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Repair Methods Indication for a Timber Coverage Structure Located in Sinop City - Brazil

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Abstract Brazil has large forest vocation in construction, however, the difficulty in obtaining adequately trained professionals associated with lack of knowledge about the physical and mechanical properties, no appropriate treatment against insects and fungi, among others, confirm the reduction of durability materials and consequently the projected structure. In order to contribute effectively in reducing disease and spread the application of concepts of prevention methods to timber structures by professionals of construction in Brazil and other countries, this research aimed, through a case study carried out in a cover structure (made with Itaúba wood specie - *Mezilaurusitaub meisn*) located in the Midwestern region of Brazil, Mato Grosso, in the city of Sinop (11°50'5,5 "S; 55°30'4,2" W), identify pathologies present in the structure, identify possible causes and point out the most appropriate methods for repair. The cover structure has the following characteristics: Ceramic roof; truss structure of Howe type with 23° inclination; dimensions plant with 14m in width and length of 32,5m; spacing between trusses 2.5m; strips with dimensions of 2,5×5,0cm^2 rafters: 5,0×6,0cm^2; purlins: 5,0×15,0cm^2; diagonal: 5,0×10,0cm^2; amounts: 2 pieces with 2,5×15,0cm^2; upper and lower flanges: 5,0×15,0cm^2 and steel joints made with through bolts. Thus, it is expected that in the near future, this study effectively contribute to the reduction of pathologies, and spread the application of concepts and prevention methods to repair the structures, contributing positively by spreading the use of wood in the design of structures.

Keywords Timber, Cover structure, Pathologies, Preventive methods

1. Introduction

Wood is a material of vegetable origin and organic, being a raw material that can be produced anywhere in the world, coming from completely renewable and abundant sources such as natural tropical forests and planted and, therefore, that material has always been present in Brazilian buildings.

However, in general, Brazil has large forest vocation in civil construction, nonetheless, the difficulty of obtaining properly qualified professionals to develop specific projects of wooden structures and monitoring this construction, the lack of knowledge of physical-mechanical and natural properties of some wood species, the inappropriate use of the material and the lack of knowledge of the methods that prolong its useful life, corroborates in the reduction of durability and has leaded, prematurely, the occurrence of pathologies affecting the aesthetic- functional aspect, besides fomenting the prejudice on the quality and use of same.

For the use of wood as a structural material, it expects some extremely important qualities, as natural durability and maintenance of the physical and mechanical properties over the course of use. Though, it is known case that the use of wood as a structural material requires cares to minimize the problems related to the decrease of mechanical properties over the years. It is noteworthy that such properties are directly influenced by moisture content (physical property) and vary according to species. Furthermore, the addition of the same due to exposure of the wood in contact with water or humid environments, is responsible for reducing the resistance properties of wood [1-7].

According to [8], the pathology of the building is nothing more than the study of the identification of the problems encountered as well the causes, being developed correction and a diagnosis. In accordance with [9], the pathology is the study of causes and symptoms, the origins of the civil construction effects, so being a study of the steps involved in the diagnosis of the problem raised.

The pathologies of wood are the result of using in unacceptable states and loss of resistant capacity, which can

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occur by three actions: human, natural or accidental [10].

The causes of pathologies originating from human actions can be classified into three phases:

a) Phase Conception and Project: poorly designed, incorrect calculations and incomplete list of materials;
b) Construction Phase: poor quality of materials, poor project execution and lack of technical skills;
c) Phase of Use: absence of geometry, unsuitable or absent maintenance and modification of the conditions of use.

Pathologies arising from natural actions are caused mainly by natural and deteriorative agents defects. The deterioration coming from the natural defects (irregular grain, presence of knots, reaction wood, false hardwood, ring crevices and pockets of resin) is directly related to the type of species and also in the form of growth. According to [11], about the deteriorative agents of wood, are divided into two groups, namely, the abiotic agents and biotic. These agents can cause from simple change of color to reduction of physical and mechanical wood properties, which can compromise the architectural and structural performance of the pieces. Abiotic agents can be divided into mechanical (abrasion effect), physical (fire), chemicals (chemical substances) and climate (humidity, temperature, solar radiation and wind), while agents of biological origin (biotic agents) are considered the main deteriorative of wood, [12]. The main organisms that attack wood are decay fungi, drills and termites, [11].

The types of pathologies caused by accidental actions are highly variable and depend on the intensity of their cause. In this case, are cited fires, earthquakes, explosions, floods and shocks.

In addition to the topics mentioned above, also arise pathologies in wooden structures, related to lack of periodic maintenance and, in face of this, the structures can achieve the serviceability limit states (excessive deformation) and last (rupture - structural elements and connections; global instability and local), being necessary the partial or complete repairs to structures [13-15].

Thus, it is understood that the periodic preparation of a diagnosis of the conservation status becomes necessary, for intervention proposals (prognostic) be prepared in proactive way [16, 17].

It is well known case, preservation is all set providences that may give the wood resistance to deterioration agents, conditioning greater durability. According to Law No. 4,797 of 1965 and the joint normative instructions IBAMA and National Agency of Surveillance (ANVISA) the wood preservative treatment is mandatory for wooden structures under conditions that contribute to the reduction of its useful life. According to [11], the preservative treatments are mainly intended to protect any wooden pieces against possible decay actions, whether they arising from natural phenomena (biotic or abiotic) or physico-chemical phenomena.

To prevent the proliferation of wood-destroying organisms, can be adopted some wood preservation techniques, as the natural preservation, indirect, biological and chemical. Therefore, it is public knowledge that some species are more susceptible to wood-destroying organisms attacks, requiring some care to prevent the biological demand. Among them, the chemical preservation stands out as being the most efficient method against deterioration of wood [3, 18, 19, 20]. Based on the literature, the preservation method through of using chemicals in the preventive treatment (pre-treatment, homemade process (without vacuum / pressure), industrial processes (vacuum / pressure)) and dressing is the most suitable. Such treatments are well discussed by [11].

In the middle of this scenario, the study by proposed case was held in the Central-West region of Brazil, State of Mato Grosso, in the city of Sinop, specifically covering structure of Sinop Forest Park (11º50′5.5” S; 55º30′4.2” W). The main objective was to identify and to diagnose the nature and types of causative agents of pathologies instituted in the structure under study and, subsequently, to suggest appropriate methods curative and preventive (prognosis) to promote an increase in lifetime of the structure.

From there, it is expected that in the near future, this study effectively contribute to the reduction of instituted pathologies, and, promote the dissemination and internalization of applying concepts of prevention methods to structures.

2. Material and Methods

For the execution of this work were used some materials, so much in the literature review, as well as in field of steps. In the literature review had as sources, the collection of the State University of Mato Grosso and the web, like, monographs, books, theses and articles. Besides these, a 18 megapixel camera Sony semi-professional was used and another equipment’s (ladder, tape measure, bubble level, props, etc.).

Wooden structures require careful and frequent maintenance. When it comes to the time to carry out further actions of rehabilitation, of buildings, in methodological terms, the greatest difficulty lies in the decision to restore, rehabilitate or replace the original solution by a new most appropriate solution to the use.

Hence, in this study it was necessary to subdivision into three parts. At first, an inspection was carried out on the coverage structure. In the second part, the diagnosis was studied (causes of pathology) and, in the third, the prognosis (forms of maintenance and recovery) was developed.

The inspection of the coverage structures occurred in December 2014. Through this stage, it was possible to determine the position of structures in relation to possible pathologies. The inspection occurred according to the following steps:

a) Elaboration of a record of history, of the environment and structure, by visiting the work and checking the

documentation: the company has no executive projects of the coverage structure and, thus, it was not allowed the identification, indirectly, of geometric parameters and the specie wood used. In this way, all the dimensions of the building, well as structural pieces were in loco measures. Furthermore, wood species identification employed in the structure was performed with the support of cataloged records of wood species of the Institute of Technological Research (IPT);

b) Inspection (visual and photographic) of the structure: visual analyzes were performed in loco in the latticed structures, in the structural components of wood and connections of structural pieces (performed with metal parts). Also, it was evaluated the general conditions of structure, in other words, the mounting details, stability and deformation of the elements, deteriorating conditions in use of the structure, among others.

At this stage, was held on the interpretation of each mapped case, determining the causes (origin) and effects (consequences) of pathologies.

After the diagnosis of pathologies, were defined forms of maintenance, restoration and replacement to be adopted in each case, through from the survey of evolution assumptions of the problem. For the determination of the prognosis it was adopted the following procedures:

a) Type of pathology;
b) Level of evolution of pathology;
c) Exposure conditions.

From the elaboration of the prognosis, it was analyzed the intervention alternatives together with pathological problems, in the following manner:

a) Eradicating the disease;
b) Prevent or control its evolution;
c) Replace partially or totally the wooden pieces and connectors.

3. Results and Discussion

The result of this work is guided in the assessment, identification of the causes of diseases instituted and the preventive and curative solutions thereof, through interventions in a wooden structure, address all the elements that compose it.

As from the visual inspection, were observed the following constructive features of the evaluated structure:

a) Species used: Itaúba - Mezilaurus Itauba (Meisn);
b) Roof type: Ceramic;
c) Type of structure: lattice type "Howe", with 23° of inclination, composed of chord (upper and lower), diagonal and studs, with the vertical and horizontal shares transferred to the foundation through of the pillars;
d) Building dimensions: plant of 14m (width) × 32,5m (length);
e) Spacing between lattices: 2.5m;
f) Transverse dimensions of the structural elements: slats: 2,5×5,0 cm²; rafters: 5,0×6,0 cm²; purlins: 5,0×15,0 cm²; diagonal: 5,0×10,0 cm²; central stud: 5,0×15,0 cm²; other studs: 2 pieces 2,5×15,0 cm²; chord (upper/lower): 5,0×15,0 cm²;
g) Length of the structural elements (Figure 1);
h) Connections: metal hook (between central stud and inferior chord); nails (among other studs and chords); notch (between diagonal and chords); sheet metal and through-bolts (amendments of the chords);
i) Bracing Structure: rafters of 5.0×6.0 cm², executed in vertical planes "X" joining the knots of the chords (upper/lower) among all latticed structures.

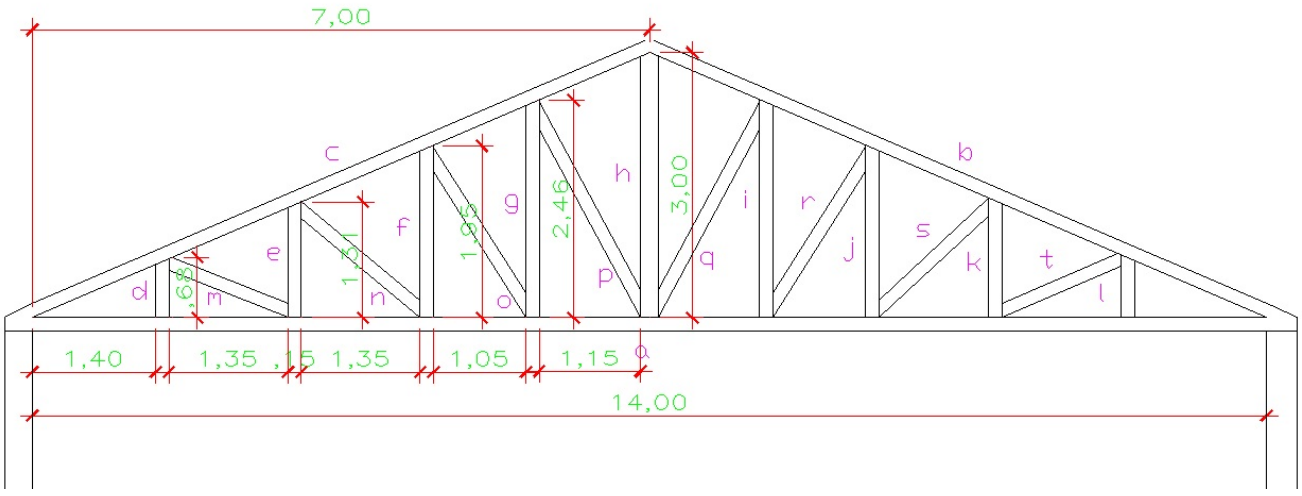

Figure 1. Geometry of the lattice (schematic)

Then, it was verified that, globally and locally, the structure is compromised; as described below. The diagnosis (causes) and prognosis (suggested actions) should be performed for the occurrence of the improvement of facilities:

a) Case 01 - Deterioration by termites:

Inspection: deterioration by biotic agents - wood decay organisms (termites).

Diagnosis: pieces (rafters, girders and lattice bars) damaged by termites, due to lack of periodic preventive maintenance (fig. 2).

Prognosis: to deteriorated pieces, as shown in the fig. 2, it is necessary to provide the replacement, because the remaining cross section becomes insufficient to withstand internal forces. For the other pieces in the initial stage of deterioration, when established that the piece of the cross section is sufficient to withstand internal forces, does the treatment as from the removing the decayed wood and cleaning the place and, then, applies the chemical (based on water) through brushing process or product introduction (galleries) with injector nozzle, as prescribed in [21].

Figure 2. Pieces (rafters, girders and lattice bars) degraded by the action of termites

b) Case 02 - Deterioration by attack of decay fungus:

Inspection: deterioration by biotic agents - wood decay organisms (decay fungus) and consequent rupture.

Diagnosis: pieces (girders, lattice bars and pillars) damaged by decay fungi attack, due to the accumulation of moisture and lack of periodic preventive maintenance and, consequently rupture by traction, due to reduction of cross section resistant (Figure 3).

Prognosis: for the damaged piece, as shown in the photo of Fig. 3a (lattice bar), must be provided the replacement in view of rupture thereof. For the other pieces, without continuous contact with moisture and early stage of decay, when established that the cross section of the piece is sufficient to withstand internal forces, it is advisable to cleanliness of the place and then treatment with application of chemical (based on synthetic pyrethroid and carbamate) through brushing process, as prescribed by [21].

For the case presented in Figure. 3 (base of column) can be applied the same procedure, however, initially, it should be removed the soil in contact with the wood base, to be able check the level of deterioration of the element under study, well as, if the remaining cross section can absorb the acting forces. In this case, knowing that such elements (columns) will be exposed to view of local patrons and, for aesthetic reasons, it is recommended to replace them. Reinstalling should be conducted with treated wood [21] and positioned to avoid direct contact with the ground.

Figure 3. Pieces (girders, lattice bars and pillars) degraded by action of decay fungus

c) Case 03 - Connection between bars of the chords:

Inspection: rupture of the connections.

Diagnosis: *a)* according to Figure 4, there was rupture of connection between the bars of the chords (upper/lower) due deterioration caused by attack of decay fungus (moisture accumulation and no periodic preventive maintenance), as well as the lack of dimensioning of the connections [21]; in fig. 4b, there is connection rupture between the bar of the lower chord due to the high shear stress parallel to the fibers acting on the tooth/notch and to the embedding in wood caused by the insufficient number of metal pins.

Prognosis: For the damaged piece, as shown in the photo of Figure. 4 (lattice bar) must be provided the replacement in view of wear thereof. The reconstruction of the connections between the bars of the chords should be performed with the use of wood connecting plates positioned on the lateral faces and with the use of metal pins (screws or nails), properly sized according to requirements of [21] - Item 8. Due to the high relative humidity of room air, it is recommended the use of metal pins with corrosion protection.

Figure 4. Connections - regions of support and middle of the span

d) Case 04 - Rupture of the structural elements (lattice bar/columns):

Inspection: rupture of the structural elements.

Diagnosis: *a)* according to Figure 5, the rupture due traction was verified, the bar of chord (tractioned) because of deterioration by decay fungi attack (moisture accumulation and lack of periodic preventive maintenance). In the same figure, it was observed cracking of the vertical bar (stud) as a consequence of the rupture of the lower chord bar and excessive vertical deformation of the structure; b) in Figure 5, it was noted in the pillar, a vertical crack (cracking) probably, originated from the implementation of notch and accelerated loss of wood moisture.

Prognosis: For pieces in a state of ruin of the lattice bar, must be provided the replacement of it. Regarding the pillar, there is three considerations to be made: *1st) About the preservation*: It is recommended the internal handling of the crack, with initial cleaning by air jet and, then, apply water-repellent products (fungicides and insecticides); *2nd) About the structure*: after checked that the cross section is resistant to the action of acting forces and, with completed the first step, the procedure is reconstitution (crack closure) through the use of through-bolts positioned perpendicular to the crack. By aesthetic reasons, the "head" the bolt and the nut and washers were embedded in the faces of the pillar; 3rd) *About aesthetics*: It is recommended the surface treatment, by cleaning and plastic mass of manual application and, thereafter, the surface finish is made (sanding, painting).

Figure 5. Structural elements in ruin (lattice bars and columns)

e) Case 05 - Local instability of the bars of the main structure:

Inspection: instability of structural elements (the bars of

upper chord).

Diagnosis: It was found that the bars of upper chord (b, c), diagonals (o, p, q, r) and the central stud (h), do not attend the requirements of [21] - Items 7.5 and 10.3, relating to local stability.

Prognosis: For the pieces mentioned, it is recommended the following adjustment (increase) of the cross section: a) superior chord, "T-type", and the "soul" of 5cm × 15cm (existing) and "table" of 2.5cm ×15cm (board to add); b) central stud, "I-type", and the "soul" of 5cm × 10cm (existing) and "upper and lower tables" of 2.5cm × 10cm (boards to add); c) diagonals: "T-type", and the "soul" of 5cm x 10cm (existing) and "table" of 2.5cm x 15cm (board to add). The parts component of the table and the soul are interconnected by threaded screws with a spacing of 10 cm, along the length.

f) Case 06 - Global Instability:

Figure 6. Vertical bracing system

Inspection: Global Instability of lattices.

Diagnosis: It was observed that the connections between the vertical bars of bracing system and the lattices were connected improperly, through metal pins (nails) (Figure 6), causing lateral instability of the lattices. It was also checked that the inclined pieces (tractioned) that comprise the vertical upwind system does not meet the requirements of [21] - Items 10.3, referring to local stability.

Prognosis: To promote lateral stability of lattices, it is recommended to locking the lattice on the supports, well as the substitution of the current bracing system (in wood), by other, distributed over the roof planes and the inferior chord bars. The foreground is composed of metal lifters (diam. 12.5 mm), forming the setting "X" and joining knots of the upper chords of adjacent lattices, comprised between two lines of consecutive girders. The second, forming a horizontal plane at the level of the lower bars of chords, composed by metal lifters (diam. 12.5 mm) positioned perpendicular to the lattices, joining knots homologous of adjacent lattices. These systems will be arranged at the end of spans of the shed, well as in the intermediate, spaced every two spans. Particularly, in the end of spans, in the horizontal plane, the metal lifters will be replaced by rigid pieces of wood (cross section "T-type", and the "soul" of 5cm × 10cm and "table" × 2.5cm 15cm) and, among them will be installed metallic lifters (diam. 12.5 mm), forming the configuration "X" and joining knots of the lower chords of two adjacent lattices. All metal lifters should be installed with "stretchers".

g) Case 07 - excessive vertical displacement:

Figure 7. Bracing vertical system

Inspection: excessive deformation of the lattice.

Diagnosis: It was observed that several lattices are with excessive vertical displacement, not answering the requirements of [21] - Item 9, and this fact is the result of several factors such as: low stiffness of the lattice and

structural elements; excessive deformation of the connections of support and of the middle span. Excessive displacement caused the loss of verticality of extreme studs, as well as disconnection of some diagonals (Figure 7).

Prognosis: To reduce the vertical displacement to acceptable levels, according to the normative document cited, two procedures are recommended: 1st) Adjust the connections between the bars of the chords (previously mentioned); 2 st) Increase the cross sections of the bars of the chords (upper and lower) of the lattice; 3) Apply inverted displacement in the central knot of the lattice.

In summary it is recommended to performing periodic preventive maintenance in the coverage structure (wood and connection), minimizing the susceptibility of the establishment of pathologies that favor more rapid deterioration of the structure. Therefore, based on the use and the environment in which the structure is inserted, it is recommended preventive maintenance at intervals of 3 to 5 years.

4. Conclusions

After visual analysis/ technical of coverage structure, it is concluded that:

- There were deterioration of wood pieces (lattice bars; girders; pillars) by biological agents (termite and decay fungus), with the necessity of replacement of the parts;
- There was a rupture of lattice bars for traction and shear / cracking;
- There was rupture / plastic deformation of the connections between bars of the chords;
- There was loss of global stability of some lattices, in the face of misunderstanding in the design and implementation of bracing system;
- The local instability, referring to some lattice bars (upper chord, central stud and diagonal), do not attend the requirements of [21];
- There was excessive vertical displacement of the lattice.

However, it is noteworthy that several lattices can be reused, if adopted corrective actions mentioned here. With this, it is expected that this study will effectively contribute to reducing of pathologies, as well as promote the dissemination and internalization of concepts of application of the calculation methods and prevention to structures.

REFERENCES

[1] Logsdon, N. B.; Calil Junior, C. (2002) Influência da Umidade nas Propriedades de Resistência e Rigidez da Madeira. Cadernos de Engenharia de Estruturas, n. 18, p. 77-107.

[2] Silveira, L. H. C.; Rezende, A. V.; Vale, A. T. (2013) Teor de Umidade e Densidade Básica da Madeira de Nove Espécies Comerciais Amazônicas. Acta Amazônica, v. 43, n. 2, p. 179-184.

[3] Pinheiro, R. V. (2001) Influência da Preservação Contra a Demanda Biológica em Propriedades de Resistência e de Elasticidade da Madeira. Tese de Doutorado Apresentada a Escola de Engenharia de São Carlos, da Universidade de São Paulo, 187p.

[4] Paes, J. B.; Morais, V. M.; Lima, C. R. Resistência Natural de Nove Madeiras do Semiárido Brasileiro a Fungos Causadores de Podridão Mole. Revista Árvore, v. 29, n. 3, p. 365-371.

[5] Costa, M. A. (2009) .Avaliação de Metodologias Alternativas Para Caracterização do ataque de Fungos Apodrecedores de Madeira. Brasília, DF, 2009. 83 f. Dissertação (Mestrado em Engenharia Florestal) – Escola de Engenharia, Universidade de Brasília, Brasília.

[6] Ridout, B. (2009) Timber Decay in Buildings: the conservation approach to treatment. London: English Heritage.

[7] Tutikian, B. Pacheco, M. (2013) Inspeção, Diagnóstico e Prognóstico na Construção Civil. Boletim Técnico. México, 17p.

[8] Verçosa, E. J. (1991) Patologia das edificações. Porto Alegre: Sagra.

[9] Helene, P. R. L. (1992) Manual para reparo, reforço e proteção de estruturas de concreto. 2 ª ed. São Paulo: Pini.

[10] Branco, F. Brito, J. (2007) Diagnóstico e Patologia de Construções em Madeira. IST – Instituto Superior Técnico, 143p.

[11] Lepage, E.S. et al. (1986) Manual de preservação de madeiras. São Paulo, IPT.

[12] Cavalcante, M. S. (1982) Deterioração biológica e preservação de madeiras. São Paulo, IPT, Divisão de Madeiras - Pesquisa & Desenvolvimento, n.8.

[13] Sartorti, A. L. (2008) Identificação de Patologias em Pontes de Vias Urbanas e Rurais no Munícipio de Campinas-SP. Campinas, 2008. 240 f. Dissertação (Mestrado em Engenharia Civil) – Faculdade de Engenharia Civil, Arquitetura e Urbanismo, Universidade Estadual de Campinas, Campinas.

[14] Milani, C. J.; Kripka, M. A. (2005) Identificação de Patologias em Pontes de Madeira: diagnóstico realizado no sistema viário do município de Pato Branco - Paraná. Revista Eletrônica de Engenharia Civil, v. 4, n. 1, p. 23-33, 2012.

[15] Carvalho, S. S. et al. (2012) Experimental Evaluation of the Employment of a Laminated Composite material with sisal fibers as reinforcement in timber beams. International Journal of Composite Material, v. 2, p. 97-100.

[16] Cruz, H; Machado, J. S; Nunes, L. (2000) Inspeção e avaliação de estruturas de madeira. Seminário sobre Estruturas de Madeira, Reabilitação e Inovação. Organizado por GECoRPA. LNEC. pp14-28.

[17] Boschetti, Walter T. E Barbosa, Aparecida, A. (2010) A madeira e a tradição construtiva capixaba no século XIX. In: II Seminário de Patrimônio Agroindustrial Lugares de memória. São Carlos – SP. Anais... São Carlos – SP, 1 CD-ROOM.

[18] Calil Neto, C. (2011) Madeira Laminada Colada (MLC):

controle de qualidade em combinações espécie-adesivo-tratamento preservativo. São Carlos, 2011. 120 f. Dissertação (Mestrado em Ciência e Engenharia de Materiais) – Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos.

[19] Vivian, M. A. et al. (2012) Qualidade do Tratamento Preservativo em Autoclave Para a Madeira de Eucalyptus grandis e Eucalyptus cloeziana. Scientia Forestalis, v. 40, n. 96, p. 445-453.

[20] Bertolini, M. S. et al. (2013) Accelerated Artificial Aging of Particleboards from Residues of CCB Treated Pinus sp. and Castor Oil Resin. Materials Research, São Carlos, v. 16, n. 2, p. 293-303.

[21] Associação Brasileira de Normas Técnicas. NBR 16143. (2013) Preservação de Madeiras – Sistemas de Categoria de Uso, Rio de Janeiro.

[22] Associação Brasileira de Normas Técnicas. NBR 7190. (1997) Projeto de Estruturas de Madeira, Rio de Janeiro, 107p.