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# HISTORICAL PERSPECTIVE ON THE USE OF WOODEN ROOF WITH A VIEW TO THE REVISION OF NBR 7190

Bruno Henrique Lourenço Camargos[1], Jaqueline Aparecida Melo[2] & Lucca Araújo Campos[3]
[1]Professor at the University of the State of Minas Gerais (UEMG – Divinópolis Unit).
Department of Civil and Production Engineering. Address: Avenue Paraná, 3001, Jardim Belvedere I, Divinópolis, Minas Gerais, Brazil. ZIP Code: 35501-170.
[1]bruno.camargos@uemg.br
[2, 3]Bachelor of Civil Engineering from the University of the State of Minas Gerais (UEMG – Divinópolis Unit). Address: Avenue Paraná, 3001, Jardim Belvedere I, Divinópolis, Minas Gerais, Brazil. ZIP Code: 35501-170.
[2]jaqueline.1694484@discente.uemg.br
[3]lucca.1698457@discente.uemg.br

## ABSTRACT

*Wood, one of the world's oldest and most widely used construction materials, has continuously evolved to enhance safety in civil engineering. This evolution began with the introduction of NBR 7190, Brazil's inaugural technical standard for timber structure designs in 1982, followed by significant updates in 1997 and 2022. This study conducts a comparative analysis of the design criteria for a Maçaranduba roof truss under the 1997 and 2022 versions of NBR 7190. Focused on a traditional wooden roof design for large buildings in Divinópolis/MG, Brazil, the study thoroughly examines the structural framework, yielding vital parameters for evaluating structural integrity under both NBR 7190 versions. Notably, the latest iteration, NBR 7190-1 (ABNT, 2022), adopts a more conservative approach, ensuring greater safety margins, even when employing larger cross-sections to meet compliance requirements. This research's primary contribution lies in its practical insights, emphasizing the heightened rigor of NBR 7190-1 (ABNT, 2022) in terms of wood property characterization and safety considerations, especially for components subjected to compression and flexo-compression stresses.*

**KEYWORDS:** *Wood Truss. ABNT NBR 7190. Design. Roof. Structural safety.*

## I. INTRODUCTION

Throughout history, wood has played an integral role in human daily life. Its wide availability and ease of access led to the mastery and refinement of wood utilization techniques, culminating in the modern standards we know today. Initially used primarily as firewood, wood gradually found its way into the construction of rudimentary hunting tools and, most notably, shelter structures. Over time, it evolved to serve more complex purposes, including the crafting of weapons, agricultural implements, furniture, decorative artifacts, and architecturally significant structures, establishing itself as one of the oldest construction materials in history (Ferrari & Lowen-Sahr [1]; Menezes *et al.* [2]).

However, with the technological advancements of the Industrial Revolution, wood lost its status as the primary choice for structural use in construction. It was supplanted by steel and reinforced concrete, dominating the market due to their relative affordability and faster construction. In Brazil, a prevalent belief persists that wooden constructions are less durable and resilient than masonry and reinforced concrete structures. This perspective, coupled with a shortage of specialized professionals for wooden structures, inhibits the adoption of wood in the Brazilian construction sector. Misconceptions about environmental conservation also play a role, influenced by unscrupulous practices (Bono [3]; Negrão; Faria, [4]; Palma *et al.* [5]; Villar-García *et al.* [6]).

Despite wood being a renewable resource, its responsible use remains crucial in structural projects. For truss-based structural designs in roof systems, various empirical hypotheses are available for structural calculations. According to Campos, Pereira & Chahud [7], this type of wooden truss roof has been in use in Brazil since the early 18th century, dating back to the colonial period coinciding with the arrival of the first explorers.

Branco, Sousa & Tsakanika [8] conducted a study focused on strengthening support regions, achieving load levels higher than the initial conditions. Local repairs to wooden beams partially restored their load-carrying capacity in trusses compared to the results obtained before the initial beam failure. Recognizing the importance of bracing in roof systems, this work aligns with the recommendations of Burdzik & Skorpen [9], suggesting that connecting bracing members closer to the purlins enhances system rigidity and bracing capacity. In the context of wooden roof structures with large spans, Munch-Andersen & Dietsch [10] emphasize that most failures result from neglecting horizontal wind loads and suction, which can lead to torsional forces that may exceed the truss members' capacity, even with a bracing system in place.

In the literature, it is evident that the adaptation of wooden roofs is closely linked to the need and challenge of restoring old buildings, whether for new uses or to preserve their historical significance. Dar *et al*. [11] note that roof truss failures primarily stem from excessive loads, deterioration, poor manufacturing, improper installation, or inadequate repairs. Pereira & Valle [12] proposed using steel as a replacement material for the restoration project of the wooden roof of the central building of the Faculty of Agronomy in the historic architectural complex of the Federal University of Rio Grande do Sul, built in 1910, to create a contemporary architectural statement that highlights the differences between new and old elements. However, Ferreira [13] argues that traditional techniques for restoring wooden roof components remain the best intervention option as they preserve the original structure's characteristics and historical record.

To establish construction parameters applicable to any type of wooden structure, the first Brazilian standard for wood projects was introduced in 1982. This publication enabled the standardization of wood use by characterizing its strength, serving as a foundation until 1997 when the standard received its first update. In 2022, NBR 7190 underwent another significant revision, bringing about substantial changes in several design criteria. Therefore, this article aims to compare the main design criteria for wooden structural elements, according to the revised and the previous version of NBR 7190, when applied to a roof truss. Additionally, it assesses the key recommendations for using wood in roof designs from an updated standard perspective.

This paper presents a structured framework organized into sections that address various aspects of the study. In the Introduction, the problem is contextualized, its relevance is highlighted, and the research objectives are outlined. The Theoretical Foundation section discusses the use of timber as a structural material and provides an overview of the Brazilian calculation standard. In the Materials and Methods section, the computer models of the timber roofs used are described and their selection is justified. This section also covers the design of the roof's timber truss bars and addresses the research's limitations. The Results and Discussion section presents the study's findings, exploring the primary differences in safety conditions as per various versions of the Brazilian standard NBR 7190. It also includes graphs, tables, and a detailed analysis. In the conclusion, the main results are summarized, and practical implications, recommendations based on the findings, and suggestions for future research are discussed.

## II. THEORETICAL FOUNDATION

Widely used in roofing systems, wood requires regular maintenance and proper treatment. It offers various structural advantages such as high tensile and compressive strength, good durability, thermal insulation, greater lightweight construction compared to concrete and steel, and expedites construction due to its prefabricated nature.

In Brazil, several types of wood are prominently used in roofing systems, including Garapeira, Cambará, Itaúba, Peroba, and Maçaranduba. All of these woods are highly resilient, ensuring a long-lasting roofing system. For this study, Maçaranduba wood is used, as it is a tree species commonly found in the country and extensively utilized in Brazilian construction. According to the Institute of

Technological Research (IPT, [14]), Maçaranduba wood is characterized by its high density and robustness, offering impressive natural durability that effectively protects it against decay fungi and subterranean termites.

The relevance of this article is underscored by the growing efforts associated with the construction and reconstruction of buildings with architectural and cultural significance, with a particular emphasis on the importance of preserving historical environments for future generations. Among the many memorable buildings in the city with wooden roofs, this paper focuses on the Historical Museum of Divinópolis. This museum, in addition to its wooden roof, is entirely structured with wood and was constructed in 1830, in the current Dom Cristiano Square, commonly known as the Cathedral Square of the Divine Holy Spirit, a historical symbol of the city. This building is known as the "Casarão" and is the oldest property in the city. It was designated as public heritage by Law 2456/1988 and Decree N°. 7.569/2007 due to being the last remaining building from 19th-century architecture in the city, as depicted in Figure 1.

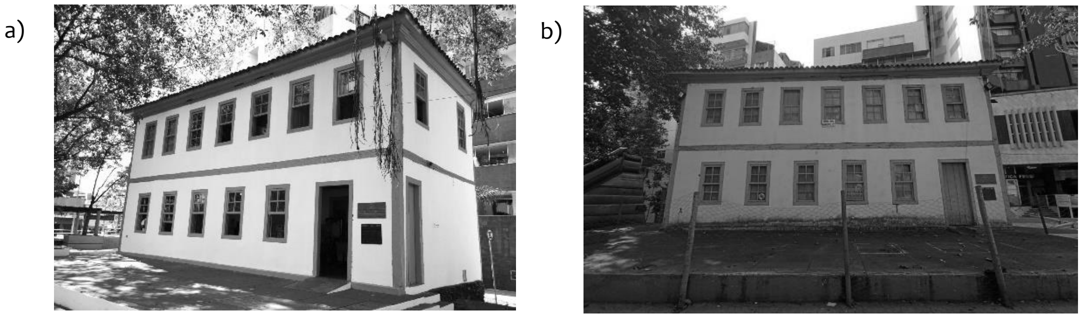


**Figure 1.** Historical Museum of Divinópolis, MG: Two-story building in Dom Cristiano Square known as the "Casarão." a) Opened to the public for visitation in 2016. b) The "Casarão" was closed due to the risk of collapse caused by structural failures in March 2017. Source: Adapted by the authors from Soares [15].

In 2017, the building was closed after the Civil Defense of the municipality discovered structural degradation, which is entirely composed of wood. Figure 2 illustrates the implementation of mitigation measures with wooden shoring, which, to this date, aims to stabilize and prevent the collapse of the structure. In March 2023, according to the Secretary of Culture of Divinópolis, the restoration project was completed and is in the approval process, so this unique city monument can finally escape its state of fragility and neglect (Azevedo *et al*. [16]).

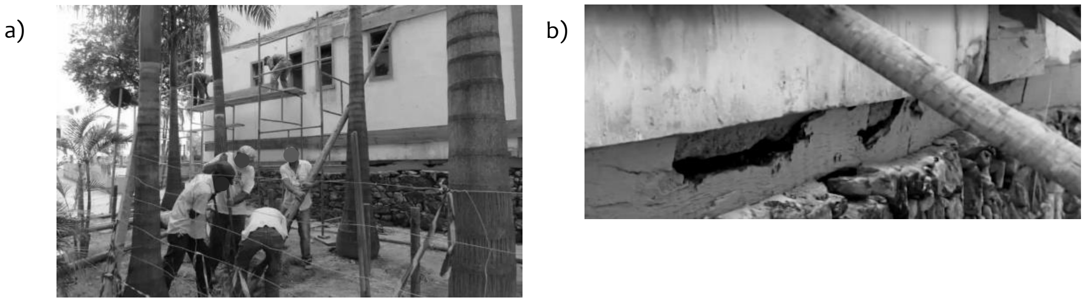


**Figure 2.** Corrective Measures. a) Placement of wooden supports to sustain the structure. b) Detail of the compromised wooden foundation beam due to degenerative pathologies. Source: Adapted by the authors from G1 Centro-Oeste de Minas & TV Integração [17].

From a historical perspective, numerous studies propose solutions applicable to the restoration of historical buildings and emphasize the importance of preserving the memory of wood usage in Brazilian construction. Noteworthy works include those by Bono [18]; Kohlrausch [19]; Mello [20]; Driemeyer [21]; Lourenço & Branco [22]; Fernandes [23]; Nascimento & Tenório [24]; Israel [25]; Dias [26]; Santos *et al*. [27] and Durante *et al*. [28].

In this context, it is essential to possess a deep understanding of the existing structure to provide technical support for choosing the most suitable intervention method. Consequently, the presence of degradation leads to a subsequent reduction in the effective section, and these alterations should be evaluated both in the present and in their potential evolution in the future in the absence of any intervention (Fraga *et al*. [29]; Branco; Sousa & Tsakanika [8]; Cuarteiro *et al.* [30]). The current condition of the Historical Museum of Divinópolis serves as an extreme example of how accurate sizing and periodic maintenance of wooden structures can enhance durability, while the omission of these procedures can jeopardize the physical well-being of users. Given the historical and cultural significance of wooden structures, as well as their structural performance, this study aims to emphasize that the revision of NBR 7190-1 (ABNT, [31]) directly enhances the stability of wooden structural components to ensure greater safety in buildings.

### 2.1 Brazilian standard for wood structure design

Published in 1951 as NB-11 and titled "Calculation and Execution of Wood Structures," the first Brazilian standard for wood structure design proposed the calculation of structures based on the safety criteria of the Method of Allowable Stresses. In February 1982, NB-11 was adopted without technical alterations, becoming an integral part of the Brazilian Association of Technical Standards (ABNT) and was renamed NBR 7190, "Calculation and Execution of Wood Structures."

The first revision was published in August 1997, named NBR 7190 (ABNT, [32]). One of the main changes was the adoption of the Limit State Design Method. This transitioned from a deterministic approach to stress analysis to a probabilistic approach, as had already been adopted in the standardization of steel and concrete structure designs. In 2002, the study for the second revision began, focusing on updating the design criteria through testing new materials and connections and considering existing relevant research. However, even though this second revision of NBR 7190 was completed in 2012, the approval and publication of the new specified testing methods were still required. Therefore, it was only on June 29, 2022, that the first edition of NBR 7190 (ABNT, [31]) was published, divided into seven parts. New strength modification factors based on tests with structural components were introduced, along with a new criterion for analysing the stability of compressed and flexo-compressed components. Recommendations for fire safety were also added, as well as a more detailed category for wood use classes, emphasizing material durability.

## III. MATERIALS AND METHODS

The analysis methodology involves conducting parametric variations to determine the optimized section, utilizing the SAP2000 software (version 23.3.1) with a foundation in a traditional wooden truss model. This allows for a comparative study between the revised and the previous version of NBR 7190.

### 3.1 Definition of the Studied Model

The truss dimensions are defined based on established parameters, including the span length and specific assembly criteria provided by the tile supplier. The chosen tile is selected from the technical catalog of “Top Telha & Telhados Cerâmicos” [33], opting for the Mediterranean line and the Terracotta Plus Hydrophobic model. As access to technical information regarding the "Casarão" is unavailable, the study focuses on a traditional roof structure suitable for large-scale buildings, commonly found in Divinópolis, MG, Brazil, using a computational model. Additional information related to the city's climate context is presented in Table 1.

**Table 1.** Geographical location data

| Federal State | Bioclimatic zone | City | Latitude | Longitude | Altitude (m) |
|---|---|---|---|---|---|
| Minas Gerais | ZB3 | Divinópolis | 20.1435°S | 44.8904°W | 850.0 |

Figure 3 details the dimensions of the wooden truss under study, with measurements provided at a 1:50 scale. This truss incorporates common features often found in residential projects, particularly in country houses. When situated in a natural setting, a modern wooden house with a colonial-style roof showcases seamless integration with the surrounding environment, along with a rustic aesthetic that can stand in direct contrast to architectural sophistication.

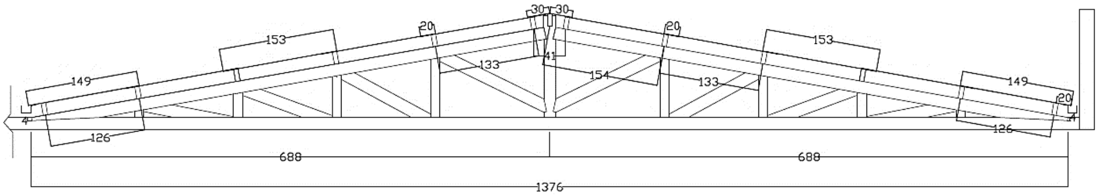


**Figure 3.** Truss-type with dimensions

According to Calil Júnior & Molina [34], building roofs should be designed to balance economy, quality, and sustainability, with a primary focus on maintaining thermal comfort by absorbing a significant portion of solar radiation and preventing its transmission to the interior. The choice of wood truss type should consider factors such as tile length, structural support conditions, span size, material efficiency, and labor. Therefore, this study adopts the Howe truss, following the recommendation of Calil Júnior, Rocco Lahr & Dias [35], who advise using trusses with inclined top chords for improved performance in these aspects. Pfeil & Pfeil [36] not only emphasize that the Howe truss is the most traditional choice for wood structures but also detail its components based on geometry and the forces acting due to gravity, including tension in the top and bottom chords and compression in the diagonals and webs. In summary, this study aligns with the primary recommendations of Dietsch [37], who evaluates various structural systems and, based on the results, proposes construction details for a robust design of wooden roof structures for large spans. The three-dimensional view of the studied wooden roof is presented in Figure 4.

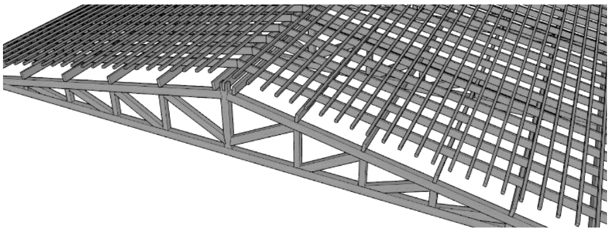


**Figure 4.** 3D Representation of the Roof

## 3.2 Structural Scheme and Specifications

The length of the purlins is set at 6 meters to avoid joints or excessive gaps between the trusses. Consequently, the distance between trusses within the same span is 4 meters. Table 2 displays the truss dimensions according to the adopted structural scheme. The roof comprises tiles, flashings, rafters, battens, purlins and the truss. Rafters and battens are not dimensioned as they are not considered structural elements, but their weights are considered. The truss's geometry is determined based on fixed parameters, including the available span length for the truss and the assembly recommendations outlined in the Technical Catalog of "Top Telha & Cerâmicos" [33]. A minimum slope of 10° is adopted, as recommended by the manufacturer. However, studies, such as that conducted by Fraga *et al.* [29], demonstrate that, in order to reduce wood consumption, some tile manufacturers should propose a slope between the top chords of up to 10% (6°). Menezes *et al.* [2] emphasize that, for Howe-type trusses, the bars of the top chords and diagonals change minimally with the slope. Nevertheless, the lower the slope, the larger the dimensions of the components composing the top chords. The technical specification of the tile is shown in Table 3.

**Table 2.** Truss Structural Scheme

| Theoretical span of Howe trusses (m) | Minimum slope (in degrees) |
|---|---|
| 13.76 | 10° (17.6%) |

**Table 3.** Technical Information of the tile.

| Modelo | Length (cm) | Width (cm) | Height (cm) | Weight (kg) | Absorption (%) | Strength (kgf) |
|---|---|---|---|---|---|---|
| Terracota Plus Hidrofugada | 41.8 | 25.5 | 7.0 | 2.93 | < 13 | > 300 |

Source: Adapted by the authors for Catalog of “Top Telhas & Telhados Cerâmicos” (2020).

The choice of wood to be used in the roof should be made by evaluating various parameters, including strength, durability, workability, flexibility, susceptibility to termite or fungal attacks, aesthetic considerations, among other factors. *Manilkara sp.* wood, commonly known as Maçaranduba or Parajú, is one of the most commonly used woods in wooden structures, particularly in the Central West, Southeast, and South regions of Brazil (Rosa *et al.* [38]; Nahuz *et al.* [39]). Additionally, Maia *et al.* [40] state that the trade of Maçaranduba wood is also very popular in the Northeast region of Brazil due to its physical-mechanical characteristics and aesthetic appearance. Paiva Filho *et al.* [41] further emphasize that wood, as a permanent item, is mostly used in roofing, with a focus on the choice of Maçaranduba for this purpose. The Brazilian Forest Service (SFB, [42]), in its Brazilian Wood Database, highlights that Maçaranduba is heavy, hard, and, in terms of natural durability, resistant to the attack of decay fungi and subterranean termites. Therefore, Maçaranduba is the wood chosen as the structural material for the studied roof. Table 4 presents the average values of strength and stiffness for Maçaranduba as per Annex E of NBR 7190 (ABNT, [32]). Table 5 shows the characteristic strength class of Maçaranduba defined in tests on defect-free specimens, as specified in Annex A.1 of NBR 7190-3 (ABNT, [43]) and NBR 7190-1 (ABNT, [31]).

**Table 4.** Average values of strength and stiffness for Maçaranduba (*Manikara sp.*)

| Class | $\rho_{ap}$ (12%) $^{1)}$ (kg/m$^3$) | $f_{c0}$ $^{2)}$ (MPa) | $f_{t0}$ $^{3)}$ (MPa) | $f_{t90}$ $^{4)}$ (MPa) | $f_v$ $^{5)}$ (MPa) | $E_{c0}$ $^{6)}$ (MPa) |
|---|---|---|---|---|---|---|
| Dicotiledônea | 1143 | 82,9 | 138,5 | 5,4 | 14,9 | 22733 |

Notes: 1) $\rho_{ap}$ (12%) is the bulk density at 12% moisture content. 2) $f_{c0}$ is the parallel-to-fibers compression strength. 3) $f_{t0}$ is the parallel-to-fibers tensile strength. 4) $f_{t90}$ is the normal-to-fibers tensile strength. 5) $f_v$ is the shear strength. 6) $E_{c0}$ is the longitudinal modulus of elasticity obtained in the $f_{c0}$ test.
Source: Adapted by the authors from Table E.1 of NBR 7190 (ABNT, [32]) for native and reforested woods.

**Table 5.** Strength classes defined in tests of Maçaranduba specimens (*Manikara sp.*)

| Class | $\rho_{ap}$ (12%) (kg/m$^3$) | $f_{c0,k}$ $^{2)}$ (MPa) | $f_{v0,k}$ $^{3)}$ (MPa) | $E_{c0,med}$ $^{4)}$ (MPa) |
|---|---|---|---|---|
| D60 $^{1)}$ | 1000 | 60 | 8 | 19500 |

Notes: 1) The strength class values for native species are available in Annex A of NBR 7190-3 (ABNT, [43]). 2) $f_{c0,k}$ is the characteristic strength for compression parallel to the fibers. 3) $f_{v0,k}$ is the characteristic shear strength parallel to the fibers. 4) $E_{c0,med}$ is the mean longitudinal modulus of elasticity obtained in the $f_{c0}$ test.
Source: Adapted by the authors from Table 2 of NBR 7190-1 (ABNT, [31]).

## 3.3 Representative Material Property Values

According to Pfeil & Pfeil [36], the mechanical properties of wood used for design can be adopted through their mean or characteristic values. If a property is represented by a specific value, where this value can be either strength or stiffness, the representative values are the mean value ($X_m$) and the characteristic value ($X_k$). Thus, according to NBR 7190 (in both versions), it is necessary to adjust the properties of Maçaranduba shown in Tables 4 and 5 to design values ($X_d$) through Equation (1).

$$X_d = K_{mod} \frac{x_k}{\gamma_w} \tag{1}$$

Where $X_d$ is the calculated value of a given wood property; $K_{mod}$ is the modification coefficient that adjusts the characteristic values of wood properties based on the structural load class and the accepted moisture class; and $\gamma_w$ is the reduction coefficient for wood properties.

The reduction coefficient for wood strength ($\gamma_w$) is determined based on the values shown in Table 6.

**Table 6.** Value of the coefficient $\gamma_w$ (dimensionless)

| Version | $f_{c0}$ | $f_{t0}$ | $f_{v0}$ |
|---|---|---|---|
| NBR 7190 (ABNT, [32]) | 1,4 | 1,8 | 1,8 |
| NBR 7190-1 (ABNT, [31]) | 1,4 | 1,4 | 1,8 |

The $K_{mod}$ coefficient is obtained through the product of Equation (2).

$$K_{mod} = K_{mod_1} K_{mod_2} K_{mod_3} \tag{2}$$

Where $K_{mod1}$ takes into account the type of wood used and the load duration; $K_{mod2}$ considers the effect of moisture, and $K_{mod3}$ considers the structural classification of the wood.

For the present work, the long-duration load class is adopted. Sawn timber is used, with ambient humidity for the summer in the city of Divinópolis/MG, Brazil. For the city, the maximum humidity for December 2022 is 77%, according to the National Institute of Meteorology (INMET, [44]), as shown in Figure 5. Since humidity has a significant effect on wood properties, the highest recorded moisture content is adopted.

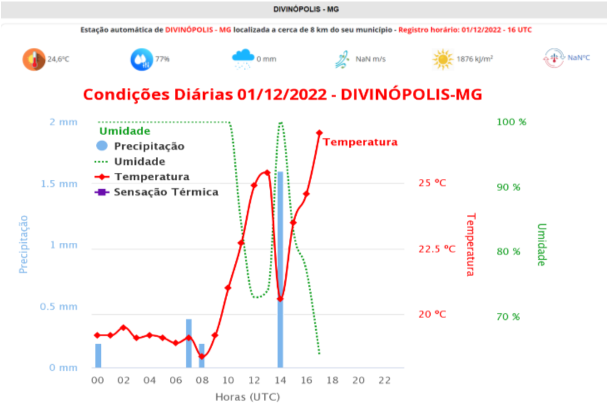


**Figure 5.** Daily Conditions.

Source: Adapted by the authors from INMET [44].

According to Pfeil & Pfeil [36], as humidity increases, the strength of wood decreases significantly until it reaches the fiber saturation point, beyond which the strength remains constant. Consequently, the value of $K_{mod}$, found in both versions of NBR 7190, is consistently 0.56 (dimensionless). It is important to note that in NBR 7190-1 (ABNT, [31]), the coefficient $K_{mod3}$ is omitted. However, since it is assigned a value of 1.0 in the previous version of the standard, this omission does not affect the final result.

## 3.4 Calculation bases according to nbr 7190

In accordance with the principles of structural statics, the forces acting on the structural elements are determined considering the elastic-linear behavior of the material. The weighting coefficients and combination factors for determining the calculation values of actions are defined according to NBR 8681 (ABNT, [45]). As for the loads acting on the truss, the recommendations of NBR 6120 (ABNT, [46]) are considered, including the adoption of a roof live load of 0.5 kN/m². To obtain the wind-induced loads, NBR 6123 (ABNT, [47]) is used. Therefore, Table 7 presents the loads classified as permanent and accidental actions acting on the roof.

**Table 7.** Acting Loads

| Permanent loads (kN/m) | Accidental loads (kN/m) | Resultant of loads (kN/m) |
|---|---|---|
| Total Self-weight (tiles + purlins + rafters + battens) | Wind + Overload | Own weight + Accidental |
| 1.01 | 5.58 | 6.60 |

Additionally, according to NBR 6120 (ABNT, [46]), it's necessary to consider that each individual roof structure element (such as battens, purlins, top and bottom chord bars of trusses) should be designed to withstand both the permanent load of the structure and a localized 1kN load positioned in the most critical region of the system.

### 3.5 Resistant Forces at Ultimate Limit States

Moliterno [48] defines the states at which the structure might compromise the construction's integrity. Ultimate Limit States (ULS) are those that, when they occur, lead to the cessation of the construction's use. Conversely, Serviceability Limit States (SLS) are those that, when they occur, result in structural effects that do not meet the conditions for the normal use of the construction, such as excessive displacements or vibrations (Calil Júnior; Rocco Lahr & Dias [35]).

## IV. RESULTS AND DISCUSSION

The initial results assess the differences that arise from sizing the purlins in relation to the two versions of NBR 7190, as both versions aim to optimize the sections. Subsequently, we present the results that evaluate the differences in sizing the structural elements of the roof truss. Finally, we discuss the primary design recommendations for wooden structures found in the literature in the context of the main recommendations of the current standard.

### 4.1 Properties of Maçaranduba (sp.)

When considering the mechanical properties of Maçaranduba obtained through the various versions of NBR 7190, is used Equation (1) to identify the primary differences in characterization between the two standard versions. This involves calculating the mechanical properties directly related to the internal forces anticipated in the roof truss, which include parallel-to-fibers compression ($f_{c0}$), normal-to-fibers compression ($f_{c90}$), inclined-to-fibers compression ($f_{c\alpha}$), parallel-to-fibers tension ($f_{t0}$), parallel-to-fibers shear ($f_{v0}$), and the average value of the modulus of elasticity in parallel-to-fibers compression ($E_{c0,m}$). The comparative results for the strength class of native forest species are depicted in Figure 6.

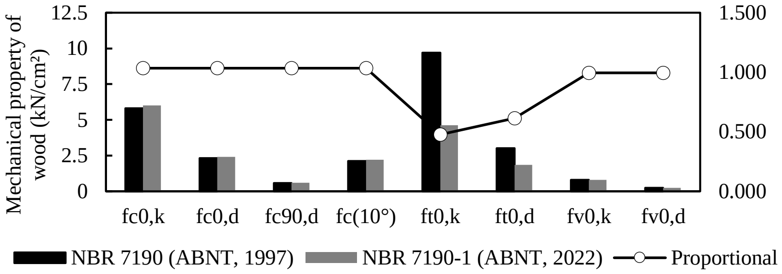


**Figure 6.** Comparison of the properties of Maçaranduba (sp.)

It's worth noting that the property most affected by the standard revision is $f_{t0}$, with a reduction of up to 52% in its characteristic strength value and up to 39% in its calculated value. Regarding $E_{c0,m}$, a reduction in strength of up to 15% is observed for both the average and effective values. For the other properties, the variations are negligible. Consequently, we observe that the determination of the characteristic properties of wood is more critical and conservative in NBR 7190-1 (ABNT, [31]). This is closely linked to the revisions of the mechanical characterization tests found in NBR 7190-3 (ABNT, [43]) and other sections of the standard. Furthermore, for native woods in NBR 7190-3 (ABNT, [43]), the test is based on the characteristic compressive strength $(f_{c0,k})$ of the representative sample, while in NBR 7190 (ABNT, [32]), it is based on the characteristic flexural strength ($f_{m,k}$). Studies such as those by Lahr *et al*. [49] underscore the importance of updating NBR 7190 (ABNT, [32]) by highlighting that the shear parallel-to-fibers ($f_{v0}$) of Brazilian woods characterized according to this standard may have up to 26% less strength. Couto *et al*. [50] also emphasize that the relationship between $f_{v0}$ and $f_{c0}$ for the species investigated can be up to 84.16% higher than the value proposed by NBR 7190 (ABNT, [32]), further confirming its obsolescence.

## 4.2 Verifications on the Purlin

The verification of an intermediate purlin is crucial because it experiences the highest level of stress. In the idealized model, the purlin is treated as a simply supported beam. When placed on an inclined plane, it presents challenges related to oblique simple bending, shear, deflection and lateral stability. Table 8 presents the results obtained in the purlin verification according to both versions of NBR 7190 for the optimized cross-section. The deflection (1.4cm) and the maximum normal stress (1.967 kN/cm²) of the purlin with a 16x16cm section are obtained through computer simulation and are illustrated in Figure 7.

**Table 8**. Critical analysis of safety conditions in the purlin

| Version | Section (cm) | $\sigma_{máx}$ (kN/cm²) | Oblique Bending | | $f_v$ (kN/cm²) | Deflection (cm) | Lateral Stability (cm) | Situation |
|---|---|---|---|---|---|---|---|---|
| | | | In x | In y | | | | |
| 1997 | 16x16 | 1.967 | 0.93 | 0.59 | $0.10 \leq 0.25$ | $2 \leq 1.45$ | $25 \leq 91.4$ | Verified |
| 2022 | 20x20 | 1.007 | 0.48 | 0.38 | $0.07 \leq 0.24$ | $1.4 \leq 0.6$ | $20 \leq 76.1$ | Verified |

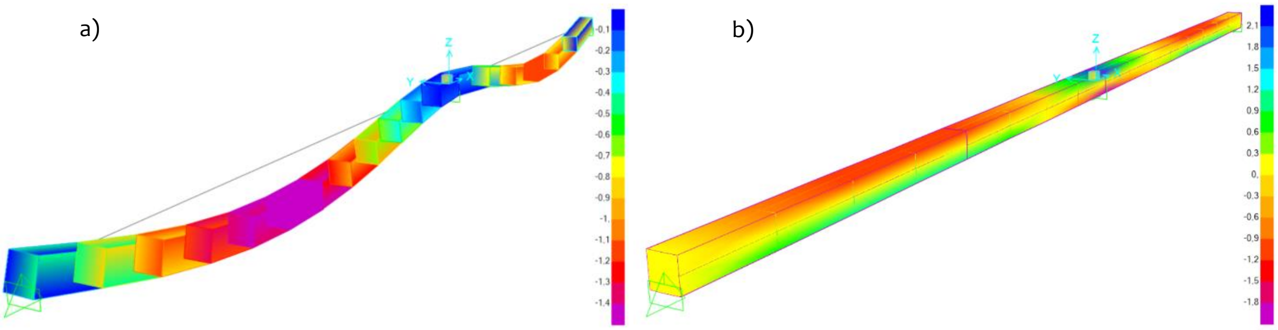


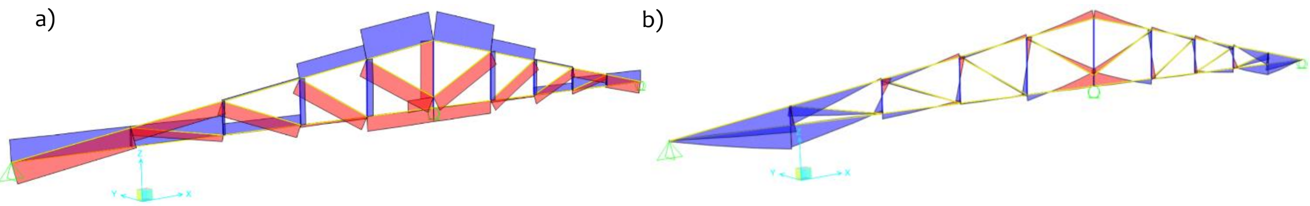
**Figure 7.** Verifications on the purlin with the 16x16 cm section. a) deflection scale (in cm). b) normal stress scale (in kN/cm²)

It is observed that, in order to satisfy all the safety conditions stipulated by NBR 7190-1 (ABNT, [31]), a larger cross-section purlin (20x20cm) is required for the same design scenario. Therefore, it becomes evident that all assessments and checks produce results that are below the prescribed limits. Consequently, it is clear that, despite the stricter characterization of wood properties, the current version of NBR 7190 is also more conservative in terms of the strength evaluations of the structural element.

## 4.3 Verifications on the truss

Support reactions, which result from the purlins bearing on the truss nodes, as well as their self-weight, are taken into consideration. According to Moliterno [48], it is common to use knee braces, which serve as bracing elements for the lower truss nodes and help reduce the bending forces in the purlins. This construction solution is employed in the study.

In Figure 8, the internal forces in the truss-type members are displayed, encompassing tension, compression, and bending moments. It is noteworthy that in this design scenario, being a statically indeterminate truss, there is a rearrangement of internal forces. Specifically, the central elements of the top chord are under tension, while the elements near the supports are in compression. Conversely, in the bottom chord, the central elements are in compression, and those near the supports are under tension. Additionally, all diagonals (webs) are in compression, with only the central vertical member following the same pattern.



Notes: 1) Tension (blue) and compression (red). 2) Positive moment (blue) and negative moment (red).

**Figure 8.** Diagram of internal forces. a) axial forces$^{1)}$ (in kN). b) bending moments$^{2)}$ (in kN.cm)

Truss verifications encompass issues related to flexural tension, flexural compression, stability and deflection. Table 9 presents the maximum values of these forces in the truss-type. Figure 9 shows the deflection and maximum stress in the truss-type, designed according to the guidelines of NBR 7190 (ABNT, [32]) and NBR 7190-1 (ABNT, [31]).

**Table 9.** Maximum internal forces in the structural elements

| Member | Tension (kN) | Compression (kN) | Bending moment (kN.cm) |
|---|---|---|---|
| Top chord | 255.68 | 141.33 | 784.07 |
| Bottom chord | 135.33 | 122.77 | 622.29 |
| Diagonal web | 0 | 143.94 | 259.94 |
| Vertical web | 53.78 | 257.68 | 238.91 |

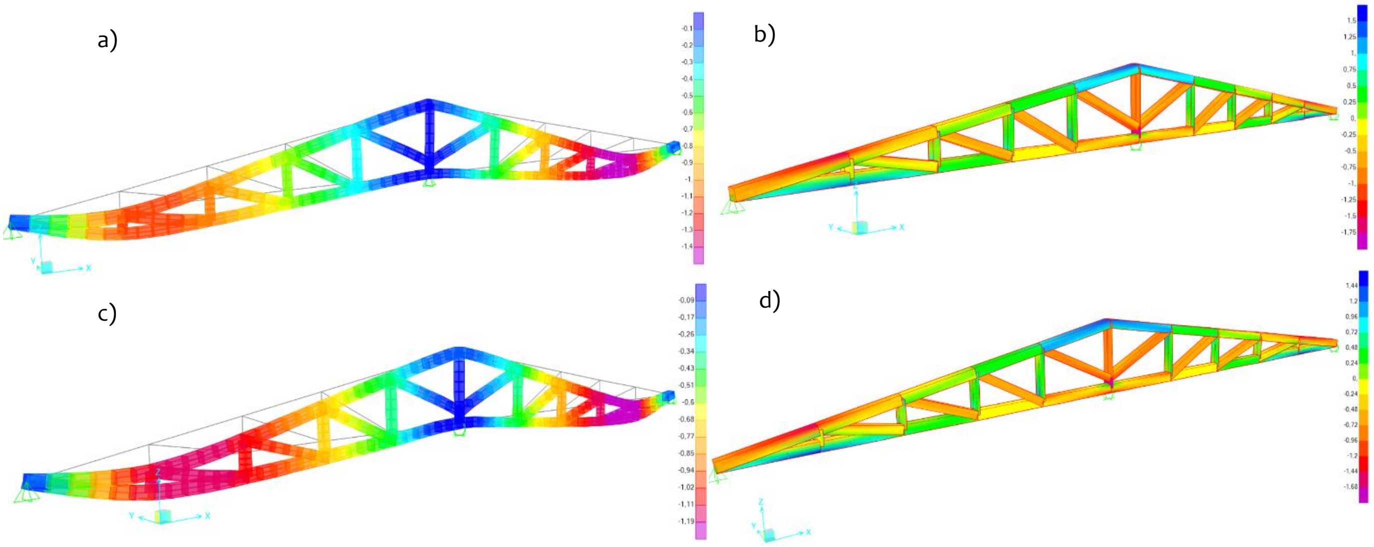
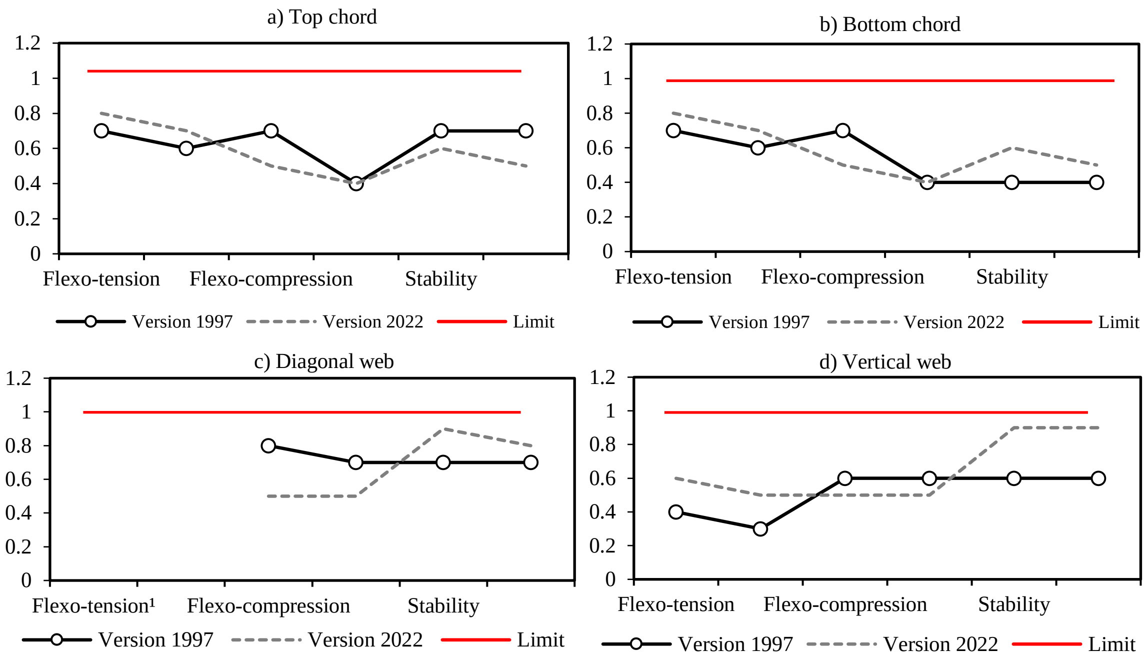


**Figure 9.** Verifications in the truss-type. NBR 7190 (ABNT, [32]): a) deflection (in cm). b) normal stresses (in kN/cm²). NBR 7190-1 (ABNT, [31]): c) deflection (in cm). d) normal stresses (in kN/cm²).

When considering the theoretical span of the truss from the support to the central knee brace (L=6.88m), it is confirmed that the safety requirements set by both versions of NBR 7190 are met when compared to the maximum deflections shown in Figure 10. Furthermore, Figure 10 presents the results obtained for the verification of structural elements according to the NBR 7190 versions, considering the optimized cross-section. The comparison of the final cross-sections, optimized according to the recommended design in both versions of the standard, is shown in Figure 11.

It is observed that meeting the safety requirements set by NBR 7190-1 (ABNT, [31]) necessitates the use of larger cross-sectional areas compared to the results obtained through the previous version of the standard for all truss structural elements. It should be noted that, as an exception, even when employing a 12x12cm section for the vertical web members, the stability limit for flexural compression is nearly reached. This further confirms the conservative nature of NBR 7190-1 (ABNT, [31]) when assessing compressed and flexural-compressed components.

Analyzing the safety condition for flexural tension, two changes in the current version of NBR 7190 become evident. The coefficient $k_m$ for rectangular sections is now 0.7 instead of 0.5, and $f_{m,d}$ is considered instead of $ft_{0,d}$, which can be assumed as $f_{m,d} = f_{t0,d}$ for native woods. As a result, the final results for this verification in both NBR 7190 versions are similar. Similarly, the safety condition for flexural compression, two changes are evident: the coefficient $k_m$ for rectangular sections is now 0.7 instead of 0.5, and $f_{m,d}$ is used in place of $f_{c0,d}$, which can be assumed as $f_{m,d} = f_{c0,d}$ for native woods. Consequently, the final results in both NBR 7190 versions for this verification are also similar. Therefore, for the same design situation and considering equivalent cross-sectional areas, differences in verification results are primarily due to variations in the characterization of wood properties. It is essential to highlight that differences in verifications can be more significant when dealing with timber from planted forests. In this case, Table 3 of NBR 7190-1 (ABNT, [31]) must be used, which is based on the characteristic flexural strength ($f_{m,k}$). Regarding the limitations of the safety equations shown in Figure 10, it can be observed that concerning flexural compression, all truss members designed according to NBR 7190-1 (ABNT, [31]) present results significantly below the limit. Meeting this new safety condition requires a larger cross-section compared to the previous version of the standard.



Note: 1) There are no flexo-tension in the diagonal's web of the truss-type.

**Figure 10.** Limitation of safety equations (dimensionless)

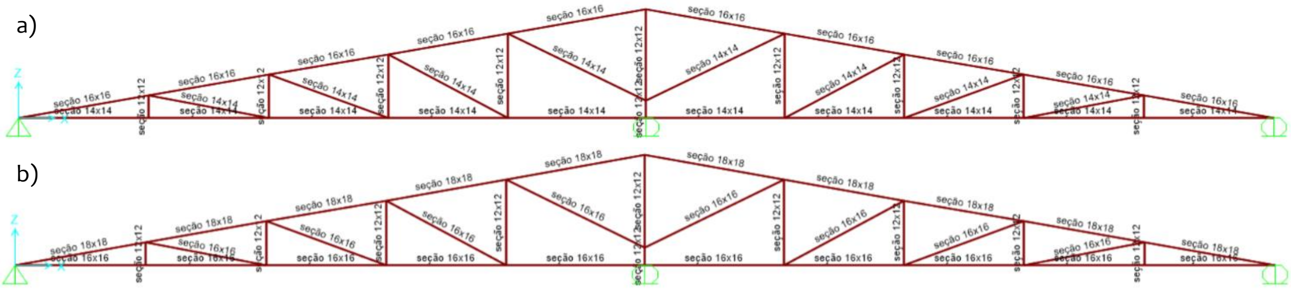


**Figure 11.** Optimized sections for the truss-type. a) According to NBR 7190 (ABNT, [32]). b) According to NBR 7190-1 (ABNT, [31]).

In contrast, regarding stability, the results are higher for the bottom chord, vertical members, and diagonals, with the top chord being the exception. This is because the top chord is mainly subjected to flexural tension forces, and this verification is not significant, as seen in Figure 9(b) and 9(d). Regarding flexural tension design, it is evident that the design according to NBR 7190-1 (ABNT, [31]) is closer to the limit. This confirms that the current version of the standard is more stringent in meeting safety requirements. Even with a larger wood piece, the limit value is almost reached for both the top and bottom chords. Menezes *et al.* [2] emphasize that when designing according to NBR 7190-1 (ABNT, [31]), the determining factor is stability in the y-axis.

With minimal length variation in the chords for each inclination, the assessment of buckling in relation to the axis of lesser inertia leads to the conclusion that compressive loads on the bars competing with the support can result in an excess of section sizes, as also highlighted in the main conclusions of this study. Figure 12 illustrates the comparison of the self-weight of the truss type obtained through the design according to NBR 7190 (ABNT, 1997) and NBR 7190-1 (ABNT, 2022). It can be observed that the design aimed at meeting the safety criteria of the most recent standard results in more robust components for the bottom chord, top chord, and diagonals web, leading to an increase in the self-weight of the truss by up to 27%.

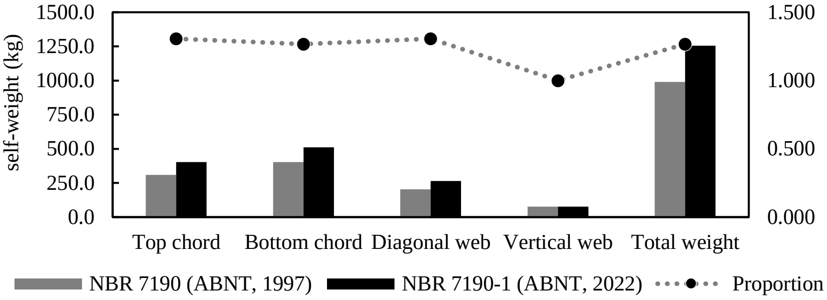


**Figure 12.** Comparison of the truss's self-weigh.

### 4.4 Design recommendation's

NBR 7190-1 (ABNT, [31]) specifies that the minimum cross-sectional dimensions for truss members should not be less than 50cm² and must have a minimum thickness of 5cm. Additionally, $L_0$ should not exceed 40 times the corresponding dimension for compressed members and 50 times for tensioned members. Nominal cross-sectional dimensions should be disregarded if they are reduced due to planning of the members. The standard also underscores that it is the supplier's responsibility, provided they comply with current legislation, to classify the wood batch into the required strength classes. In addition to the guidelines of the current version of NBR 7190, there are several key design recommendations from Oliveira, Pedrini & Pinto [51]: always use certified wood for both native and planted species; prevent the accumulation of moisture in the wood; adopt modularity in the local construction system to optimize execution; familiarize yourself with the local market for suppliers and skilled labor; protect exposed wood from weather, biological, or chemical damage; and consider hiring a designer to prevent over or under dimensioning of structures. Especially for roofing, it is advisable to choose lightweight roofing materials to reduce the amount of wood required. From a bioclimatic architectural perspective, when applicable, prefer white thermal and acoustic insulation roofing materials to increase solar reflectivity and enhance thermal comfort in the environment. Additionally, consider adopting a high ceiling to enhance the effectiveness of natural ventilation.

## V. CONCLUSION

Wood plays a significant role in construction in Brazil, particularly in roofing systems. Wooden roofs, at their core, utilize wood as the primary building material. Typically, wood is employed for crafting beams, battens, and rafters that constitute the structural framework of roofs due to its durability and strength, making it capable of withstanding heavy loads, such as those imposed by snow or rain.

Wooden roofs can feature various types of coverings, including ceramic tiles, fiber-cement, metal, or other materials. The choice of roofing material depends on factors like the region's climate, available budget, and architectural style. Incorporating wood in roofs offers several advantages, including durability, strength, and thermal and acoustic insulation properties. However, proper maintenance is essential to ensure the longevity of the roof, including regular applications of moisture protection and termite prevention measures. The design of a robust and secure roof structure is a critical undertaking. Key determinants in this process encompass wood species, rafter spacing, roof pitch, structural connections, weatherproofing, and load calculations, in accordance with the guidelines specified by NBR 7190. In Brazil, this standard governing the design of wooden structures. Since its initial release in 1997, significant technological and scientific progress has been achieved in the field. In June 2022, NBR 7190 underwent a substantial update, introducing significant improvements compared to its prior version. This update is pivotal for several reasons. First, it considers new construction materials, production techniques, and innovative wood utilization in engineering and architectural projects. Furthermore, the revised standard introduces critical updates concerning structural safety, ensuring that wooden constructions are safer and more durable.

As for the characterization of Maçaranduba wood properties, there's a noteworthy reduction of up to 52% in the resistant value of $f_{t0,k}$ and up to 15% in the value of $E_{c0,m}$. This reduction underscores the increased stringency of the new testing methods. Additionally, the updated NBR 7190 introduces new design parameters, particularly for compressed and flexural-compressed elements. Notably, the stability verification of these elements concerning the y-axis (lesser inertia) necessitates an increase in the cross-sectional area of the bars to meet safety standards. This results in an overall weight increase of up to 27% for the truss. Furthermore, the revised standard includes new tables and formulas for calculating loads, with considerations for reforested woods, among other factors. Another crucial aspect of the NBR 7190 (ABNT, [31]) update is its alignment with international wooden structure design standards, enhancing compatibility with requirements in other countries and bolstering construction reliability.

In summary, the update of NBR 7190 (ABNT, [31]) is indispensable for ensuring the safety and quality of wooden constructions in Brazil, reflecting the advancements in technology and science within the field. Consequently, architects, engineers, builders, and other industry professionals must stay informed and prepared to implement the new regulations established by this standard around the globe.

## DECLARATION OF COMPETING INTEREST

The authors affirm that they possess no identifiable conflicting financial stakes or personal connections that might have seemed to exert an impact on the research presented in this paper.

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