Sizing of a chalet building with amazonian species according to NBR 7190:2022

Dimensionamento de uma edificação tipo chalé com espécies amazônicas de acordo com a NBR 7190:2022

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Keywords: Construction, Chalet, Amazonian species.

1 INTRODUCTION

The design of a wooden structure is based on simple concepts, but with complex details. It is fundamentally based on structural analysis to show that the strength and stiffness of the structure exceeds the expected load request that should be applied throughout its existence. Thus, it is a mathematical analysis of estimated strength and stiffness of the material that must be higher than the efforts and deformations that the structure will suffer due to the estimated load that will be applied to it.

When dealing with the dimensioning of a wooden structure, more specifically a residential building, in which people and objects will be accommodated, it is necessary to use calculation rules, more specifically, ABNT NBR 7190:2022, which was launched in July of the above-mentioned year to replace NBR 7190:1997. These rules address topics related to the durability of wood, care in the execution of structures, minimum dimensions of structural elements and connectors, and characteristics of the structural project itself.

Civil construction is one of the largest consumers of inputs, with several challenges to achieve a level of sustainability, in this scenario, wood is one of the materials that can meet this ecological demand, because although lay people associate the use of wood to the devastation of forests, this is not the reality. It is forgotten that it is a renewable material and that during its growth it captures carbon from the atmosphere and transforms it into wood, i.e., it contributes to the reduction of the greenhouse effect. Secondly, the harvesting of the tree and its sawing are processes that involve low energy consumption, when compared to the manufacture of cement, for example, which consumes an average of 1,750 kilowatt hours to produce one cubic meter, while wood consumes only 350 kilowatt hours per cubic meter of sawn and laminated wood.

When it comes to the Amazon, wood presents itself as an abundant resource in view of the capacity of wood production, and as to its properties, a material of wide application, whether as an element of insulation, coating, or structural.

Thus, this work sought to develop and present the new equations and understandings, as a way to subsidize studies aimed at structural calculations of wooden buildings, with emphasis on the application of Amazonian species and to encourage the application of wood in the construction of buildings.

2 OBJECTIVES

2.1 GENERAL OBJECTIVE

Sizing of a chalet building using Amazonian species of wood in accordance with ABNT NBR 7190:2022.

2.2 SPECIFIC GOALS

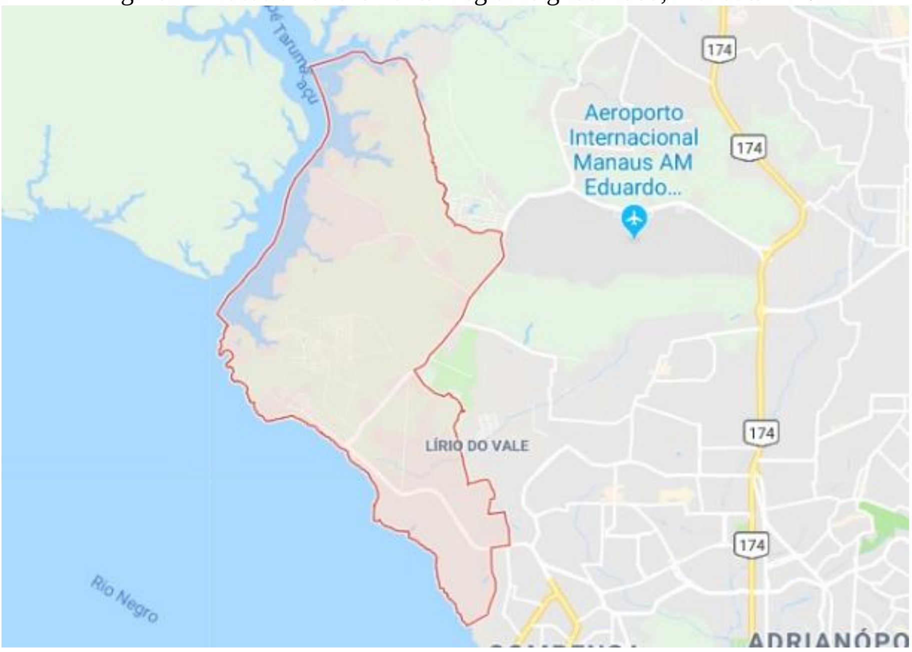
- Use of Amazonian species in structural design;
- Structural analysis of the building, with the formulation of calculation considerations;
- Proposed calculation regarding compliance with the new requirements of the updated Standard.

3 METHODOLOGY

3.1 STUDY AREA

For this work, we adopted the project named "CHALÉ PORTELA WOOD" owned by PORTELA INDUSTRIA E COMERCIO DE MADEIRAS LTDA registered in the National Register of Legal Entities (CNPJ) under No. 04.364.879/0002-92. Project created to attract the public interested in building with wood in the city of Manaus/AM, with a probable execution site located in the Ponta Negra neighborhood, west zone of the city. Its adoption in this work was by authorization of use for academic purposes and dissemination in events and activities of scientific nature.

Figure 1 - Location of the Ponta Negra neighborhood, Manaus/AM.

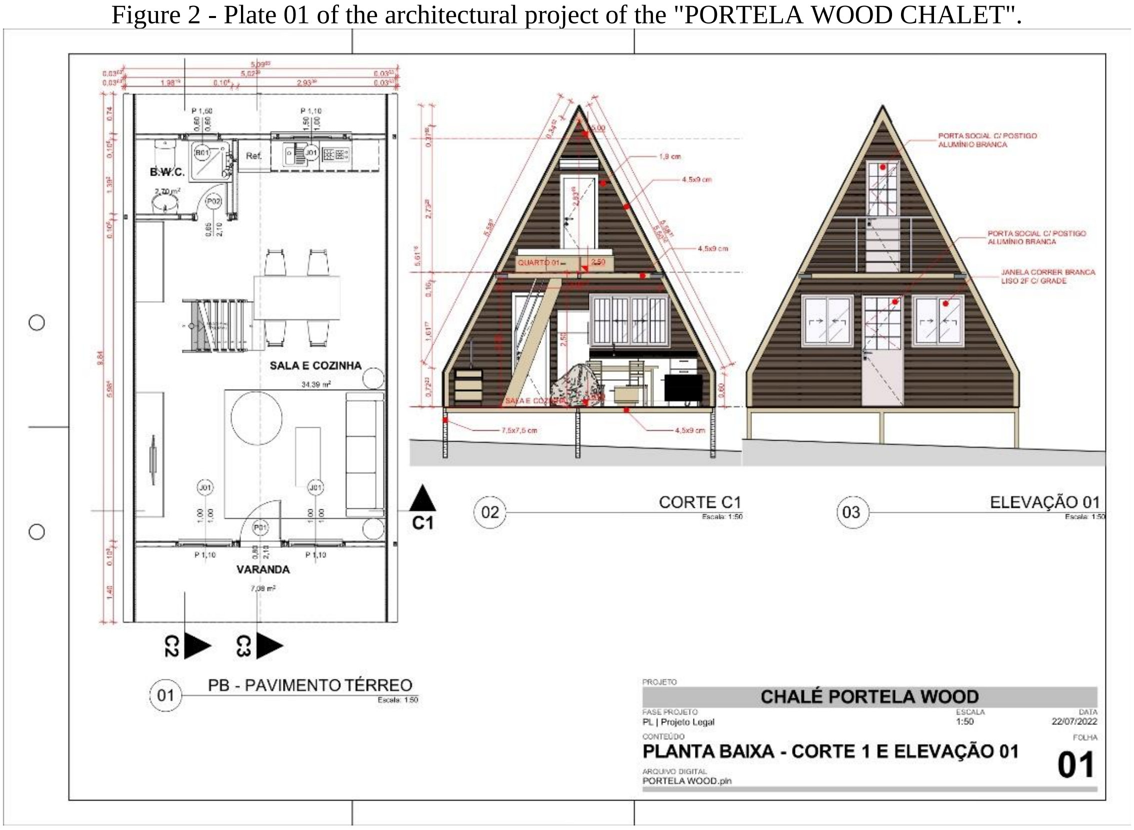


Source: Encontra Manaus (2019).

3.2 MATERIAL

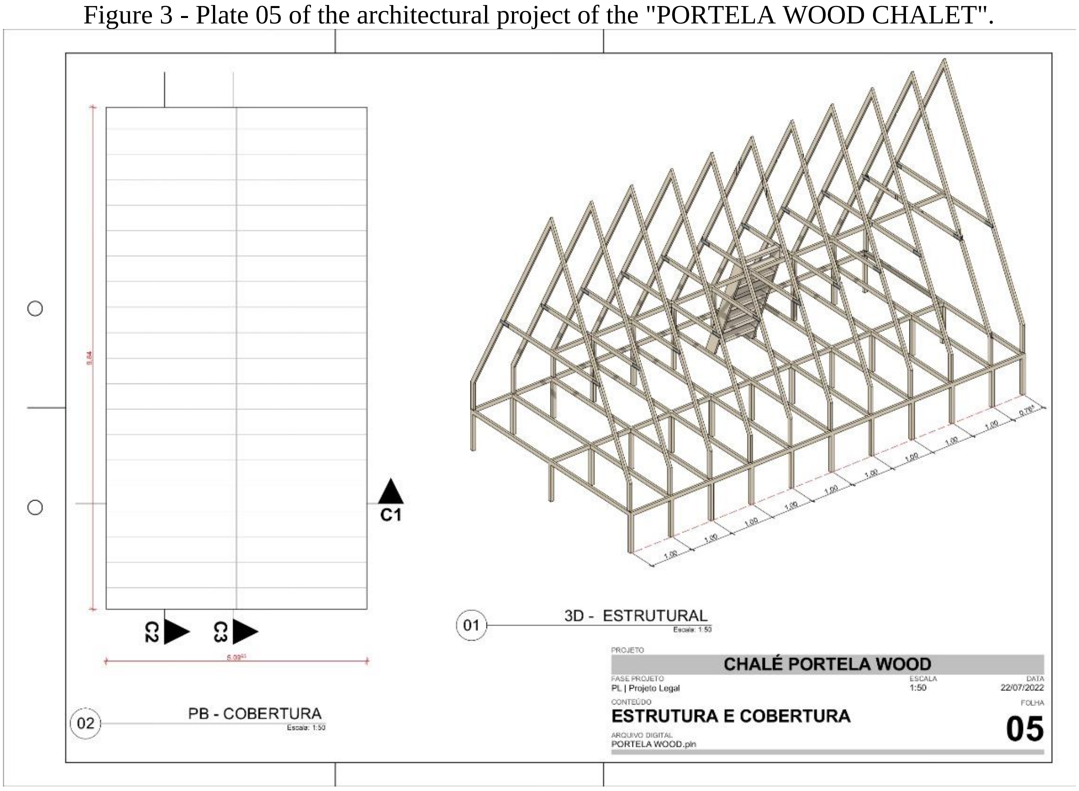
The work consists of the structural design of a wooden chalet building in accordance with the architectural project plans shown in Figures 2 and 3.

Figure 2 - Plate 01 of the architectural project of the "PORTELA WOOD CHALET".



Source: PORTELA INDUSTRIA E COMERCIO DE MADEIRAS LTDA (2022).

Figure 3 - Plate 05 of the architectural project of the "PORTELA WOOD CHALET".



Source: PORTELA INDUSTRIA E COMERCIO DE MADEIRAS LTDA (2022).

To do this, the following tools will be adopted:

- **Ftool:** interactive graphic program of the structural behavior of plane elements and frames;
- **Mathcad:** software for verification, validation, documentation, and reuse of mathematical calculations;
- **MaDim (developed by the author):** program directed to the sizing and evaluation of wood pieces;
- **SketchUp:** software for creating 3D models;
- **AutoCAD:** CAD software used for 2D and 3D drawings.

With the following names as references:

- **ABNT NBR 7190:** 2022 - Design of wood structures;
- **ABNT NBR 6120:** 2019 - Actions for the calculation of building structures;
- ABNT NBR 6123:1988 - Forces due to wind in buildings;
- ABNT NBR 8681:2003 - Actions and safety in structures (Procedure).

3.3 METHOD

Fundamentally, it is intended to distribute the activities:

- **I.** Architectural design review.
- **II.** Analysis of the structural system adopted to have compression of the elements most requested by loads or in unfavorable positions, the most critical points of connections and those vulnerable to deteriorating agents.
- **III.** Determination of design loads and efforts according to ABNT NBR 6120:2019, ABNT NBR 6123:1988 and ABNT NBR 8681:2003.
- **IV.** Definition of the most appropriate species for application according to the classification of use in the building system and based on physical and mechanical properties, as well as considering workability aspects, possible drying defects, and availability on the local market.
- **V.** Dimensioning the structural elements of the chalet. The design will be based on the normative references of ABNT NBR 7190:2022.
- **VI.** Detailing of the parts and connections of the structural elements.
- **VII.** Elaboration of the descriptive calculation memorial, boards containing the project's views and cuts.

4 AMAZONIAN WOODS

The logging activity is one of the alternatives for the development of the Amazon. Currently, about 5% of the economically active population of the so-called Legal Amazon (territory that includes all the States of the Northern region, besides Mato Grosso and part of the State of Maranhão) works directly or indirectly with logging activities (Lentini et al., 2003).

According to Higuchi et al (2006) the Amazon rainforest is considered the largest continuous tropical forest reserve in the world. The Amazon is home to a great plant diversity where each of its forest environments has a rich and varied floristic quantity, which in the great majority of cases is exclusive to a particular environment (OLIVEIRA; AMARAL 2004).

4.1 WOOD PRODUCTION

In the Amazon, the exploitation and use of wood has its own peculiarities. Most of the wood legally used comes from management plans. It is noteworthy, therefore, that given the floristic diversity of the Amazonian ecosystem it is practically unfeasible to use only one species in wooden buildings. This diversity of wood species with distinct properties induces the grouping of species by similarity of characteristics, as a way to increase the volumes extracted per unit of area and consequently reduce extraction costs.

For ecological reasons, there are few areas of planted forests in the Amazon, even if there were, they should be made up of several species so that biodiversity could be maintained and pressure on the more commercial forest woods reduced, including replacement by others with similar technological characteristics. Making with this production inside the forest, implies diversity of species, stem and diameters produced without quality control - in fact a product of nature.

Thus, the wood originating from a management plan would be found "in natura" with its defects and levels of deterioration according to the environment in which it is found. In addition, the volume of wood per species per hectare available in the forest is relatively low, according to ZENID (1997) the diversity of species found in tropical forests has been a problem for mechanical wood processing companies, because from a wood volume of 100 to 180 m^3 per hectare, only a volume around 10 to 20 m^3 per hectare is exploited.

This implies that it is economically unfeasible to use a single species in the construction of a wooden dwelling.

In addition, some difficulties faced in the effective implementation of sustainable forest management are related to the need for high initial investment, the bureaucracy of regulatory agencies, unfair competition with clandestine logging companies, and the lack of land tenure security in the Amazon region. Sabogal et al. (2005) highlighted the following economic factors as limiting the adoption of management:

a) the low price of (legal) wood in the market;
b) the difficulty in inserting new species in the foreign market;
c) the lack of research on new species.

Therefore, when designing and developing the calculation for buildings made with Amazonian wood one must be aware of the need to adopt groupings to make it economically viable.

4.2 WOOD BUILDINGS IN AMAZONAS

Throughout the state of Amazonas one can observe various wooden constructions, some of them characteristically local to the region:

- Wooden houses, both in the capital Manaus/AM, and in the interior of the state;
- Bridges;
- Floating.

4.3 COMPLEXITY OF AMAZONIAN SPECIES

The physical and mechanical properties of wood are important in defining the purposes for which it will be used. Most timber species from temperate zones have good density, good resistance and stiffness, and are easy to work and finish. In the case of the Amazonian species there is a differentiated situation. In general, the species are of medium and high density, the relation resistance and stiffness with their density is low, they are difficult to debark, do not have good dimensional stability, suffer cracking and have difficulties in good finishing.

In addition, most of them do not accept nails easily and are difficult to drill and glue. Compared to the species from temperate zones, it has positive aspects in that it has better natural durability and is less flammable. But the aspects about the quality of Amazonian wood do not invalidate the possibility of its being used in civil construction if properly handled. After all, it is the most abundant construction material in the region.

Because, together with other aspects (economic, aesthetic, durability, workability, etc.) and according to their properties, the woods can be classified and grouped in uses to which they are more adequate, such as structures, internal and external environments, furniture, panels, packaging, and flooring (Araújo, 2002).

Ferreira & Kageyama (1978) emphasize that density has great commercial importance, because the desired end product and the technology to be employed depend directly on it. In other words, for the forest sector, the choice of wood to be used, whether high, medium or low density, will depend on the specific needs of the industrial sector.

5 STRUCTURAL CALCULATION BASES

5.1 STRUCTURAL ANALYSIS

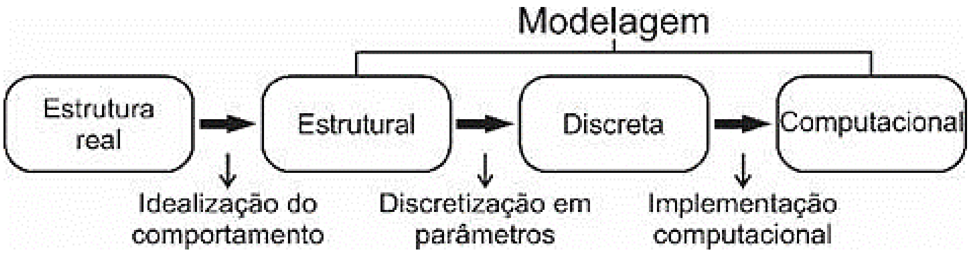
According to Martha (2010, p. 1), the structural analysis is a stage of the structural project in which the behavior of the structure is idealized and expressed by different parameters, aiming to determine the internal efforts in structural elements, and consequently the corresponding stresses and strains, as well as the support reactions and displacements of the structure. When sizing the structure, it needs to resist safely and without exaggerated deformations all the efforts both during the period of execution and during its use (CARVALHO; FILHO, 2014).

To this end, the real structure is idealized in a structural model, which is subsequently analyzed by a certain method, which can be of manual or computational application, depending on its complexity and formulation (BENINCÁ, 2016).

Kimura (2007, p. 128) says that, in theory, the best model is the most realistic, that is, the one that best simulates the real structure.

According to Martha (2017) contemporary structural analysis consists of four levels of abstraction, as per Figure 2.

Figure 2 - Levels of abstraction referring to a structure in structural analysis.



Source: Martha (2017).

The real structure refers to the physical world, which is transformed into a structural model and this is modified to a discrete model for the cases of structures composed of bars, finally, a computational model is employed to facilitate the development of calculations (MARTHA, 2017).

5.2 STRUCTURAL SYSTEMS

The response of a structural element that is part of the system, as is typically the case in light-frame residential construction, can change the performance of the entire system. Timber structures in general are made up of repetitive elements and share the load capacity between them, i.e., the set of components (or elements) connected to each other form a "composite member" with greater capacity and stiffness of the component parts.

The capacity and rigidity of the response of the wood structural system to the actions (or loads) it is undergoing depends on the way the various structural elements have been assembled and how these elements are connected. For example, connections by pins or by adhesive. The adhesive connection has more rigidity and the adhesive between the components can help prevent shear slippage, especially if a rigid adhesive is used.

The stiffness and strength of the structure as a whole can be slightly affected by the lack of clear interpretation suffers the path that actions travel in lightweight structures (walls, floor, roofs) and the behavior of the joints of structural elements under the effect of loading. Thus, classical compression of the load path and how these loads are transferred between various assemblies of a structural system is of utmost importance.

5.3 LOAD PATH

Once an initial conceptual design has been completed, attention will turn to the design of the system from top to bottom. Understanding the load path of the structure is imperative with specific considerations given to gravity loads, lateral loads, and uplift on the various elements within the structure. One should distinguish the agents, actions, combinations of actions and their effects. For example:

- Agent: gravity, wind, solar radiation, snow, earthquake;
- Actions: load, pressure, temperature;
- Combinations of actions: actions that can occur simultaneously;
- Effect: tension, force and moment, rotation, displacement, and deformation.

Loads produce stresses in the structural system and its elements, and in connections as the load-induced forces are transferred through the structure to the ground. The path by which the loads are transferred is known as the loading path. A continuous loading path is capable of resisting and transferring the loads that are carried throughout the structure from the load's point of origin to the foundation.

Defining or identifying the load path in a conventional house is directed at understanding the cause of structural configuration, load sharing and redistribution of forces between the building elements. It requires critical analysis skills, experience, and sensitivity to the local and global stability of the structural system.

It is difficult to do an accurate accounting of the structural effects of the actual load distribution on the structure; this would likely require the use of specific, high-cost software that is not justified for a simple house. As far as possible, it is recommended to consider system effects, recognizing that there are inherent uncertainties that can make the results inaccurate. To some extent, these uncertainties are already shared in the calculation standards for structural design. Evidently, in the cases of more complex buildings, one should get as close as possible to reality, performing mathematical simulations and even experimentation with similar prototypes.

In general, the loading has two paths of loading; the vertical due to self-weight and overloads and the horizontal due to wind effects (in the case of Amazon). Both must be reflected in the soil that in turn guarantees the stability of the structure by the foundation. Thus, at the beginning of the analysis the following items should be analyzed (considering that you already have the complete architectural project).

- Determination of the actions acting on the structural system of the house;
- Understanding the path of the load to the ground considering housing design and functionality;
- Load distribution over the structural elements.

5.4 VERTICAL LOADING

The vertical loads are due to self-weight, over conventional loads and accidental loads due to wind and eventually other types of loads applied sporadically in the building. These loads are generally distributed from the secondary beams to the primary beams and then to the columns until reaching the foundations. Openings generally have larger beams that are supported by columns at their ends; these beams, known in masonry as lintels, relieve the load of the span distributed to the lateral columns.

5.5 SIDE LOADING

In the case of Amazonas, the horizontal load acting on the structure is caused by the wind. In simple housing and mainly chalet type, the actions due to the wind effect are not significant, the risks are small. In any case, it is good to check for the possibility of having some inversion of effort that can compromise the structural system as a whole.

It is also important to note that all action, both horizontal and vertical, is reflected in the foundation of the building. This implies the need for some constructive aspects so that the transfer of this load happens efficiently. The path of the horizontal load depends on the relative stiffness of the various components that make up the structural system and connections.

The lateral forces of the wind tend to cause sharp lateral deformations, rolling or tipping in the building. It is important to observe the structure as a whole and verify its global stability, given the need for bracing, verification of details and forces acting on the connecting elements, and correct dimensioning of the columns in their ultimate and service limit states.

In general the vertical acting load due to permanent loads, overloads etc. are much greater than the load that may tend to lift the whole house, in this case, the concern of the wind effect in "turning" the house is minimal for light structures such as housing. On the other hand, the concerns should be with the roof where the wind effect can reverse stresses on the structural elements of the roof and can also rip the roof off.

5.6 STRUCTURAL MODEL ACCORDING TO THE PORTELA CHALET PROJECT (DIAGRAM OF THE ISOLATED STRUCTURAL SYSTEM)

Visualization of the forces and moments acting on the structure and observance of its boundary conditions is extremely important to visualize the structure's behavior as close to reality as possible. Such information is crucial to correctly feed a software for structural design.

There are several constructive and structural systems of wood construction. In general, the construction system is adopted according to the dimensions of the building and the degree of prefabrication available on the market. Currently, in places where timber construction has reached advanced levels of technology both in terms of forestry aspects and in the prefabrication of components, wood frame, cross laminated timber (CLT) and structures with glued laminated timber beams (MLC) are used.

In Amazonas, unfortunately, the structural system used is the simplest because it consists of pillars and beams in the conventional way. The most modern look for this type of structure in the Amazon region is in the distance between the sets of pillars, shears, and beams, which allows the construction of a light and rigid building.

The closest graphical representation of the functioning of the structural system proposed for a building, the safest for its users to have better safety and comfort conditions, is given by the interpretation of the structure's behavior, by carefully evaluating the connection elements and the boundary conditions that the structure must have to guarantee its stability.

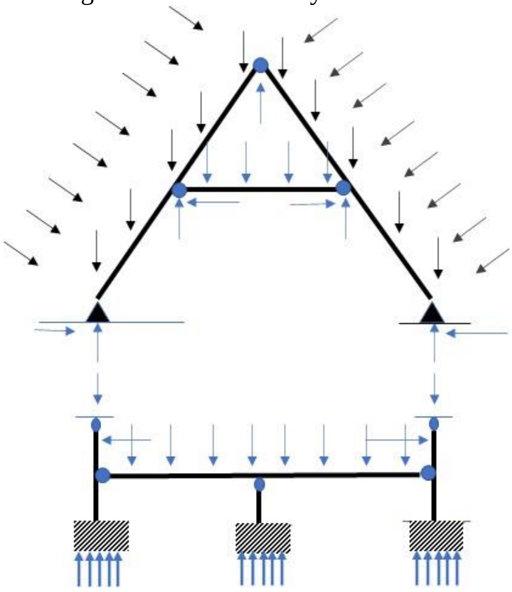
One of the important mechanisms to make a critical analysis of the structural behavior of a building is sketching the free-body diagram of the structural system of the building, this implies that the designer must decide how the structural and constructive system of the dwelling should be adopted to ensure the overall stability of the building. Emphasis should be given to the connections and the boundary conditions.

The elaboration of the structure's free-body diagram will allow the structure's analysis, calculation and design software to be fed with information that is closer to the structure's operating reality. Incorrect information can cause disastrous effects on the work, putting the user at risk and substantially increasing the cost of the work.

In the case of timber construction works, one tries to visualize previously the structural analysis, even if in the form of a sketch of how the supports and connections of the structural elements should be, in order to use them in the calculations of stress and strain of the structure and its structural elements. Thus, the analysis should not be done only by imposing the type of support and connections that will be adopted in the structure, but through a preliminary analysis of a probable connection model and support modals, considering the natural limitations of the wood (dimensions, pin spacings, fiber directions and types of stresses on the wood pieces). A poorly designed and built wood structure may collapse or present deformations that will make its use unfeasible.

At first, in view of the architectural design of the Portela chalet, the diagram of the book body of the structural system of this building can be thus represented according to Figure 4:

Figure 4 - Diagram of the book body of the structural system.



Source: Author (2023).

5.7 ACTING LOADS

The wood structural element behaves according to the action it is being subjected to and the speed at which the load is being applied to the structure. It is worth pointing out that the dynamic load resistance of wood is greater than its static load resistance, and the slow deformation effect of wood is very pronounced. Besides this, the risks of some structural problem happening and its consequences to the user depend on the purpose of the building and the estimated lifetime of the construction, i.e., a temporary construction the coefficients are different to a permanent structure.

Table 1: Definition of loading classes.

Classes of loading	**Main variable action of the combination**	
	Accumulated Duration	Order of magnitude of the cumulative duration of the characteristic action
Permanent	Permanent	More than ten years
Long life	Long life	Six months to ten years
Medium Duration	Medium Duration	One week to six months
Short duration	Short duration	Less than a week
Instant	Instant	Very short

Source: ABNT NBR 7190 (2022).

In addition to the classification according to the duration of the charge, there is also the classification according to its mode of action.

ABNT NBR 8681:2003 presents how the forces are designated by direct actions and the deformations imposed by indirect actions. In function of their variability in time, the actions can be classified as:

5.7.1 Permanent

Actions that occur with constant values or a small variation around of its average, during practically the whole life of the construction. The variability of permanent actions is measured on a set of analogous constructions. In the case of wood structure, the connection elements must be considered in the self-weight. According to ABNT NBR 7190:2022, the weight of the hardware is estimated to be 3% of the timber structure's self-weight. The permanent actions have constant values or have small variation around the average throughout the life of the construction.

5.7.2 Variables

Variable actions are considered as accidental loads of the constructions, as well as effects, such as friction, impact and centrifugal forces, the effects of wind, temperature variations, friction in the support devices and, in general, hydrostatic and hydrodynamic pressures. According to their probability of occurrence during the life of the construction, the variable actions are classified into:

a) normal variable actions: variable actions with sufficiently high probability of occurrence to be mandatorily considered in the design of the structures of a given type of construction;

b) special variable actions: in structures in which certain special actions must be considered, such as seismic actions or accidental loads of a special nature or intensity, they must also be admitted as variable actions. The combinations of actions in which special actions occur must be specifically defined for the special situations considered.

5.7.3 Exceptional

These are actions of extremely short duration and with very low probability of occurrence during the useful life of the construction. They must be considered in the project if their effects cannot be controlled by other means. Examples are earthquakes, explosions, fires, vehicle collisions, floods, etc. Fires, rather than being treated as a cause of exceptional actions, can also be taken into account by reducing the strength of the materials constituting the structure.

5.7.4 Accidental

These are the variable actions that act on the buildings due to their use (people, furniture, vehicles, various materials).

In the Amazon case the most important accidental action to be considered is the wind action on the structure.

5.8 WIND ACTION

The estimation of the wind load effect on the structure is determined as prescribed by ABNT NBR 6123:1988.

It presents the characteristic velocity (V_k) as the velocity used in design, obtained from consideration of the local base velocity, topographical factors (S_1), the influence of roughness (obstacles around the building) and building dimensions (S_2) and the building use factor (which considers the useful life and type of use) (S_3). The characteristic speed can be expressed by Equation 1:

$$V_K = V_0 \, S_1 \, S_2 \, S_3 \tag{1}$$

Where:

V_0 is the basic speed;

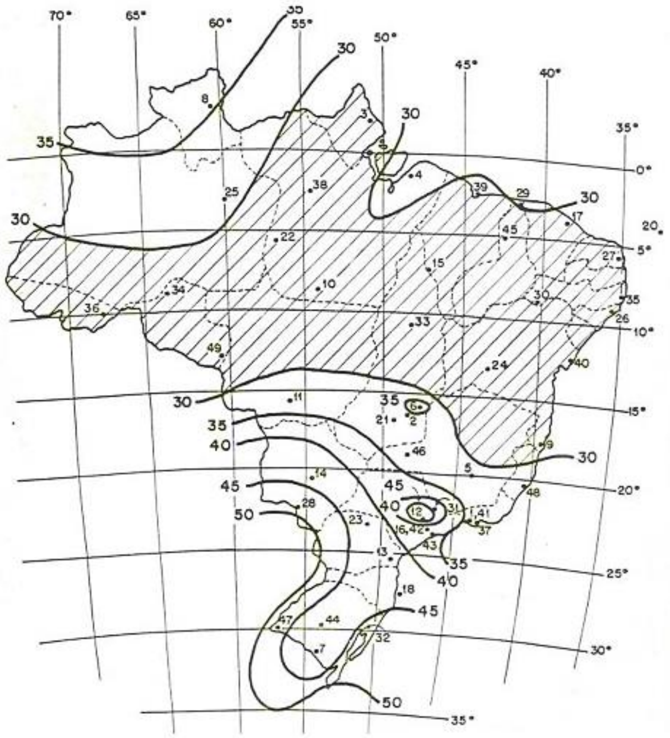
S_1 is the topographic factor;

S_2 is the roughness factor and building dimensions;

S_3 is the statistical factor.

Figure 5 shows the basic velocity for Manaus - Amazonas, as being on average 30 m/s.

Figure 5 - Isoplet of the basic velocity V_o (m/s).



Source: ABNT NBR 6123 (1988).

Actions and load combinations in lightweight timber dwelling-type structures

The Brazilian standard recommends load combinations in structural design. Such combinations provide the designer with a set of loading conditions that must be considered when designing the structure. They establish the probability of loads acting simultaneously in a favorable and unfavorable manner. It is necessary to make the judgment in any particular application and obey the guidelines established by ABNT NBR 8681:2003 - Actions and safety in structures (Procedure) and ABNT NBR-6123: Wind action.

The calculation values of the reduced combination actions are based on the situation of each project and categorized as follows: normal construction use (normal ultimate combinations), transient (special or construction ultimate combinations), and exceptional (exceptional ultimate combinations).

The ultimate normal combinations are the most adopted, since most of the buildings built are dwellings, sheds, and other structures used for conventional purposes. Therefore, in Chalé Portela the normal ultimate combinations should be employed, given by Equation 2:

$$F_d = \sum_{i=1}^{m} \gamma_{gi} F_{Gi,k} + \gamma_q \left[F_{Q1,k} + \sum_{j=2}^{n} \psi_{0j} F_{Qj,k} \right] \quad (2)$$

Where:

F_d is the resultant action, calculated in the ULS;

$_{gi}\ \gamma$is the boost coefficient for permanent actions;

$_{q}\ \gamma$is the boost coefficient for the vaiable actions;

$F_{Gi,k}$ is the characteristic value for permanent actions;

$F_{Q1,k}$ is the characteristic value of the variable action considered as the main action for the combination;

$\psi\ F_{0j\ Qj,k}$ is the reduced combination value of each of the other variable actions.

In special cases two combinations must be considered: in one, the permanent actions are allowed to be unfavorable, and in the other, they are favorable for safety.

It is important to emphasize, however, that the actions considered as main in the combination and that have a very short acting time (wind or the portion of the mobile loads due to impact) must be multiplied by 0.75.

In this case the variable action considered is only the wind effect, therefore the calculation value of the reduced actions is determined by Equation 3:

$$F_d = \sum_{i=1}^{m} \gamma_{gi} F_{Gi,k} + \gamma_q F_{Q1,k} \quad (3)$$

5.9 REPRESENTATIVE VALUES FOR WOOD STRENGTH AND STIFFNESS

According to ABNT NBR 7190:2022, wood structures should take into consideration the following representative values:

5.10 AVERAGE VALUES

The average value X_{med} of a wood property is determined by the arithmetic mean of the values corresponding to the sampling of the elements that make up the batch of material considered.

5.11 CHARACTERISTIC VALUES

The lower characteristic value $X_{k,inf}$, smaller than the average value, is the value that has only a 5% probability of not being reached for a given batch of material. The upper characteristic value, $x_{k,sup}$, greater than the average value, is the value that has only a 5% probability of being exceeded in a given batch of material.

In general, unless otherwise specified, it is understood that the characteristic value x_k is the lower characteristic value $x_{k,inf}$. Timber strengths are assumed to have normal probability distributions.

5.12 CALCULATION VALUES

The calculation value X_d of a wood property is obtained from the characteristic value x_k , by Equation 4:

$$X_d = \frac{K_{mod}\, X_k}{\gamma_w} \tag{4}$$

Where:

k_{mod} is the modification coefficient;

γ_W is the coefficient for the reduction of wood properties.

5.13 CHANGE COEFFICIENTS

The modification coefficients k_{mod} change the characteristic values of the wood's strength properties as a function of the structure's loading class and the admitted moisture class. The modification coefficient k_{mod} is calculated according to Equation 5:

$$k_{mod} = k_{mod1} * k_{mod2} \tag{5}$$

Coefficient of change k_{mod1}

The partial modification coefficient k_{mod1} , takes into account the loading class and the type of material used, as shown in Table 2.

Table 2: Definition of load classes and k-values$_{mod1}$.

Load Classes	**Main variable action of the combination**		**Types of Wood**	
	Accumulated Duration	Order of magnitude of the cumulative duration of the action characteristic	Lumber Round wood Glued laminated timber (MLC) Cross Laminated Glued Veneer (MLCC) Glued Laminated Timber (LVL)	Reclaimed wood
Permanent	Permanent	More than ten years	0,60	0,30
Long life	Long duration	Six months to ten years	0,70	0,45
Medium Duration	Average duration	One week to six months	0,80	0,65
Short duration	Short duration	Less than a week	0,90	0,90
Instant	Instant	Very short	1,10	1,10

Source: ABNT NBR 7190 (2022).

The loading class of a given combination of actions is defined by the expected cumulative duration of the variable action taken as the main variable action in that combination.

Change coefficient k_{mod2}

The partial modification coefficient k_{mod2} , which takes into account the moisture class and the type of material used, is given in Table 3:

Table 3: Values of k_{mod2} .

Moisture classes	**Lumber** **Round wood** **Glued laminated timber (MLC)** **Cross Laminated Glued Veneer (MLCC)** **Glued Laminated Timber (LVL)**	**Reclaimed wood**
(1)	1,00	1,00
(2)	0,90	0,95
(3)	0,80	0,93
(4)	0,70[a]	0,90
[a] The MLCC is not allowed to be used for moisture class (4).		

Source: ABNT NBR 7190 (2022).

5.14 GROUPING OF SPECIES

The grouping of wood is fundamental to the success of a building made up of Amazonian species. Without this previous selection work, the cost of the work can be excessively expensive and uncompetitive with other construction materials. Thus, two grouping criteria can be approached according to the purpose of use and resistance. The adoption of the two criteria concomitantly is idealized.

5.15 GROUPING BY STRENGTH CLASS

ABNT NBR7190:2022 establishes resistance classes aiming to be used in the design of wood structures with standardized properties, according to the values established in Tables 4 and 5.

Table 4: Strength classes of native forest species defined in tests on defect-free specimens.

Classes	**fc0k** MPa	***fv0*,k** MPa	**Ec0,med** MPa	**Density at 12 kg/m³**
D20	20	4	10000	500
D30	30	5	12000	625
D40	40	6	14500	750
D50	50	7	16500	850
D60	60	8	19500	1000
NOTE 1	He values in this Table were obtained according to ABNT NBR 7190-3.			
NOTE 2	Values refer to moisture content equal to 12%.			
NOTE 3	The strength class values for native species are available in ABNT NBR 7190-3:2022, Table A.1.			

Source: ABNT NBR 7190 (2022).

Table 5: Strength classes defined in tests for structural parts.

		Conifers												Leafy							
	Symbol	C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50	D18	D24	D30	D35	D40	D50	D60	D70
Resistance properties MPa																					
Flexion	*fb*,*k*	14	16	18	20	22	24	27	30	35	40	45	50	18	24	30	35	40	50	60	70
Parallel Traction	*ft*,*0*,*k*	8	10	11	12	13	14	16	18	21	24	27	30	11	14	18	21	24	30	36	42
Traction perpendicular	*ft*,*90*,*k*	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
Compression parallel	*fc*,*0*,*k*	16	17	18	19	20	21	22	23	25	26	27	29	18	21	23	25	26	29	32	34
Compression perpendicular	*fc*,*90*,*k*	2,0	2,2	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9	3,1	3,2	7,5	7,8	8,0	8,1	8,3	9,3	11	13,5
Shear	*fv*,*k*	3,0	3,2	3,4	3,6	3,8	4,0	4,0	4,0	4,0	4,0	4,0	4,0	3,4	4,0	4,0	4,0	4,0	4,0	4,5	5,0
Stiffness properties GPa																					
Modulus of elasticity at 0° mean	*E0*,*m*	7	8	9	9,5	10	11	12	12	13	14	15	16	9,5	10	11	12	13	14	17	20
Modulus of																					

elasticity at 0° characteristic	$E_{0,05}$	4,7	5,4	6,0	6,4	6,7	7,4	7,7	8,0	8,7	9,4	10	11	8	8,5	9,2	10	11	12	14	16,8
Modulus of elasticity at 90° mean	$E_{90,m}$	0,2	0,3	0,3	0,3	0,3	0,4	0,4	0,4	0,4	0,5	0,5	0,5	0,6	0,7	0,7	0,8	0,9	0,9	1,1	1,33
Mean transverse modulus of elasticity	G_m	0,4	0,5	0,6	0,6	0,6	0,7	0,7	0,8	0,8	0,9	0,9	1,0	0,6	0,6	0,7	0,8	0,8	0,9	1,1	1,25
Density kg/m³																					
Characteristic Density	ρ_k	290	310	320	330	340	350	370	380	400	420	440	460	475	485	530	540	560	620	700	900
Average Density	ρ_m	350	370	380	390	410	420	450	460	480	500	520	550	570	580	640	650	660	750	840	1080
Note 1	Values obtained according to ABNT NBR 7190-4																				
Note 2	Values referring to moisture content equal to 12																				

Source: ABNT NBR7190 (2022).

5.16 GROUPING BY PURPOSE OF USE

Once the class of resistance has been chosen, it is possible to group the wood species according to the purpose of use based on their technological characteristics.

Among the technological characteristics of wood, natural durability in contact with the soil expresses the average useful life and the susceptibility to the incidence and attack of xylophagous organisms. The results of durability evaluations allow the wood to be classified as to the possibility or not of being used in contact with the soil or for use in construction and support structures, or even in other applications where there are risks of damage by climatic and abiotic factors and by the diversity of insects and xylophagous fungi (JESUS et al., 1998).

For, the natural durability of a wood is defined as the average useful life in service when exposed to abiotic factors (temperature, moisture, luminosity, acidity, etc.) and xylophagous organisms, mainly fungi and insects (LEPAGE et al., 1986; SANTINI, 1988; JANKOWSKY, 1990; JESUS et al., 1998). Wood is biologically degraded by xylophagous organisms that use the natural polymers of the cell wall as a source of nutrition, and some of them have enzyme systems capable of metabolizing them (LEPAGE et al., 1986). The natural durability of wood is interpreted by its ability to resist the action of deteriorating agents, both biological and physicochemical, thus the wood can present high, medium or low resistance to the action of these agents (GOMES; FERREIRA, 2002).

Among the xylophagous insects, termites are the most serious wood-destroying agents. Termites can be divided into two groups: subterranean and non-subterranean. The subterranean ones live in the soil, in humid environments, from where they build galleries that protect them in conditions of high humidity and darkness, and allow them to reach the wood on which they feed. The non-subterranean termites find their home and food in the wood. As they live in low humidity conditions, they attack relatively dry wood. Their presence is indicated by small crumbs next to the attacked wood, which are the fecal residues of the termites (GALVÃO, 1975).

The wood borers, another important group of xylophagous organisms, whose adults are the beetles, are not social insects and belong to a taxonomic group of the order Coleoptera. From the living tree to the wood in use, different types of borers attack the wood at different stages of its processing (LELIS, 2000).

The choice of species must be made carefully so as not to run the risk of placing pieces of wood whose physical and mechanical properties, natural durability, treatability with preservative products and mechanical fixation are not able to resist the actions of biological agents. In this sense, it is suggested to observe the Classes of Use for wood in civil construction, according to the condition of use in the project, and the corresponding xylophagous organisms that can attack the wood, CALIL et al (2006).

Table 6: Use Classes for wood in civil construction.

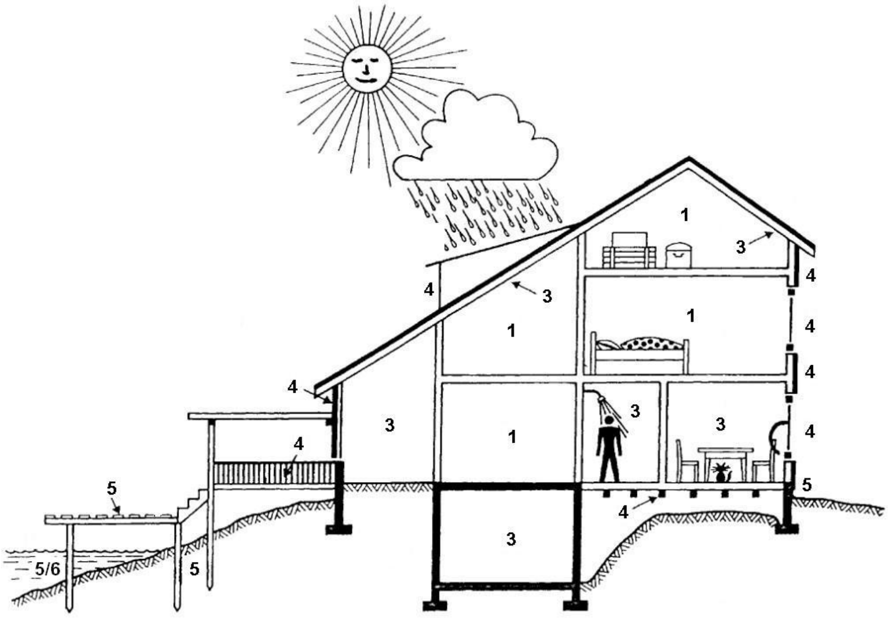
Classes	Conditions of use	Xylophagous Organism
1	Inside buildings, out of contact with the ground, foundations or masonry, protected from the weather, internal sources of moisture. Places free of access to subterranean or arboreal termites	Drywood termites Wood drill bits
2	Inside buildings, in contact with masonry, without contact with the ground or foundations, protected from the weather and internal sources of moisture	Drywood termites Wood drill bits Subterranean / arboreal termites
3	Inside buildings, out of contact with the ground and continuously protected from the weather, which may occasionally be exposed to moisture sources	Drywood termites Wood drill bits Subterranean / arboreal termites Fungal blotting / staining / rotting fungi
4	Outdoor use, out of contact with the ground and subject to weathering	Drywood termites Wood drill bits Subterranean / arboreal termites Fungal blotting / staining / rotting fungi
5	Contact with soil, fresh water, and other situations favorable to deterioration, such as crimping in concrete and masonry	Drywood termites Wood drill bits Subterranean / arboreal termites Fungal blotting / staining / rotting fungi
6	Exposure to salt or brackish water	Marine Drills Fungal blotting / staining / rotting fungi

Source: CALIL et al (2006).

The use class was elaborated according to the type of biological attack that the wood can suffer in function of its application, that is, according to the exposure of the wood or wood product in use situations. The purpose of the use classification is to contribute and guide the designer or engineer to choose the botanical species that are more adequate to the destination purposes, as well as the most appropriate preservative products and treatment methods.

In order to facilitate the understanding of the classes of use in Table 6, Figure 6 illustrates how in structural and constructive systems of residential buildings the wood components can be classified in the Classes of Use.

Figure 6 - Use class, as a function of the deterioration risk situation in a residence.



Source: CALIL et al (2003).

Although the main purpose of the use class is to identify the type of treatment that should be done on the wood to resist the described agents, you can use this information to help in the identification of the wood.

Several studies of grouping wood species according to their use have been made since the 1970s. In this sense, the Catalogue of Brazilian Wood for Civil Construction (2013) defines the following General Classification of Uses directed to civil construction: Heavy civil construction:

- **External:** heavy structures, crosses, stakes, props, stilts, doors, planks, slats, beams.

- **Internal:** resilient carpentry in general, shears, purlins, beams, trusses, structures, columns, crosspieces, planks, rafters, laths

Light civil construction:

- **External and temporary use:** Mortar, posts, scaffolding, beams, planks, rafters, frames, trimmings, laths, slats, concrete forms
- **Internal Decorative:** boards, laths, panels, moldings, profiles, trimmings, skirting boards, slats.
- **Structural:** beams, rafters, laths, slats, trapdoors.
- **Window Frames:** doors, door leaf, shutters, frames, door jambs, windows, slats.
- **General uses:** boards, slats, laths, cords, linings, trimmings, half reed trimmings, skirting boards, handrails.
- **Flooring:** Tacos, planks, parquets, blocks, floorboards.

The evaluation of twenty (20) wood species selected for use in each civil construction use group is summarized in Table 7:

Table 7: Indication of use of wood in civil construction.

Species	Heavy		Light					Temporary Use	Floor
	External	Internal	External	Internal					
				Decorative	Structural	Windows and doors	General Usefulness		
Angelim amargo	–	–			–			–	
Angelim-pedra		–	–	–	–	–		–	
Angelim-vermelho					–	–	–	–	
Cedarwood	–	–	–	–		–			–
Cumaru	–	–	–	–	–	–	–	–	–
Cupiúba	–	–	–		–				
Curupixá				–	–	–		–	
Garapa	–	–	–	–		–			–
Jatoba	–	–	–	–		–			–
Cassava					–		–	–	
Muiracatiara		–	–	–		–			–
Yellow Oiticica				–	–	–		–	
Pau-roxo	–	–	–	–		–			–

Piquiarana	–	–							
Quaruba			–		–		–	–	
Tachi					–		–		
Tatajuba	–	–		–		–			–
Tauari					–	–	–		
Tauari-vermelho			–		–		–		
Uxi	–	–							

Source: Brazilian Wood for Construction Catalog (2013).

5.17 CONNECTING ELEMENTS FOR PORTELA CHALET

A wood structure is a set of parts joined together by means of connectors. In wood engineering, the connection is usually the critical factor in the design of the structure.

The strength of the connectors in the joint usually dictates the strength of the structure, its stiffness will greatly influence its overall behavior, and member sizes are usually determined by the numbers and physical characteristics of the connector, not the strength requirements of the structural element.

According to ABNT NBR 7190:2022, the traditional mechanical connections in wood pieces can be divided into four groups according to the mode of force transmission between the connected elements:

a) metal pin connections;
b) connections by metal rings and plates with stamped teeth;
c) connections by sambles or notches;
d) bonded connections.

The structural elements of the Portela chalet will be joined together generally by means of bolted connections.

6 DESIGN METHOD FOR BOLTED CONNECTIONS

6.1 CHARACTERISTICS OF THE CONNECTING ELEMENTS

According to NBR 7190:2022, the bolted connection elements must meet the minimum conditions of the following dimensions and resistances, according to Table 8:

Table 8: Materials used in metal pins.

Metal pin specification	Classification	fy,k MPa	fu,k MPa	Minimum Nominal Diameter
Flat nail with standard head ABNT NBR 6627	ABNT NBR 5589	-	635	3.00 ≥ mm d ≥ 3.54 mm
		-	600	3.55 ≥ mm d ≥ 4.99 mm
		-	490	5.00 ≥ mm d ≥ 10.00 mm
ASTM standard through bolt	A307	250	415	d ≥ 3/8 in or d ≥ 10 mm
	A325	635	825	
	A490	895	1 035	
Standard through bolt ISO 898-1	Class 4.6	235	400	d ≥ 10 mm
	Class 8.8	640	800	
	Class 10.9	900	1 000	
Sovereign Thread Screw		250	415	d ≥ 3/8 in or d ≥ 9.5 mm

Source: ABNT NBR 7190 (2022).

6.2 BOND STIFFNESS (KSER)

Identifying and defining what type of stiffness is acting in a given wood connection is one of the biggest challenges. In general, depending on the boldness of the structural design, it is recommended that a test be done in order to know the behavior of the connection when under load. But, in the case of light structures, the experience of the designer is used to evaluate how a certain connection should behave. The standard recommends that for lack of experimentation, the value of connection stiffness should be adopted using the following situations:

6.2.1 For the service limit state

If it is not possible to perform the test, the axial stiffness of connections in wood elements can be estimated according to Table 9:

Table 9: K-values$_{ser}$ for connectors in N/mm.

Connectors	Kser
Pins Nut and washer bolt with or without clearance[a] Self-Tapping Screw Nail (with pre-drilled hole)	$\rho_{med}^{1,5} \frac{d}{23}$
Nail (without pre-drilling)	$\rho_{med}^{1,5} \frac{d^{0,8}}{30}$
Metallic Ring	$\frac{\rho_{med} d_c}{80}$

a	The clearance can be added separately from the deformation.
Legend	
Kser	is the service stiffness of a shear section of a metal stud, expressed in Newton per millimeter (N/mm).
ρmed	is the average specific gravity in $kg/m3$, given by multiplying the characteristic bulk density by the value 1.20.
d	is the effective diameter of the metal pin, expressed in millimeters (mm).

Source: ABNT NBR 7190 (2022).

6.2.2 For the ultimate limit state (K)u

The service stiffness K_{ser} must be used to verify the service limit states and, for the ultimate limit states, the ultimate stiffness K_u must be used, calculated according to Equation 6:

$$K_u = \frac{2}{3} K_{ser} \tag{6}$$

The stiffness of connections in wood and steel elements can be considered as double that calculated using the same equation for wood elements, considering ρ_m as the density of the wood element.

The equations only apply for connections with metal pins installed perpendicular to the shear sections.

6.2.3 Wood pre-drilling

It is important for the rigidity and stability of the structure to observe the minimum dimensions of the wood pre-drilling according to Table 10:

Table 10: Pre-drilling diameter for wood connections.

Metal pin	**Pre-drilling diameter**
Nails	Conifers $d_0 = 0.85\,d$ Leafy: $d_0 = 0.98\,d$
Through bolts	$d \leq d_0 \leq d + 1mm$
Sovereign threaded bolts	$d_0 = 0.70\,d$

Source: ABNT NBR 7190 (2022).

6.3 SAFETY CONDITIONS OF SCREWED CONNECTIONS

The safety conditions imposed by design codes are that the design resistance of the connection (R_d) must be greater than the design load (S_d) acting on the same connection.

The calculation value of the bond strength is defined from the characteristic value of the bond strength and adjusted by the modification coefficients (K_{mod1}, K_{mod2}) and weighting coefficients (γ_{lig})according to Equation 7:

$$R_d = K_{mod1} * K_{mod2} * \frac{R_K}{\gamma_{lig}} \quad (7)$$

Where:

R_k is the characteristic value of the connection resistance and must be determined according to ABNT NBR 7190-5;

γ_{lig} is the value of the undermining coefficient of the bond strength properties, set equal to 1.4.

When dimensioning connections using steel connectors, the value of K_{mod1} cannot be greater than 1, even for combinations of actions with instantaneous duration.

The characteristic value of the resistance of the elements of wood connections with metal pins can be estimated by Equation 8:

$$R_k = F_{v,Rk} * n_{SP} * n_{ef} \quad (8)$$

Where:

N_{sp} is the number of cutting sections per metal pin;

n_{ef} is the effective number of pins per connection;

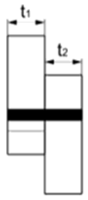
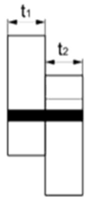
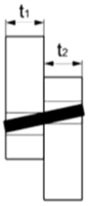
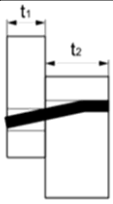
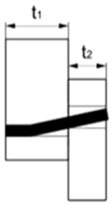
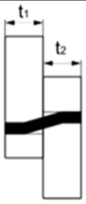
$F_{v,Rk}$ is the characteristic resistance of a pin, corresponding to a given cut section.

6.4 DETERMINATION OF THE CHARACTERISTIC STRENGTH OF BOLTED CONNECTIONS

NBR 7190:2022 uses the failure method and determines the characteristic strength value for each failure situation, in the case of one shear section there are six failure possibilities and in the case of two there are four failure possibilities.

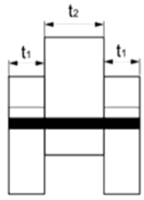
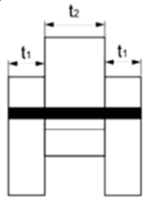
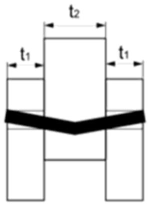
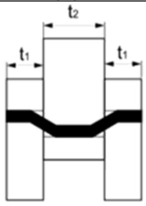
The characteristic resistance value for the calculation is the lowest value obtained from the equations proposed in the failure model in Tables 11 and 12.

Table 11: Failure modes and equations for wood element connections with metal studs (one section shear)

Failure Mode	**Calculated characteristic force per cutting plane and per pin used**
 (Ia)	$F_{v,Rk1} = f_{e1,k}\, t_1\, d$
 (Ib)	$F_{v,Rk2} = f_{e1,k}\, t_2\, d\, \beta$
 (Ic)	$F_{v,Rk3} = \frac{f_{e1,k}\, t_1\, d}{1+\beta}\left[\sqrt{\beta + 2\beta^2\left[1+\frac{t_2}{t_1}+\left(\frac{t_2}{t_1}\right)^2\right]+\beta^3\left(\frac{t_2}{t_1}\right)^2} - \beta\left(1+\frac{t_2}{t_1}\right)\right]+\frac{F_{ax,Rk}}{4}$
 (IIa)	$F_{v,Rk4} = 1{,}05\frac{f_{e1,k}\, t_1\, d}{2+\beta}\left[\sqrt{2\beta(1+\beta)+\frac{4\beta(2+\beta)M_{y,k}}{f_{e1,k}\, d\, t_1^2}} - \beta\right]+\frac{F_{ax,Rk}}{4}$
 (IIb)	$F_{v,Rk5} = 1{,}05\frac{f_{e1,k}\, t_2\, d}{1+2\beta}\left[\sqrt{2\beta^2(1+\beta)+\frac{4\beta(1+2\beta)M_{y,k}}{f_{e1,k}\, d\, t_2^2}} - \beta\right]+\frac{F_{ax,Rk}}{4}$
 (III)	$F_{v,Rk6} = 1{,}15\sqrt{\frac{2\beta}{1+\beta}}\sqrt{2M_{y,k}\, f_{e1,k}\, d}+\frac{F_{ax,Rk}}{4}$
$F_{v,Rk}$ is the lowest value among the results of the six failure modes.	

Source: ABNT NBR 7190 (2022).

Table 12: Failure modes and equations for pinned wood member connections metal (two cutting sections)

Failure Mode	**Calculated characteristic force per cutting plane and per pin used**
 (Ia)	$F_{v,RK1} = f_{e1,k}\, t_1\, d$
 (Ib)	$F_{v,RK2} = 0{,}5 f_{e1,k}\, t_2\, d\, \beta$
 (II)	$F_{v,RK3} = 1{,}05 \frac{f_{e1,k}\, t_1\, d}{2+\beta}\left[\sqrt{2\beta(1+\beta) + \frac{4\beta(2+\beta)M_{y,k}}{f_{e1,k}\, d\, t_1^2}} - \beta\right] + \frac{F_{ax,Rk}}{4}$
 (III)	$F_{v,RK4} = 1{,}15 \sqrt{\frac{2\beta}{1+\beta}}\sqrt{2M_{y,k}\, f_{e1,k}\, d} + \frac{F_{ax,Rk}}{4}$
$F_{v,Rk}$ is the lowest value among the results of the four failure modes.	

Source: ABNT NBR 7190 (2022).

6.5 DETERMINATION OF THE Β VALUE

The ratio between the embedding strengths of the interlocked pieces of wood is given by Equation 9:

$$\beta = \frac{\text{Resistência de embutimento da espécie 2}}{\text{Resistência de embutimento da espécie 1}} = \frac{f_{e2,k}}{f_{e1,k}} \qquad (9)$$

In the case of having only one species the value of this ratio is obviously 1.

6.6 DETERMINING THE INLAY RESISTANCE OF THE CONNECTION

Determined according to Equation 10:

$$f_{e0,k} = 0{,}082(1 - 0{,}01)\rho_k \qquad (10)$$

The value of $f_{e0,k}$ will be in N/mm^2 and ρ_k is the characteristic density of the wood used.

If the screw arrangement has an angle α in relation to the wood fibers, Equation 11 is used:

$$f_{e\alpha,k} = \frac{f_{e0,k}}{k_{90}\ sen^2\alpha + \ cos^2\alpha} \tag{11}$$

To determine k_{90} Equation 12 is employed:

$$k_{90} = \begin{Bmatrix} 1{,}35 + 0{,}015d \text{ (Para madeiras de coníferas)} \\ 1{,}30 + 0{,}015d \qquad \text{(Para painéis de LVL)} \\ 0{,}90 + 0{,}015d \text{ (Para madeiras de folhosas)} \end{Bmatrix} \tag{12}$$

Where:

d is the nominal diameter of the metal pins.

6.7 DETERMINATION OF THE CONFINEMENT EFFECT OF THE CONNECTIONS CAUSED BY COMPRESSION OF THE WASHERS ON THE OUTER SIDES

The contribution of the confinement effect should be limited to the following percentages of the equation plots representing failure modes I, II, and III, disregarding the friction factor:

a) smooth cylindrical nails (15%);

b) ringed nails (25%);

c) through bolts with nut and washers (25%);

d) Sovereign thread screws (100 %);

e) adjusted metal pins (0 %).

It is recommended that the contribution of the confinement effect be considered after experimental investigation that proves the phenomenon. For the case of connections with through bolts, the F value$_{ax,Rk}$ can be estimated by the smaller value between the tensile strength of the bolt and the washer embedding strength in the wood.

For nail connections, the F-value$_{ax,Rk}$ can be estimated as the lower of the nail's tensile strength and the nail head's inlaying strength into the wood piece's outer side.

In connections where the connectors transfer *inclined forces in* relation to the wood fibers, the possibility of rupture by localized normal tension, caused by the force F_{Ed} .senα, perpendicular to the fibers, must be verified, meeting the safety condition of Equation 13:

$$F_{v,Ed} \leq F_{90,Rd} \quad (13)$$

Taking $F_{v,Ed}$ as the largest value among the values, we have $F_{v,Ed,}$ 1 and $Fv_{,Ed,2}$ (Figure 7).

Where:

$F_{v,Ed}$ is the design shear force acting in the region of the connection;

$F_{v,Ed,1}$ and $Fv_{,Ed,2}$ are respectively the values of the shear force immediately to the left and right of the connection;

$F_{90,Rd}$ is the calculation resistance force, calculated from the characteristic force $F_{90,Rk}$, defined by Equation 14:

$$F_{90,Rk} = 1{,}4 * b * \sqrt{\frac{h_e}{1-\frac{h_e}{h}}} \quad (14)$$

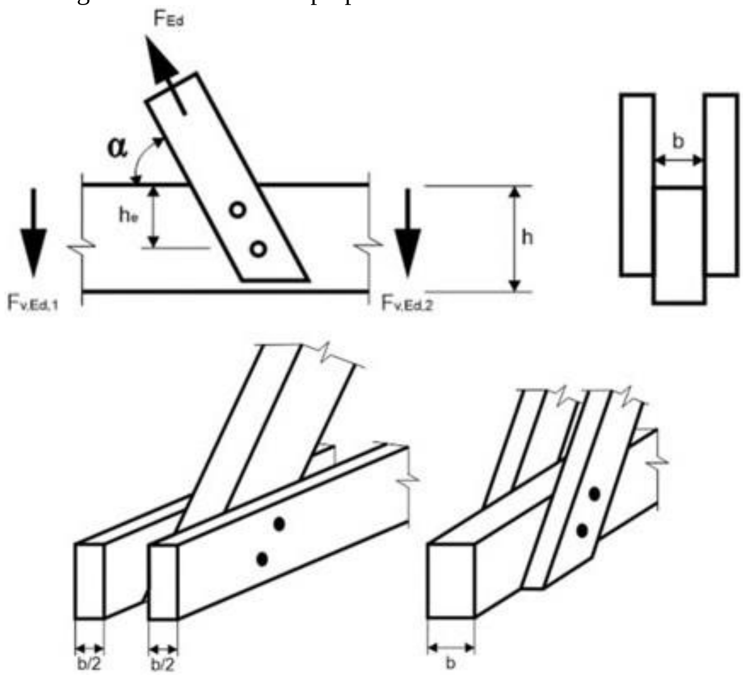
Where:

b, *h* are respectively the width and height of the verified wood element, expressed in millimeters (mm);

he is the distance from the farthest connector to the edge of the element, expressed in millimeters (mm);

$F_{90,Rk}$ is the characteristic localized normal tensile strength in Newtons (N).

Figure 7 -Tensile stress perpendicular to the fibers in bonds.



Source: ABNT NBR7190 (2022).

7 CONSTRUCTION ASPECTS

It is not allowed to consider the forces transmitted by secondary elements such as stirrups, brackets, or clamps, in the calculation of the connections.

In case of metal pin connections, the spacing and pre-drilling specified in the standard in force must be respected, to avoid early splitting of the wood due to the introduction of the joining elements. Connections with only one metallic pin are not allowed.

The connecting elements used in timber structures must meet the following minimum dimensions and resistances according to ABNT NBR 7190:2022:

a) the structural nails must have a minimum nominal diameter of 3.0 mm, complying with the specifications of ABNT NBR 6627, and be made of steel with low carbon content, complying with the specifications of ABNT NBR 5589;

b) The through structural bolts with nut and hexagonal washer shall be of nominal diameter d minimum 9.5 mm, made of low carbon steel meeting the specifications of ASTM A307, ASTM A325, ASTM A490, or ISO 898-1. Nuts and washers must be made of low-carbon steel with a characteristic yield strength $f_{y,k}$ of at least 250 MPA. Washers must have an outside diameter greater than or equal to *3d*, thickness greater than or equal to 0.3 *d*, and must be used on both sides of the bolt;

c) Sovereign thread bolts must have a nominal diameter d of at least 9.5 mm, and must be made of low carbon steel, meeting the minimum characteristic yield strength $f_{y,k}$ of at least 250 MPa.

In principle, the ultimate limit state of the connection can be reached by deficiency of strength of the wood of the structural member or of the connecting element. The connections made by the usual means of wood pieces or by the use of steel intermediate elements should have their safety verified according to this Standard, in the case of wood elements, or according to ABNT NBR 8800, in the case of steel intermediate elements.

7.1 SPACING BETWEEN CONNECTING ELEMENTS

The recommended minimum spacings and distances in connections with metal studs (pre-drilled nails, through bolts with nuts and washers, threaded bolts, set screws, flat studs) are presented in Table 13. In connections of more than three connected parts, the nails should be spaced so that the spacings are met on the inner and outer parts.

Table 13: Minimum spacings and distances for metal pin connections.

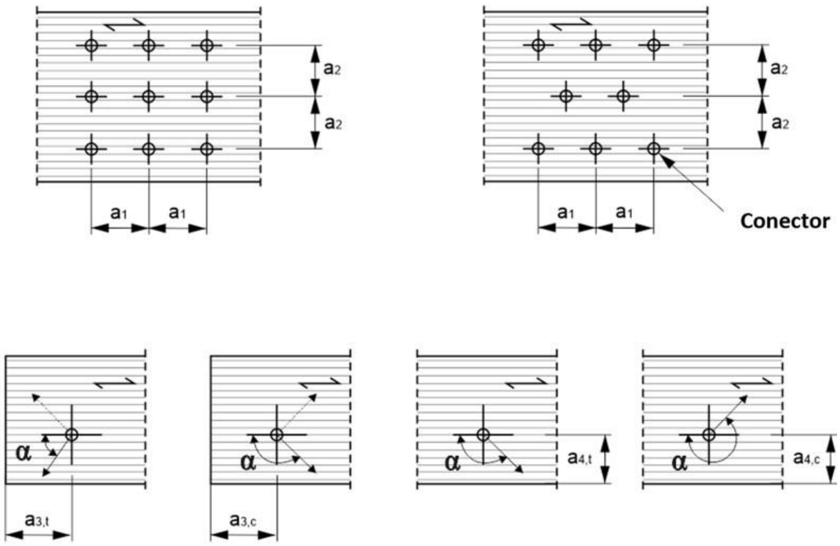
Spacing or distance	**Angle** a	**Pre-drilled nails**	**Through bolts, socket screws, and set screws**	**Smooth pins**
Spacing a1 (parallel to the fibers)	0° ≤ α ≤ 360°	(4 + 3 □cos α|) d	(4 + 3 □cos α|) d	(3 + 3 □cos α|) d
Spacing a2 (perpendicular to the fibers)	0° ≤ α ≤ 360°	(3 + 6 □sen α|) d	4 d	3 d
Distance a3,t (loaded end)	-90° ≤ α ≤ 90°	(7 + 5 □cos α|) d	Highest among 7 d e 80 mm	Greater between 7d e 80 mm
Distance a3,c (uncharged end)	90° ≤ α < 150° 150° ≤ α < 210° 210° ≤ α ≤ 270°	7 d 7 d 7 d	(1 + 6 sen α) d 4 d (1 + 6 □sen α|) d	Greater between [(a3,t □sen □□) d] and d 3d Largest between [(a3,t □sen □□)] d and d
Distance a4,t (loaded side edge)	0° ≤ α ≤ 180°	For d < 5 mm: (3 + 2 sen a) d For d ≥ 5 mm: (3 + 4 sen α) d	Highest between (+ 2 sena) d e 3 d	Greater of (2 + 2 sen □) d e 3 d
Distance a4,c (unloaded side edge)	180° ≤ α ≤ 360°	3 d	3 d	3 d

Source: ABNT NBR7190 (2022).

- a_1 is the spacing between the center of two connectors situated on the same line parallel to the fiber direction;
- a_2 is the spacing between the centers of two connectors situated on two lines perpendicular to the fiber direction;
- $a_{3,c}$ is the distance from the center of the connector to the uncharged end of the part;
- $a_{3,t}$ is the distance from the center of the connector to the loaded end of the part;
- $a_{4,c}$ is the distance from the center of the connector to the unloaded side edge of the part;
- $a_{4,t}$ is the distance from the center of the connector to the loaded side edge of the part;
- α is the angle between the force and the fiber direction.

The spacings from Table 13 are shown in Figure 8:

Figure 8: Minimum spacings and distances for connections with metal connectors.



Source: ABNT NBR7190 (2022).

8 CONSIDERATIONS

The project under study presented some measures designed by conventional construction standards, however, some of them needed to be changed, as in the case of the floor, in which the beams were spaced every 1.00 m, and after sizing, began to intercalate at 0.60 m, similarly, the upper wefts went from a spacing of 1.00 m to 1.20 m.

Another changed point involves the connection of the vertical element (column) with the inclined beam of the structure, in the initial sketch the direct connection of the elements was considered, however, the best alternative involved the addition of a support beam to perform the connection and distribution of actions.

As for the approach that deals with the use of abundant Amazonian wood and of low commercial value, it showed to be viable for the execution of the project "PORTELA WOOD CHALET", since the method of grouping species was used. This way, the use of wood for housing and commercial purposes can be incorporated into the architectural model, which is not usual in the region, becoming an eye-catching element, in addition to stimulating the use of wood species from forest management and with low commercial interest.

We conclude that the use of Amazonian species of wood is viable in terms of construction aspects, which involve structural behavior, environmental comfort, economics, and architecture.

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