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Roof modular system in wood and particle board (OSB) to rural construction

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ABSTRACT: Wood is a material of great applicability in construction, with advantageous properties to form various structural systems, such as walls and roof. Most of the roof structural systems follow models that have remained unchanged for a long time. A roof modular system in distinguished materials is proposed: reforested wood (*Pine*), oriented strand board (*OSB*) and roof tiles made of recycled long-life packaging material in order to be applied in rural construction. In this alternative, besides the benefit of giving destination packages with long-life thermal comfort, it also highlights the use of reforestated wood being the cultivation of such species that provides incentive for agribusiness. The structural performance of this alternative was evaluated through computer modeling and test results of two modular panels. The analysis is based on the results of vertical displacements, deformations and stresses. A positive correlation between theoretical and experimental values was observed, indicating the model's feasibility for use in roof structures. Therefore, the modular system represents a solution to new architecture conceptions to rural construction, for example, storage construction, cattle handling and poultry, with benefits provided by prefabricated building systems.
Keywords: structural system, recycled tile, reforestation wood

Introduction

Wood is a material of great applicability in construction, with advantageous properties to form various structural systems, such as walls and roof (Nolan, 1994). In Brazil, there is a major trend in the use of reforestated wood, among which Pine and Eucalyptus stand out, due to the great potential of Brazilian conditions for these species to be grown (Krüger et al., 2009).

Currently, most of the roof structural systems follow models that have remained unchanged for a long time. However, this type of structure often makes it overdesigned, directly impacting the cost of the work. Roof and wall system prefabrication is an issue that has been studied most notably in recent years. This technique basically uses wood frames and drywall or sandwich panel. Details can be seen in (APA, 1997; Hu et al., 2007; Sandberg, 2008). Gaetani et al. (2010) have established a prefabricated panel roof system using reforestated wood and ceramic tiles, with the objective of replacing current roof structural system. Roof systems with tiles made of recycled long-life packaging material were evaluated by Fiorelli et al. (2009). The results indicated no difference between the temperatures under recycled tile roofs and ceramic tile roofs, concluding that the recycled tile is an efficient option, with respect to thermal comfort.

It is necessary to check the state limits of the structural elements in order to suggest an alternative wood roof system which aims at the rationalization of construction processes (ABNT, 1997). In this sense, computer simulation by the finite elements method, for example, allows the verification and the optimization of structural systems. Based on these concepts, a proposal for a roof modular structural system is presented. In the context of the product development, the structural behavior of two panels is evaluated through the theoretical and experimental analysis of displacements, stresses, and strain.

Materials and Methods

The development of new products requires a series of assumptions that are established at the beginning of the project activity. Baxter (2002) defines this moment as "conceptual design", where the requirements the product must fulfill are established. These requirements vary according to the pursued objectives, considering performance and production process. So, the development of new products aims to meet the user's expectations. Thus, a roof modular structural system was developed in reforestation wood, OSB, and roof tiles made of recycled long-life packaging (Figure 1A). The choice of these building elements, which are alternative materials in roof building, comes from the concern about sustainability. The roof modular structural system can be used in some architecture conceptions to rural construction, for example storage construction, cattle and poultry (Figures 1B, 1C and 1D).

After the development of the roof modular system, two panels were sized. The panel designated P200, 88-cm wide and 200-cm long (Figure 2A), was made up of pre-sized pine rib, following the recommendations of ABNT (1997). The 3.7 cm × 12 cm cross section dimensions were defined, given the findings of the ultimate state limit. The rib of the panel forms a grid with three frame rails and three transverse lines. In order to compose the panel bottom, a 1 cm thick OSB was used, fixed on the grid by 12 × 12 nails (diameter 1.8 mm and length 35 mm) with 25-cm spacing. Similarly, the panel called P300 was built 88-cm wide and 300-cm long, with three frame rails and four transverse lines and its slats presented cross sections equal to 4 cm × 12 cm (Figure 2B).

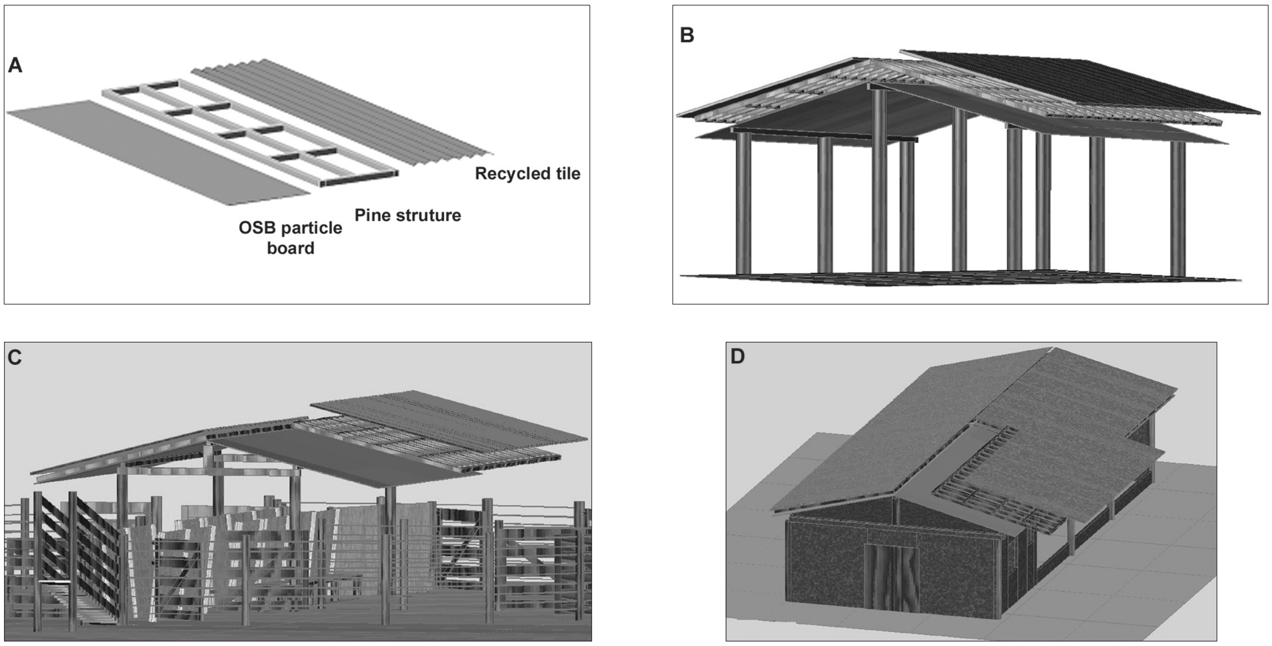

Figure 1 – Roof modular system project and applications. A) Concept, B) Storage construction, C) Cattle handling construction, D) Poultry construction.

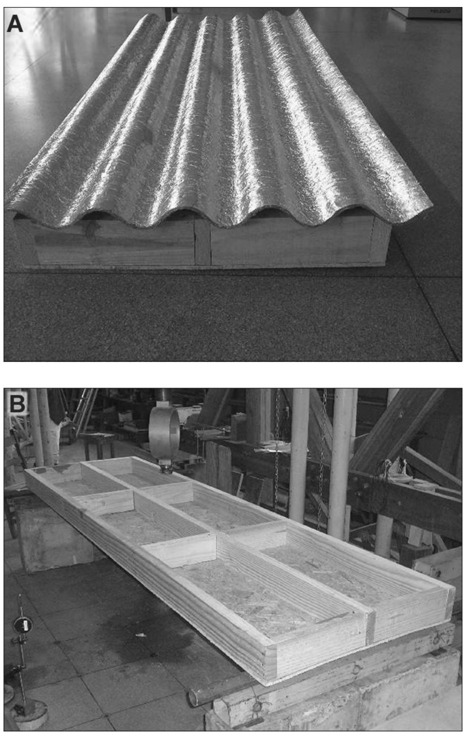

Figure 2 – Panel system. A) Tile and structure, B) Rib and OSB.

Material properties: To computational simulation of panel, the mechanical properties not considered the weightings. The comparison was made directly for tests results. By the characterization testing, the pieces of Pines used in this study were classified as C25 ABNT (1997), with moisture content equal 12 %. For this class we have the characteristic compression strength parallel to grain equal to 25 MPa, and the correspondent average longitudinal elasticity modulus equal to 8500 MPa. For the OSB, as required by the manufacturer, the longitudinal elasticity modulus of 3700 MPa was used. The characteristic strength to tension is given by 39 MPa. For the elements used in the simulation of nails, the elasticity modulus 205 GPa was adopted.

Tests: In the experimental evaluation stage, the structure formed by the *Pinus* grid and by the OSB was installed on hydraulic press, thus imposing the conditions of bi-supported structure. The increments of load were applied through steel profile, considered as stiff, placed in the midline of the span of the panel to allow the distribution of force in the three frame rib. On every force increment the vertical displacements were registered, measured with the aid of dial indicators, placed in three points along the midline of the panel span (Figure 3). These conditional tests simulate the effect of bending of the whole; however the actions combinations (self weight, wind, stationary equipments, accidental load etc) should be prescribed and enforced for the specific project. In the panels' central region, for each increment of load, the corresponding deformation of the top of the rib and the bottom of the OSB were registered. The respective averages were used for analysis and comparison with the values obtained through computer modeling. This stage followed ASTM (1997).

Computer modeling description: The simulation of the structural prototypes was made with the aid of the

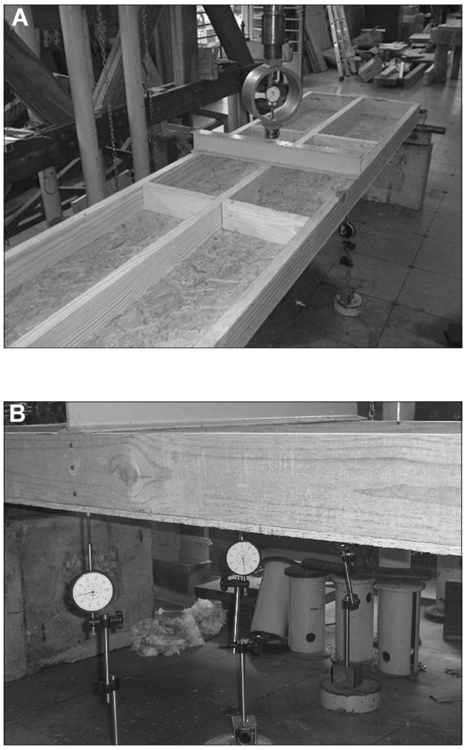

Figure 3 – Experimental procedures. A) Steel profile and load cell, B) Instrumentation.

computational tool, using the program ANSYS©, with the grid pieces represented by the element of three-dimensional Beam4 (the keypoints that identify the grid plans were used to generation of the nodes of connectivity between transverse and longitudinal and the plate (OSB) discretized by Shell63 elements (Figures 4A and 4B). The plans of the grid and plate are distinct. In these situation Beam44 elements of circular cross section, were used to simulate the connection between the grid and the plate nodes (Figures 4C and 4D), which radius was assumed to be the same as of the nail (0.9 mm). Therefore, instead of using contact element, each connection was simulated by bar elements connecting the node positioned at the gravity center of the grid element corresponding to the node positioned at half height of a plate element, which flexural simulates the effect of sliding (resulting from flexion and embedment of the nails). These connection elements were distributed in the same position of the nails (spacing 25 cm).

Results and Discussion

From testing the modular system of roof, for every force increment, the deflections were determined by dial indicators, as well as the deformations of the top and bottom of the P200 and P300 panels, which were loaded to a value of 5.41 and 8.65 kN, respectively, without the occurrence of damage. The deformations and stresses along the height of the panel are repre-

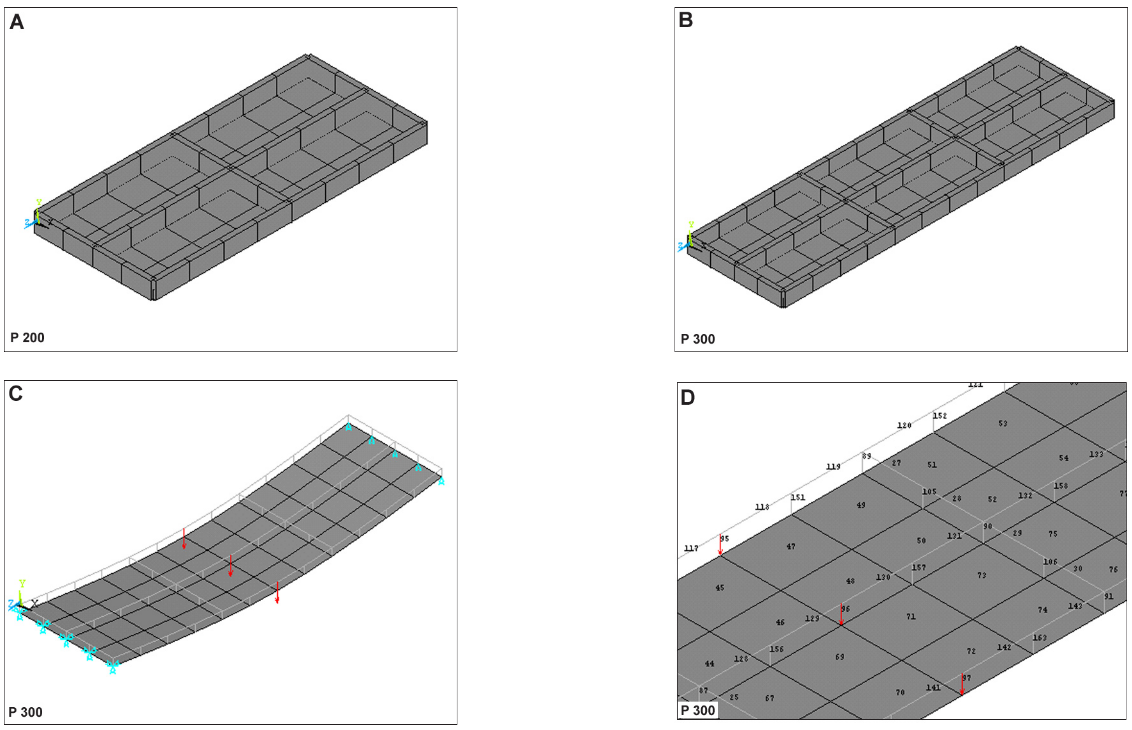

Figure 4 – Panel modeling. A) Elements shape of P200 panel, B) Elements shape of P300 panel, C) Deformed Panel, (D) Detail of connections elements.

sented schematically in Figure 5. Only the P200 panel was taken to break during the tests, when it achieved a load of 19.48 kN.

Displacement: to analyze structural stiffness efficiency, the average experimental values were considered, which present a linear behavior of structural systems (Figure 6). To evaluate the structural system tested and the adequacy of the computational model considered, the state limit of use referring to vertical displacements with the limit L/200 was checked, according to ABNT (1997), where L represents the distance between supports. In this case it was 196 cm and 296 cm for the P200 and P300 panels, respectively. Figure 6 present the experimental results (EXP) and results of the computational simulation (SIM).

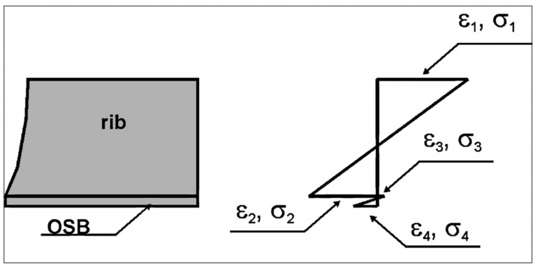

Figure 5 – Strain and stress diagram.

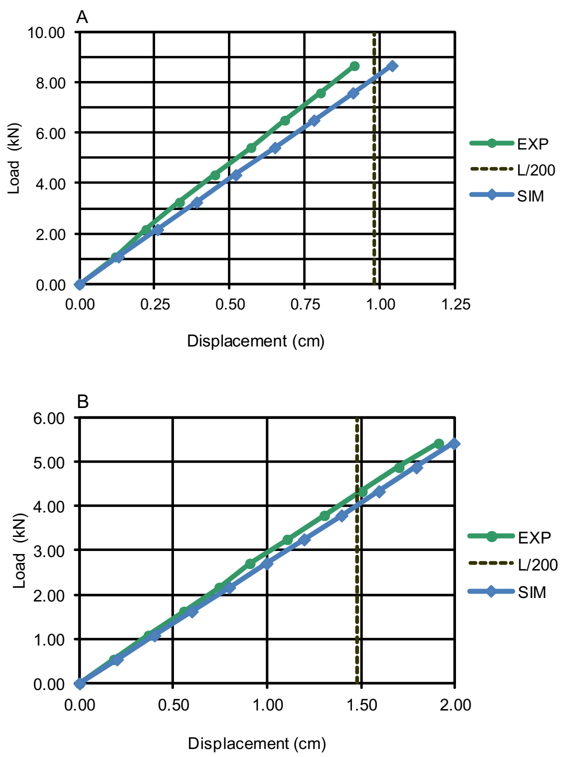

Figure 6 – Load versus displacement curves. A) P200 Panel, B) P300 Panel.

Given the using limit state defined by the vertical displacement (L/200), loading of panels would be limited to a value close to 9.30 kN and 4.26 kN (these values were obtained by linear adjustment of the experimental data, with R^2 = 0.9998 and R^2 = 0.9994, respectively). With the condition of deflection limit (L/200) and through computational model, with the extrapolation of the results presented in Figure 6A, the corresponding values of maximum load to panel P200 were estimated at 8.17 kN (curve SIM). For panel P300 (Figure 6B) the limits of 4.02 kN (curve SIM) were estimated. The panels tested presented a superior efficiency in comparison with the model used in simulation. That is, in the situation of displacement limit on panel P200 there is a difference for the load values of approximately 13.8 %. For panel P300 this difference was of 6.0 %, when it was evaluated for displacement limit of L/200.

Deformations: Tables 1 and 2 present deformations obtained through computational modeling and tests for some levels of loading. As shown in Figure 5, ε_1 and ε_2 correspond to deformations in the rib, while ε_3 e ε_4 represent deformations in the particle board (OSB). Computational modeling results show the presence of two neutral lines, with the occurrence of tension and compression stresses in rib and OSB.

By computational analysis with the deformations resulting modules practically coincident to ε_1 and ε_2, and also for ε_3 e ε_4, permit to conclude that the connection system (with 12 × 12 nails, spacing 25 cm) used provided the low efficiency to impediment of slip on beam and OSB contact surface.

As the connection system influences the deformation state in modular system elements, with the purpose of reducing the sliding, on the model used to both panels allow an optimized structural analysis by replacing nails with larger diameters and also more closely spaced. A more rigid connection reflects directly on the structural performance with the redistribution of stresses and strains, as well as reducing the vertical displacement of the proposed system.

Table 1 – Deformations in Panel P200.

Pk (kN)	Computational Modeling				Experimental	
	ε_1 10–6	ε_2 10–6	ε_3 10–6	ε_4 10–6	ε_1 10–6	ε_4 10–6
2.16	-488.3	488.0	-42.3	42.8	-470.0	150.0
4.33	-976.5	976.0	-84.5	85.6	-990.0	290.0
6.49	-1464.8	1464.0	-126.8	128.3	-1540.0	420.0
8.66	-1953.0	1952.0	-169.0	171.0	-2020.0	570.0

P_k = load applied. ε = deformation.

Table 2 – Deformations in Panel P300.

Pk (kN)	Computational Modeling				Experimental	
	ε_1 10^{-6}	ε_2 10^{-6}	ε_3 10^{-6}	ε_4 10^{-6}	ε_1 10^{-6}	ε_4 10^{-6}
0.54	-163.1	163.0	-13.2	13.8	-110.0	40.0
2.16	-652.4	652.0	-52.8	55.2	-480.0	120.0
3.79	-1141.7	1134.0	-92.4	96.6	-890.0	200.0
5.41	-1631.0	1630.0	-132.0	138.0	-1330.0	300.0

P_k = load applied. ε = deformation.

Table 3 – Stress (σ) in P200 and P300 (kN cm^{-2}).

P_k (kN)	Computational Modeling				Experimental	
	σ_1	σ_2	σ_3	σ_4	σ_1	σ_4
			P200			
8.66	-1.66	1.66	-0.07	0.07	-1.72	0.21
			P300			
5.41	-1.39	1.39	-0.05	0.05	-1.13	0.11

P_k = load applied.

The difference between values obtained from experimental and computational analysis could probably be reduced using a solid modeling; however some features of wood anatomy may not be exactly reproduced by the model, such as the exact direction of the fibers and the presence of pith. The experimental values of the deformations ε_1, on panel P300, for instance, were lower than the computational analysis values, a fact that may derive from a defect not observed in the pine rib inspection.

Stress: The stresses determined by computer modeling and testing are presented in Table 3. The values of σ_1 and σ_2 (pieces of Pine) and σ_3 and σ_4 (OSB) were assessed for the levels of loading 8.66 kN and 5.41 kN for the panels P200 and P300, respectively. The experimental values were calculated for the correspondents strain and elastic modulus described in material properties section. Similarly to the deformations, the connection system used permitted the occurrence of two well defined neutral lines in stress distribution (Table 3), in accordance with Figure 5. From this point of view, for the loading levels evaluated, the analyzed structures were safe, comparing these stress levels to the corresponding characteristic strength that can be obtained of the values presented in Material properties section. The OSB as well as providing a finish to the underside, being fixed to the elements of the grid, stabilizes this pieces and using a more rigid connection system can also influences the bending stiffness of the assembly.

This proposal system is feasible due to the facilities to fix the tiles on the grid and, plus, can be easily transported. Each panel needs an external support, as showed in the modeling, which can be promoted by beam or walls.

Conclusion

The roof modular system in reforestation wood (*Pine*), OSB and roof tiles made of recycled long-life packaging can be indicated as roof to rural and urban construction with advantages of being a sustainable building system, manufactured with materials from renewable sources**.** The assembly of the panel showed the feasibility of the building system under development. Concerning the comparison of experimental and modeling, results allowed considering the possibility of improving the stiffness of connection system to reduce the slip between grid and OSB, with the bending stiffness increasing the mechanical performance of the panel. Thus, same limits of vertical displacement could be overcome and, consequently, promoting a better strain and stress distribution to the pieces that composed de structural system.

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