**Original Research Article**

# Technical feasibility study of the use of softwoods in lattice structure “Howe” type for roofing (gaps between 8-18 meters)




**Abstract**

**Introduction:** Wood is a material of biological origin widely used in construction, and its mechanical properties allow the material to form the lattice structure of roofs used in warehouses of industrial use, however, the paradigm as to the behaviour of the material makes the design decision less susceptible.

**Aims:** This work intends to verify the feasibility and optimize the use of unconventional wood in triangular roof truss structures in regions of flat topography, with a characteristic wind speed of 30 m/s.

**Methods:** The design methodology was fully based on the recommendations of ABNT NBR 7190
For the elements dimensioning, it was necessary to define the geometric and structural parameters that directly influence the actions and loads, as well as the behaviour of the structural elements.

**Results:** The choice of wood in this context, it was proposed the elaboration of projects of roofing structures with the following characteristics: "Howe" latticework (inclination of 10º - steel roof tile); Spans of 8, 10, 12, 14, 16 and 18 meters (ratio width: length, in plan, environment of 1: 3); Typology of the lateral openings of the building - (relationships between main opening area: other openings) 1:1, 2:1, 6:1 and insulated coverings (coverage on a medium of reduced dimensions).

**Conclusion:** The ratio of the volume of wood per floor area ($m^3.m^{-2}$) for C20 and C30 grade timber was determined, as well as the consumption of metallic pins per floor area, following the requirements of Brazilian standards, proving the technical feasibility.


**Keywords:** Wood, roofing structures, Howe truss, lattice structure, Brazil

## 1. Introduction

Wood is one of the most widespread materials in construction and one of the main materials used, mainly due to the ease and adaptability of its use [1]. This material can be used both in temporary constructions, shapes and anchors, as well as in permanent constructions, such as side closures or trellis structures for roofs [2 and 3].

Because it is plant material, its cellular structure is susceptible to attacks by spoilage pests such as fungi and termites. It is certain that untreated wood structures over time may present pathologies due to biological and physic-chemical factors. However, pathologies can be avoided with the use of preservative treatments, being the most common in Brazil those with saline solutions, as pointed out by Bertolini et al. [4].

Although there is a notable prejudice in Brazilian society in relation to material, wood, as a renewable natural resource, does not emit harmful chemical pollutants in its production, it has advantages over other materials, mainly due to the socio-environmental appeal [5].

In this way, this work intends to verify the feasibility and optimize the use of unconventional wood in triangular roof truss structures in regions of flat topography, with a characteristic wind speed of 30 m/s.

## 2. Material and Methods

The design methodology was fully based on the recommendations of ABNT NBR 7190 [6]. For the elements dimensioning, it was necessary to define the geometric and structural parameters that directly influence the actions and loads, as well as the behaviour of the structural elements.

*Geometric Parameters*

The projects have the following characteristics:

a. Geometric relation in plan around 1:3, obtaining the following relations:

- Model 1 – 8 x 27.50 m (five spans of 5.50 meters - tracks "A" through "E");
- Model 2 – 10 x 33 m (six spans of 5.50 meters - tracks from "A" to "F");
- Model 3 – 12 x 38.50 m (seven spans of 5.50 meters - tracks from "A" to "G");
- Model 4 – 14 x 44 m (eight spans of 5.50 meters - tracks from "A" to "H"); (Figure 1)
- Model 5 – 16 x 49.50 m (nine spans of 5.50 meters - ranges from "A" to "I"); and
- Model 6 – 18 x 55 m (ten spans of 5.50 meters - tracks from "A" to "J").

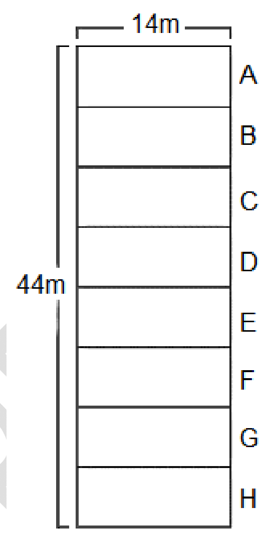


Figure 1 – Representative scheme of the Model 4

b. Height (ceiling height) preset to 5 meters;

c. Opening ratios: 1:1, 2:1, 6:1 and isolated cover (open)

*Structural Design*

The structural elements characteristics of the project are:

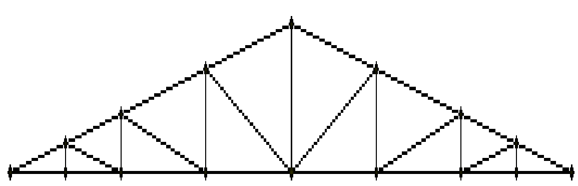

Figure 2 – Representative scheme of the Model 4

a. Trellis: hyperstatic, "Howe" type, with a 10° slope, considering the bars continuity of the flange (top/bottom), while the internal bars (diagonals/uprights), hinged at their ends. In the flange bars, spans of 8, 10, 12, 14, 16 and 18 meters.

b. Rectangular Purlin: isostatic beam in "x", supported on the trusses knots; hyperstatic beam in "y", with end supports on truss knots. The internal support, given through chain lines (metal rods), is located in the middle of the span; and
c. Bracing System: layout of the top flange consists of the purlin and steel cables with stretchers arranged in an "X" shape; the bottom flange plane consists of "T" beams (top table - 2.5 x 15 cm; core - 2.5 x 15 cm) locked transversely at the midpoint (5 x 6 cm piece), fixed at the ends of the lower flange nodes and positioned in the following form:

- Model 1 - tracks “A”, “C”, ”E”;
- Model 2 - tracks “A”, “C”, “D”, ”F”;
- Model 3 - tracks “A”, “C”, “E”, “G”;
- Model 4 - tracks “A”, “D”, “E”, ”H”;
- Model 5 - tracks “A”, “C”, “E”, “G”, ”I”;
- Model 6 - tracks “A”, “C”, “E”, “F”, “H”, ”J” (Figure 3).

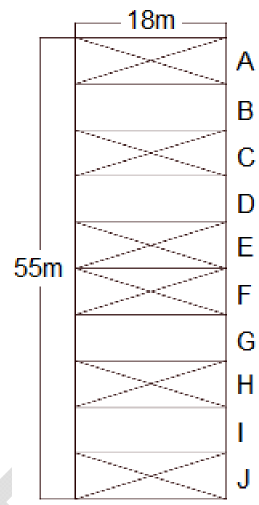


Figure 3 – Bracing scheme for the span of 18 meters (Model 6)

*Actions and Loads in Structure*

The actions in the structures are permanent and variable. The permanent ones are structural and not structural, including the proper weight of trusses, purlin and tiles (0.05 kN/m²). Variable actions are due to wind loads. For the permanent actions (structural and non-structural) calculation, the standards ABNT NBR 7190 [6] and ABNT NBR 6120 [7] was used.

The classes of truss and bracing resistances are C20 for all projects and C30 for purlin. These characteristics were determined based on the availability of the alternative woods in the region.

For the variable actions calculation due to the wind, the prescriptions and recommendations contained in ABNT NBR 6123 [8] were adopted, considering that the study building is located in the regions of basic velocity (Vo) equal to 30 m/s.

Combinations of actions (loading) were performed based on the recommendations of ABNT NBR 8681 [9] and ABNT NBR 7190 [6], both for State Limit Ultimate and State Limit of Service. Ftool support software was used to calculate internal efforts.

*Sizing and Verification*

In the dimensioning and stability analysis of the structural elements of the bracing system and the truss (flange, uprights and diagonals), the tensile and compression situations parallel to the fibres are considered (short piece, medium slender and slender) and, for purlin, which is an element subject to oblique flexion, the situation of simple oblique flexion was considered. Regarding the connections, consideration was given to the pin bending and the wood inlay. In these procedures, the Ultimate Limit State was adopted, considering the requirements of ABNT NBR 7190 [6] and ABNT NBR 8681 [9].

For the study of displacements, the State Service Limit, which considers the weight of the structure, is used for long-term combinations, according to ABNT NBR 7190 [6] and ABNT NBR 8681 [9].

*Materials Quantification*

Finally, the total wood consumption was determined for all the cases under study, being represented by the relation "$m^3_{wood}/m^2_{area}$", as well as the relation of pin number per square meter of area.

## 3. Results and Discussion

*Wood Volume*

After scaling and calculation the results of each structure were added and separated into purlin, trusses and bracing system. With this data the following charts and tables were generated:

Table 1 - Volume (m³) - open

| Span (m) | Trusses (m³) | Purlin (m³) | Bracing (m³) | Total (m³) |
|---|---|---|---|---|
| **8** | 0.99 | 1.54 | 0.37 | 2.90 |
| **10** | 1.52 | 1.98 | 0.37 | 3.87 |
| **12** | 2.95 | 3.31 | 0.82 | 7.08 |
| **14** | 4.29 | 4.88 | 1.15 | 10.33 |
| **16** | 6.68 | 6.48 | 1.48 | 14.65 |
| **18** | 10.43 | 6.98 | 1.48 | 18.90 |

Table 2 - Volume (m³) - 6:1

| Span (m) | Trusses (m³) | Purlin (m³) | Bracing (m³) | Total (m³) |
|---|---|---|---|---|
| **8** | 1.03 | 1.45 | 0.37 | 2.80 |
| **10** | 1.54 | 1.89 | 0.37 | 3.81 |
| **12** | 2.70 | 2.79 | 0.82 | 6.32 |
| **14** | 4.03 | 3.82 | 1.15 | 9.02 |
| **16** | 5.02 | 5.23 | 1.48 | 11.75 |
| **18** | 8.07 | 5.92 | 1.48 | 15.48 |

Table 3 - Volume (m³) - 2:1

| Span (m) | Trusses (m³) | Purlin (m³) | Bracing (m³) | Total (m³) |
|---|---|---|---|---|
| **8** | 0.90 | 1.45 | 0.37 | 2.73 |
| **10** | 1.42 | 1.76 | 0.37 | 3.55 |
| **12** | 2.19 | 2.64 | 0.82 | 5.65 |
| **14** | 3.56 | 3.70 | 1.15 | 8.40 |
| **16** | 4.23 | 4.97 | 1.48 | 10.69 |
| **18** | 6.26 | 5.74 | 1.48 | 13.48 |

Table 4 - Volume (m³) - 1:1

| Span (m) | Trusses (m³) | Purlin (m³) | Bracing (m³) | Total (m³) |
|---|---|---|---|---|
| **8** | 0.88 | 1.34 | 0.37 | 2.59 |
| **10** | 1.19 | 1.69 | 0.37 | 3.25 |
| **12** | 1.87 | 2.46 | 0.82 | 5.15 |
| **14** | 2.90 | 3.52 | 1.15 | 7.57 |
| **16** | 3.44 | 4.53 | 1.48 | 9.46 |

| | | | | |
|---|---|---|---|---|
| **18** | 4.71 | 5.37 | 1.48 | 11.56 |

The consumption of wood in all the analyzed spans had the highest consumption of insulated roofs, since the values of high suction winds combined with a structure with the low inclination and low self-weight tile made the wind the largest agent of effort, thus inverting values of self-weight efforts. Followed by the 6:1 aperture ratio, which by having a large air inlet opening, but six times less air outlet apertures, provided wind pressure coefficients as high as those of insulated covers. And with the lowest total wood consumption, the ratio of 1:1 opening stood out, because with an air outlet of the same input value, obtained smaller coefficients, which relieved the structure.

The consumption of wood in the areas just after the middle of the building was similar, as the low wind performance made the structure slightly loaded, which made the dimensions in this area become the minimum required for connection, leaving a larger reserve of resistance, which restricted the material economy. The bracing system did not show any major changes since the main factor is the number of zones to be braced.

With the data acquired, graphs were also made, grouping the consumption by area of each gap.

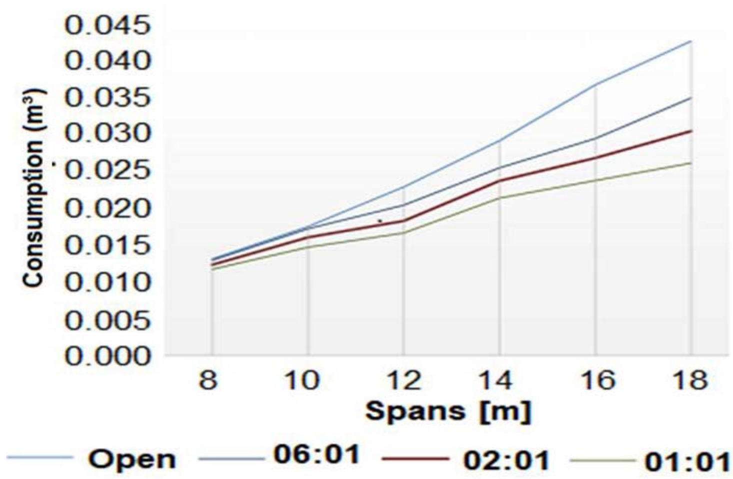


Figure 4 – Graphical representation showing comparative consumption for all spans

It has been observed that in all the vain the almost of linear form, however, it is not possible to extrapolate values, since the efforts tend to grow non-linear.

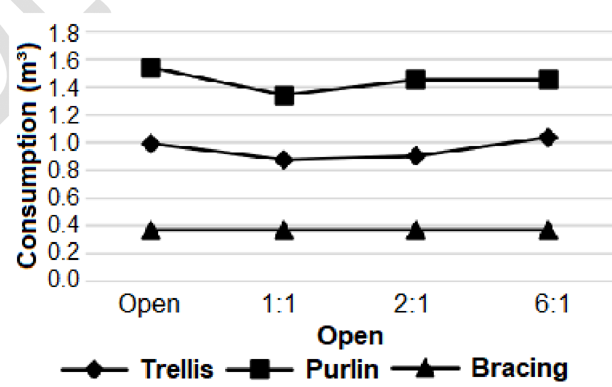


Figure 5 - Graphical representation showing comparative consumption for 8 meters span

When comparing the consumption of each item of the structure, similar behaviour in all the vain can be noticed: the purlin with greater consumption, followed by the trellis and bracing.

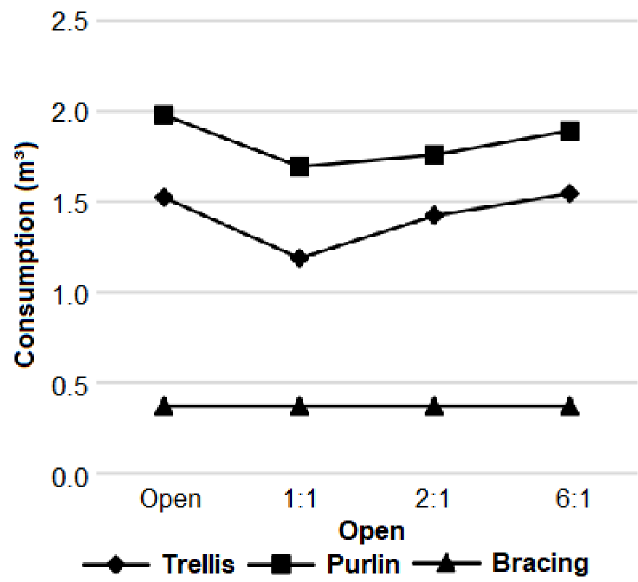


Figure 6 - Graphical representation showing comparative consumption for 10 meters span

The bracing remained almost constant, for all projects analyzed.

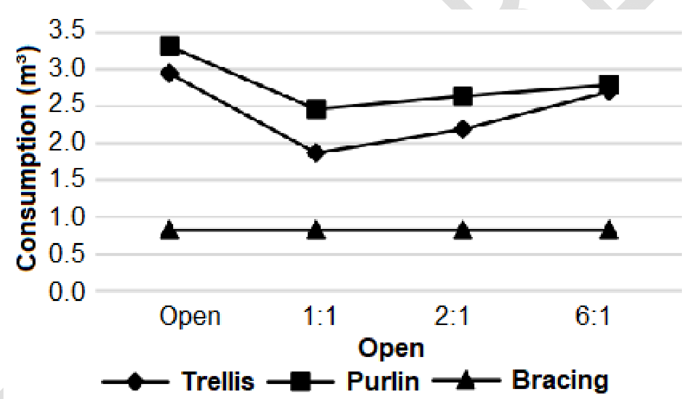


Figure 7 - Graphical representation showing comparative consumption for 12 meters span

In the larger spans, the trusses tended to get closer to the purlin.

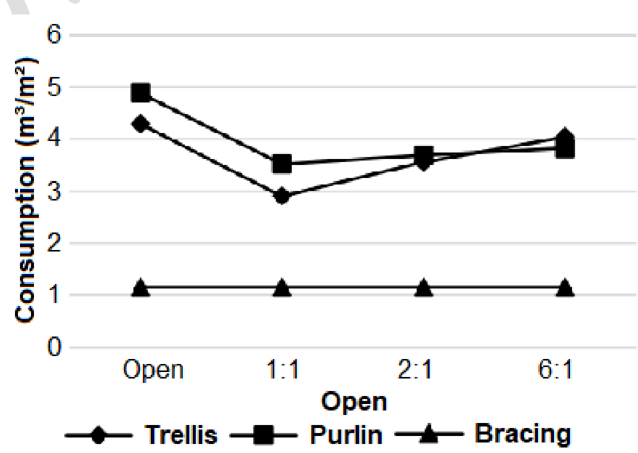


Figure 8 - Graphical representation showing comparative consumption for 14 meters span

In the spans above 14 m, it was already possible to find overlaps between the lines of purlin and trellis.

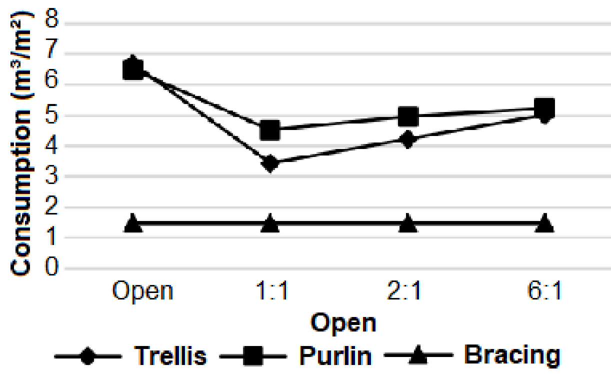


Figure 9 - Graphical representation showing comparative consumption for 16 meters span

This approximation of the trellis line suggests that if the research is extended, trellis consumption is likely to outperform purlin in all openings.

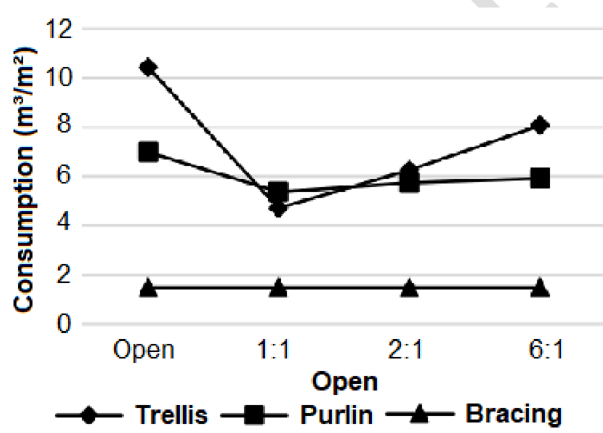


Figure 10 - Graphical representation showing comparative consumption for 18 meters span

In the last gap, it is already possible to notice the distance of the two lines.

The pins calculation also resulted in Table 5 and graph of Figure 11.

Table 5 - Total number of pins required for each project.

| Span (m) | 1:1 | 2:1 | 6:1 | Open |
|---|---|---|---|---|
| **8** | 722 | 744 | 1120 | 1000 |
| **10** | 1633 | 2065 | 2495 | 3738 |
| **12** | 1928 | 2440 | 2932 | 3332 |
| **14** | 3339 | 4147 | 4971 | 5096 |
| **16** | 3735 | 4889 | 6033 | 7083 |
| **18** | 4706 | 6252 | 7716 | 8186 |

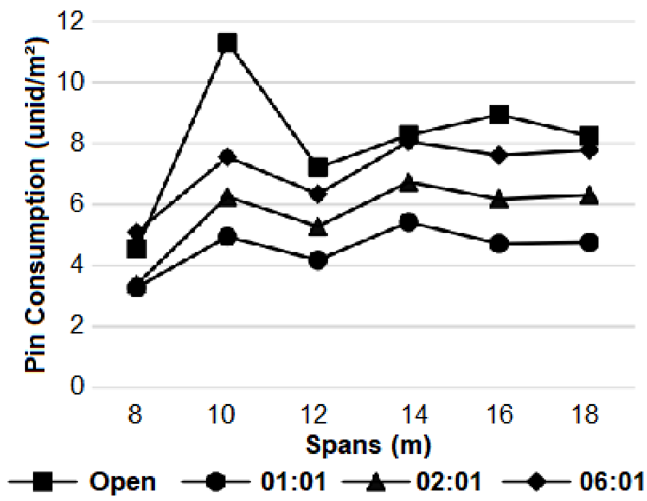


Figure 11 - Graphical representation showing comparative consumption for 18 meters span

As in wood consumption, the pin consumption followed the trend of the open having the highest consumption followed by the ratio of opening 6:1.

### 4. Conclusions

The research addressed factors that influence the wood consumption, as well as the possibility of building these spans with low resistance woods using the calculated typologies, thus leaving an estimate of the consumption of wood cover inputs. In this way, the proposed viability was proven. the ratio of the volume of wood per floor area ($m^3.m^{-2}$) for C20 and C30 grade timber was determined, as well as the consumption of metallic pins per floor area, following the requirements of Brazilian standards, proving the technical feasibility.

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