the size of the project and is based on the dimensions of the materials in your commercial site measurements, such as columns, beams, plates, and cladding to be used.

In our country, it is customary to use a 1.22 x 2.44-meter grid, or its derivatives, from the size in which many construction materials are marketed. You can use the module divided into 3, 2, or 1, 40.5, 61.0, or 122 centimeters for smaller buildings, 244 centimeters for medium buildings, and 366 4.88, 6.00, or 7.32 centimeters, or more, for large (extra large) structures.

2.3 LANGUAGE

In the words of Peter Zumthor, "construction is the art of configuring a whole with meaning from many particularities" [2]. Wooden architecture brings with its discontinuity. To build a wooden building, it is necessary to join pieces and parts, assembling and joining different components to achieve a unitary body. For this reason, the carpentry trade is essentially the trade of joining and assembling.

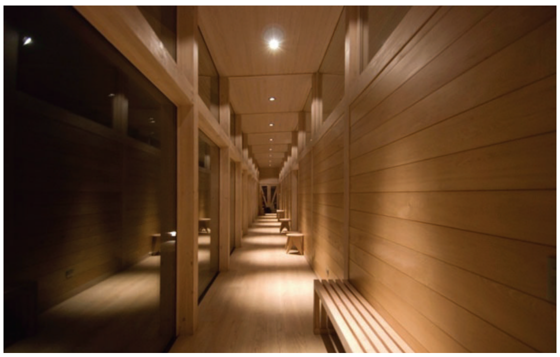

Figure 13: *The parts vs. the whole. Casa Colico 2, Chile.*

Once the decision is made on the most appropriate modulation for the program that will be housed, the detail emerges as an assembly point, a solidary union to build a continuous envelope, where the gaze does not stop at the discontinuity of the detail but rather the totality traps that.

"The details, when they come out well, are not decoration. They do not distract, do not entertain, but lead to the understanding of the whole, to whose essence they necessarily belong." [3].

Figure 14 : *Craft Structure Galpon Osorno.*

Architecture has always needed to find a language that supports the physical image of the project. The buildings developed with reticular structures have exposed the supporting structure as the accurate skeleton that underlies the form, expressed through the vectors that conduct the static and dynamic loads derived from the structural weight.

Modernism, supported by mathematical calculation as an indisputable truth, which uses the aesthetics of constructive logic in a spirit of stripping away everything that is not strictly necessary to sustain the building, resulted in an abstract aesthetic of elements that conduct the forces of gravity. Still, they do not necessarily resolve the physical expression of the building envelope, which is mediated by other needs of the architectural form.

Figure 15: *Main structure and secondary structure.*

Mies Van der Rohe, perhaps one of the fathers of constructive puritanism, in his well-known Seagram Building project in Chicago, uses two structures for the façade: (a) load-bearing steel covered with concrete, which remains "hidden" as the main load-bearing structure; (b) a second façade structure, built with slimmer steel profiles that give rhythm and proportion to the building's walls.

This freedom in design possibly allows for play, assigning to the main supporting structure the static and dynamic requirements of the system, plus the required fire resistance requirements, and freeing the secondary structure of the façade to build with it the visual language of the building.

3 THE INDEX

The index is a figure which summarizes, in a number, a complex web of factors that determine a reality. The carbon footprint is a good example. Let's compare it with the automobile industry, and we have to design, for example, a very affordable city car. We use as a parameter that its fuel consumption should be between 25 and 30 km/lt.

This index involves several parameters at the beginning of a design to achieve the objective. For example, size, weight, and relative dimensions will be present before starting to study the form of the model to be developed.

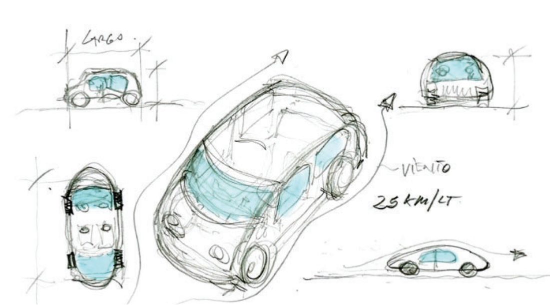

Figure 16: *Sketches to design an economical city car.*

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In our case, applied to wood construction, the index should be a helpful tool for architecture students to identify a primitive order before defining a shape based on a premise: the best structure is the one that uses the least quantity. Of wood to achieve the same results required.

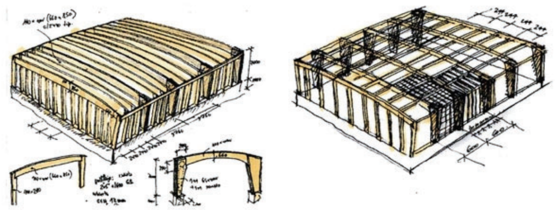

Figure 17: Sketches of an example of an economic structure.

3.1 A TOOL FOR ARCHITECTURE STUDENTS

In the same way, the design of a building begins specified by qualitative parameters, also determined by the enclosure program, but also by specific quantitative metrics usually determined by the expected cost per m2. The first parameter has been studied for various types of buildings, even forming part of construction laws and ordinances that set minimum standards according to the activity to be carried out, which determines lighting and ventilation conditions, average comfort temperature, acoustic reverberation, etc.

The cost of the structure of a wooden building in Chile is determined by the concurrence of three factors: seismic stability, fire resistance, and wind resistance. Given its low weight, it is not the problem of seismic stability that mainly determines the sections of the elements. Even so, studying it is essential to develop the system of joints and hinges necessary to resist earthquakes. At the same time, the most critical conditions for a wooden structure are its stability against the wind and its resistance to fire. Quantifying these variables allows the study of different combinations of parts and components, which imply different costs.

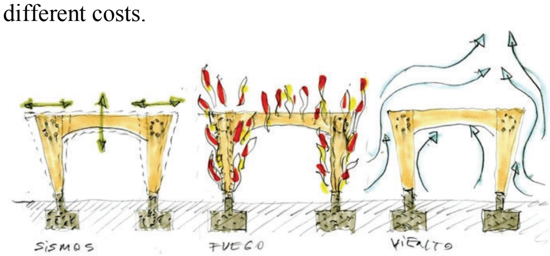

Figure 18: *Sketches of seismic stability, fire resistance and wind resistance.*

Understanding the above, through 3D modeling of different projects, students quantify and compare the volume of concrete in cubic meters and the steel foundation; sawn timber structures; glued laminated wood structures; the fittings and connection components, and the square meters of coatings and skins for each project.

The initial results in a structure efficiency index or IEE, associated with the cost per m3 of material, determine a quantitative parameter of design efficiency concerning the built area.

This index can also be associated with a recycling rate for the building -generally associated with the wooden elements it uses- to show its sustainability and the estimated carbon footprint index.

3.2 MORE THAN A FORM, AN STRUCTURE.

As Alberto Campo Baeza points out, “gravity builds the space (…) the load-bearing structure, rather than transmitting loads of the building to the ground, what it transmits is the order of the space, it builds the space. As a result, the structure supports not only endures but is well resolved, tuned, waiting to be pierced by light” [4].

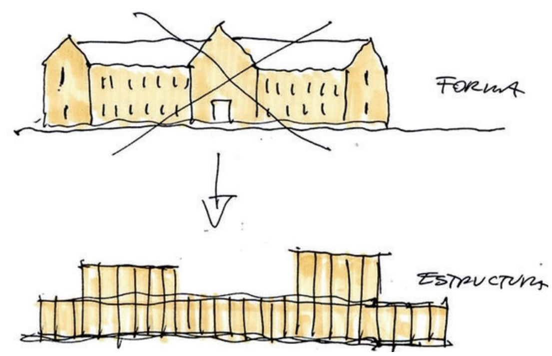

Figure 19: *Sketches of the “More than a shape, an structure” concept.*

To develop a wood project, the first thing that students do in the course, after carefully studying the conditions of the place, the program in charge, and the available resources, is to discover the deep organization that will order it. More than finding a plastic form, which depends on the design of a "skillful hand" of the person who makes it, an order is sought, a deep structure that organizes the program and the construction in a straightforward matrix, which builds the entire project.

Once this internal order is discovered, the project flows into a sequence of reasonable, appropriate, and consistent decisions between what, to quote Louis Kahn, a building "wants to be" [5] and the material that will be used to make it.

In this previously described way, innumerable data, intuitions, tastes, and sensibilities converge to know "what" and "what" should be what we are doing. The form is thus a consequence and not a goal.

3.3 A METHOD FOR AUSTERITY

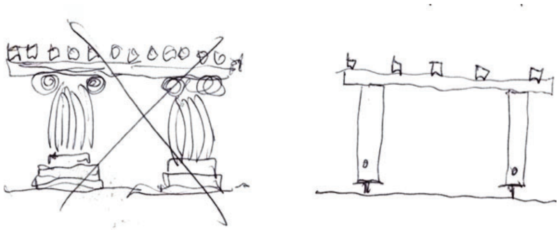

Figure 20: *"A method for austerity" scheme.*

For various reasons, most of the carpentry in Chile has been developed under the premise of an essential economy of resources.

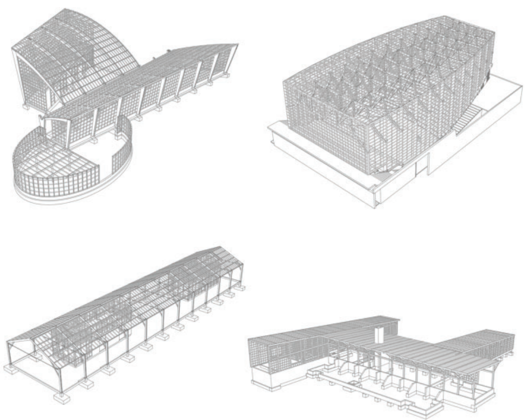

Figure 21: *Mim Museum, Matucana Theater 100, Haras Las Camelias and House 2 wooden structure models.*

Chile is a country that hardly looks at the benefits of development, where most people live at subsistence levels. Therefore, preparing a student to work under strict austerity measures seems ethically prudent. This self-discipline has meant that when tackling each project, we are very strict in leaving what is essential or the minimally necessary to accommodate the requested program, and with this finding the most suitable material for the available budget.

In this way, based on years of experience in the design of a significant number of wooden buildings and university teaching on building with this material, the need arose to have quantitative judgment elements when making decisions arose. Decisions regarding the supporting structure of a building are a way to optimize and create more efficient use of resources.

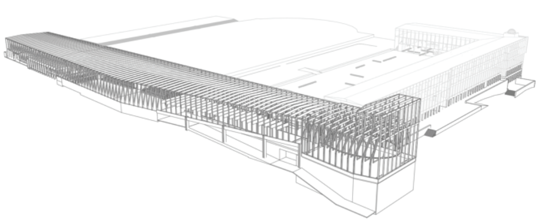

Figure 22: *Wooden structure model of the San Francisco Javier School Puerto Montt.*

4 CONCLUSIONS

After different editions of the course, studying and measuring the m3 of wood per m2 of the building became a way of helping to decide and project the structure of a building without this being a mere result of the structural calculation at the end the process.

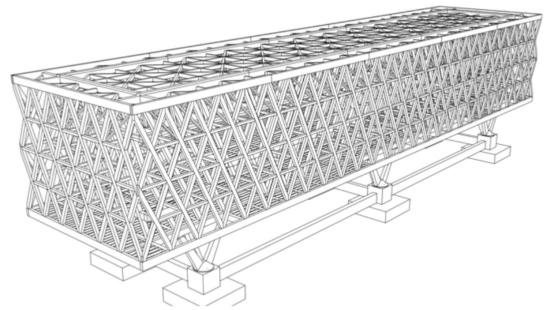

Figure 23: *Wooden structure model of the Expo Milan 2015 Chilean Pavilion. Undurraga Deves Architects.*

The students, by modeling and drawing the details of each building studied, the product of a careful selection of significant works of architecture in wood, allowed us to understand why the author decided on one or another modulation of the structure, to know how he solved the details, to question his plastic expression and increase their architectural culture.

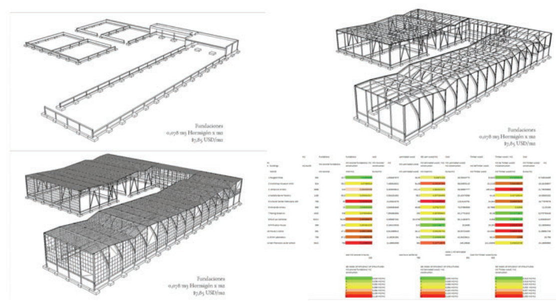

Figure 24: *Foundations, main structure and secondary structure of the Greenvic Packing.*

4.1 THE PROBLEM

Regarding the concepts present in large part of the architecture treatises, such as proportion, scale, rhythm, order, and, ultimately, the harmony of the whole, the idea of parameterizing cases and extracting valuable lessons for future projects, He delivered a method of systematization in decision-making based on the consideration of seismic, fire and wind conditions, which make evident what determines the dimensions of the structure of a building. Being able to identify the craft and constructive wisdom, later managing to design with criteria of beauty by taking into account costs, but also the proportion and language of the structures as plastic resources to provide "architectural identity" to the buildings.

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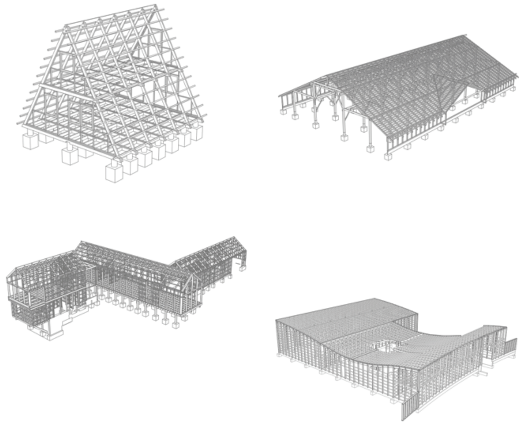

Figure 25: *A-Frame House, Osorno Warehouse, Molinahue House and Nadalie Barrel Factory wooden structure models.*

4.2 MAIN FINDINGS AND RESULTS.

From a methodological point of view, the results obtained, both quantitative (index) and qualitative (what and how the designer thinks), have motivated: the permanent realization of the workshop, the participation and obtaining of prizes in different national competitions for students and the creation of a book as a permanent contribution to knowledge in this area.

4.3 CONTRIBUTION TO LITERATURE AND KNOWLEDGE IN THE AREA: THE MANUAL

After two years, the study managed to comparatively systematize several historical and contemporary examples of good wooden architecture, finding efficiency parameters in terms of discovering the wisdom of the trade present in the amount of material necessary to build a wooden building, similar to the index used by engineers in reinforced concrete constructions, which measures the weight (kg) of steel per volume (m3) of concrete, knowing a priori when a structure is within reasonable efficiency margins.

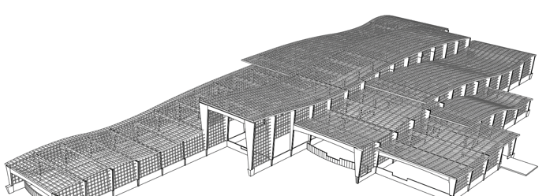

Figure 26: *Viña Almaviva Winery wooden structure model.*

This result will become a Manual for architects, builders, and students, to verify the amount of wood in the structure during the design process, involving in this edition, thirteen projects developed in our architecture office, four historical projects and three contemporary wooden buildings.

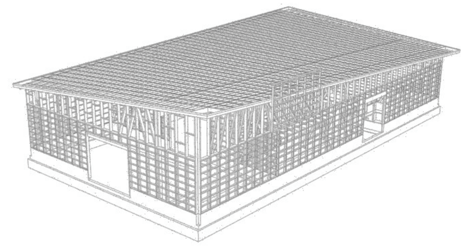

Figure 27: *Wooden structure model of the INFOR Laboratories.*

IEE INDEX OF EFICIENCY OF STRUCTURES							
m3 concret fundations/ m2 constructio n		m3 laminated wood / m2 constructio n		m3 Timber wood / m2 constructio n		Cost Euros / m2	
A	0.020 m3/m2	A	0.030 m3/m2	A	0.010 m3/m2	A	0-55 Euros/m2
B	0.036 m3/m2	B	0.048 m3/m2	B	0.016 m3/m2	B	56-71 Euros/m2
C	0.052 m3/m2	C	0.066 m3/m2	C	0.023 m3/m2	C	72-87 Euros/m2
D	0,068 m3/m2	D	0,084 m3/m2	D	0,030 m3/m2	D	88-104 Euros/m2
E	0,084 m3/m2	E	0,102 m3/m2	E	0,037 m3/m2	E	105-121 Euros/m2
F	0,100 m3/m2	F	0,124 m3/m2	F	0,043 m3/m2	F	122-138 Euros/m2
G	0,116 m3/m2	G	0,146 m3/m2	G	0,050 m3/m2	G	139-155 Euros/m2

Figure 28: *IEE Index of Eficiency of Structures..*

Nr	buildings	m2 construction	m3 laminated wood / m2 construction
	INDICE		m3 mad/m2
1	Peugeot Shop	582	0,049
2	Workshop Museum MIM	524	0,103
3	Almaviva Winery	3688	0,063
4	Nadalie Barrel Factory	1190	0,057
5	Cultural Center Matucana 100	765	0,124
6	Morande winery	660	0,075
7	Paking Greenvic	4303	0,068
8	Stud Las Camelias	625,3	0,065
9	Pirihueico House	380	0,022
10	House 2 Colico	481	0,054
11	ECIM Laboratory	755	0,046
12	San Francisco Javier school	6322	0,108
13	Achao Church	490	0,000
14	House A	56	0,081
15	Chile Pavilion Expo Milan	2121	0,321
16	Architecture School PUC	1428	0,196
17	CMPC Headquaters Los Angeles	6946	0,207
18	Las Quemas Barn Osorno	687	0,054
19	Building 42 Sewell	657	0,083
20	Infor Concepción	1216	0,081

Figure 29: *20 cases compared by the IEE index.*

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REFERENCES

[1] Iturriaga, S.: Cristián Valdés: La Medida de la Arquitectura. Ediciones ARQ. Santiago, Chile, 2008.

[2] Zumthor, Peter. Thinking Architecture. Birkhäuser, Basel, 2010.

[3] Íbid.

[4] Campo Baeza, A.: La estructura de la estructura. Nobuko, Buenos Aires, 2010.

[5] Kahn, L.: Order and Form. Perspecta 3: The Yale Architectural Journal, 1957.