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Development of a post-occupancy assessment method system to evaluate the durability of external cladding of prefabricated timber panels

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Abstract. The global environmental crisis has increased interest in sustainability within the construction sector. Timber construction is a viable option, but concerns about its short- and long-term durability still need to be addressed. This article presents a developed Assessment Method System for evaluating the durability of external cladding of prefabricated timber panels. First, an Assessment Form was created to map and catalogue the panels' state of conservation based on on-site observations. The form includes an evaluation worksheet that lists and classifies the frequency and intensity of six defects: 1) Rotted Parts; 2) Detachments; 3) presence of Wood Knots; 4) Cracks and/or Broken Parts; 5) Wood planks; and 6) Sill Failure. On-site observations were conducted in case studies to complete the Assessment Form and document the condition of the specific building's timber panels. The collected data were then tabulated and used as a basis for the panel's durability diagnosis. Comparative studies were then carried out between five case studies to validate the Assessment Method System. As a result, the work highlights aspects, such as material, design, and execution, of the durability of timber wall panels built in specific conditions. In that sense, the Assessment Method was a fundamental tool to stress how these aspects were carried out. In addition, this can enhance the scientific basis of timber architecture and aid architects and researchers in making informed decisions regarding optimising future timber projects.

1. Introduction

The construction sector is widely known for its profound environmental impact, mainly due to the production chains involved in its operating cycle, such as the extraction of non-renewable raw materials, industrial processes with high energetic consumption, high carbon emission rates and unmeasured generation of waste, according to the United Nations Environmental Programme (2020) [7]. Due to this, there is a growing need for the actors involved in the construction sector to investigate and propose solutions to mitigate this environmental impact, whether by reducing greenhouse gas emissions or finding ways to sequester and store these gases.

In this context, timber construction is a viable option for both solutions. The carbon emissions of the material are lower when compared to traditional construction materials. According to the Canadian

Wood Council (1999) [2], timber constructions have 75% less carbon emission rates than steel and 90% less when compared with concrete. Although it is important to build with low-carbon materials - such as timber - it is just as important to be concerned about its short-term and long-term durability. Therefore, developing appropriate material evaluation methods is essential to achieve a truly sustainable construction. This concern is significant because timber buildings are increasingly being built.

This article presents the Assessment Method System (AMS), developed to evaluate the durability of external cladding of prefabricated timber panels. AMS was applied to five real case studies built with reforestation wood between 1994 and 2002 in Brazil. It is important to note that only the external side was evaluated, as there was no evidence of defects in the structure or internal layers, and the panels could not be dismantled during the visitation.

2. Objectives and methods

The Assessment Method System presented in this article was based in the work of Groat and Wang (2013) [5] and has a qualitative approach - whose tactics will be further presented for each stage - and aims to catalogue the conservation of the external cladding of prefabricated timber panels. The article attempts to address a gap in the literature regarding assessment methods for the durability of timber construction materials after construction.

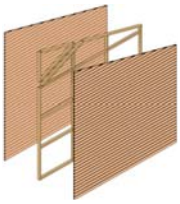
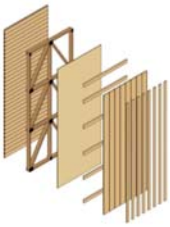
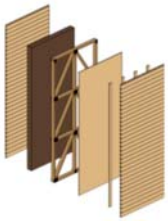
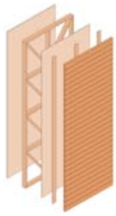
The AMS was developed in three main steps. Firstly, literature (1) was analysed to define the assessment criteria and determine the data required to investigate the panels' durability. After collecting and selecting the data scope, an analysis plan (2) was created based on Arakaki's work (2000) [1]. This review enables the creation of a tool that considers applying and adapting theoretical knowledge from literature in field studies. Field studies (3) were conducted on target buildings to validate the AMS. The data collected during these on-site visits was organised and systematised, allowing individual analysis (4) of each external cladding panel. Finally, a complete comparative study (5) was carried out to investigate the relevant points observed in each panel and analyse whether the proposed AMS structure was coherent. The literature review was also crucial in gathering data on the case study panels' design, project and construction.

3. Development and Results

1) Literature review: The data collected to analyse the buildings included the project context, construction process, materials, and subsystem strategies. Table 1 displays this information. Considering the case studies, this information was mainly searched in previous articles and research of the HABIS Group, which was responsible for the project and construction of the evaluated panels. For the evaluation criteria, the primary references of information were extracted from the work of Galinari (2003) [4], Yuba, Ino; Shimbo (1998) [8] and Ino; Shimbo (1998) [6].

When considering post-occupancy analysis and the necessary theoretical references, focusing on performance criteria, construction system durability, and relevant studies on external cladding panels was critical. The methodology developed by Arakaki (2000) [1] was the primary reference used. It considers product performance based on the fact that a product must have specific characteristics to fulfil its function under certain conditions. In the case of buildings, they must satisfy the needs of their users, taking into account their exposure conditions. It was essential to define the requirements and criteria used to evaluate performance.

Table 1. Case Studies Overview

Building (year)	Horto (1996)	Mananciais (1998)	002 - Habis (1999)	001 – Nomads (1999)	Imaflora (2002)
Picture					
Panel					
Wood species	Pinus	Pinus	Pinus	Pinus	Eucalyptus
External layer	Male-female panelling	Male-female panelling	Board-and-batten pieces	Trapezoidal panelling	Trapezoidal panelling
Treatment	Varnish	CCA	Insecticide	Insecticide	CCA
Filling layer	Air	Air	Air	1st: Expanded clay 2nd: Glass wool 3rd: Air	Air
Maintenance	no	no	no	Painting and stain (2006 and 2011)	Sanding and stain every 2 years
Eaves	75 cm	60 cm	no	70 cm	no

2) Analysis planning: An evaluation worksheet (Assessment Form) was created to facilitate the durability and performance of the prefabricated timber panels. The Assessment Form was used to catalogue the panels' state of conservation during site observations by completing the worksheet. The frequency and intensity of six defects were listed and classified: 1) Rotted parts; 2) Detachments; 3) presence of Wood knots; 4) Cracks and/or Broken parts; 5) Wood planks; and 6) Sill failure. Examples of each defect analysed are presented in Figures 1 to 6. Those aspects were approached and measured visually and tactilely.

Figure 1. Example of rotted parts

Figure 2. Example of detachments

Figure 3. Example of wood knots

Figure 4. Example of cracks

Figure 5. Example of wood planks

Figure 6. Example of sill failure

The evaluation of the frequency was quantified from A to D:

A. No piece was affected;
B. Up to 10% of the pieces were affected;
C. 10% to 50% of the pieces were affected;
D. More than 50% of the pieces were affected by the defect.

The evaluation of the intensity was qualified from 1 to 4:

1. Pieces that did not present any defect;
2. The defect that does not compromise the piece;
3. The defect that compromises part of the piece;
4. The defect that compromises the whole piece.

3) Field studies: On-site visits were conducted to complete the Assessment Form and record the state of conservation of the building's external cladding panels. It's important to highlight that each of the five field studies was led by a specific researcher for each case study, accompanied by at least one additional assistant. This approach not only facilitated technical activities but also ensured comprehensive support for discussions and inquiries pertaining to the analysis. Moreover, targeting five different researchers to test and apply the method across the case studies, was aimed at enhanced validation of the assessment tool and greater consistency in analyzing the results. The procedures adopted in this phase included visual inspection, photographic registration and measurement of deterioration points. The buildings studied are presented in Figures 7 to 11.

Figure 7: Building 001 – Nomads

Figure 8: Building 002 – HABIS

Figure 9: Building Casa do Horto

Figure 10: Building Imaflora

Figure 11: Building Mananciais

4) Individual analysis: The data collected during site observation were then organised into spreadsheets of the building's performance, and the diagnosis was divided into three stages. First, the performance of each external cladding panel was evaluated individually, generating quantitative data, accompanied by drawings of each facade and the specifications of the layers of each external cladding panel. At this stage's end, a performance diagnosis was carried out, identifying the factors that influenced its durability.

Next are some examples from materials (tables and graphics) developed during the individual analysis, as shown in Tables 02 to 06, and Figures 12 to 16.

Table 02. General Data: 001 - Nomads

Number of modules	12
Total parts	309
Rotted parts	3
Detachments	86
Wood knots	79
Cracks	42
Wood planks	82
Sill failure	0

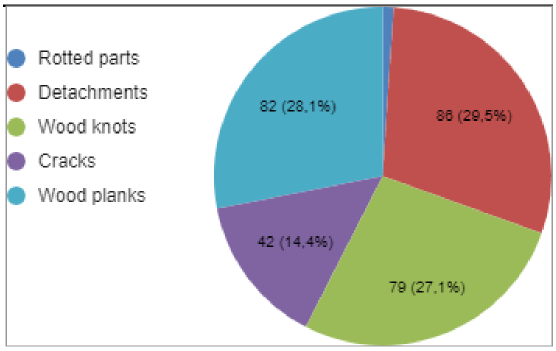


Figure 12. Graphic of the general data (001 – Nomads)

Table 03. General Data: 002 - HABIS

Number of modules	18
Total parts	256
Rotted parts	209
Detachments	145
Wood knots	230
Cracks	167
Wood planks	60
Sill failure	14W

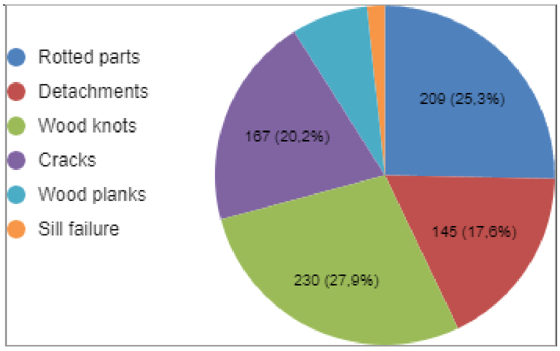


Figure 13. Graphic of the general data (002 – HABIS)

Table 04. General Data: Casa do Horto

Number of modules	10
Total parts	163
Rotted parts	6
Detachments	2
Wood knots	16
Cracks	18
Wood planks	0
Sill failure	1

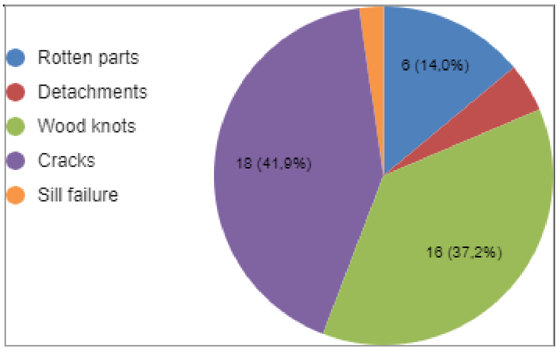


Figure 14. Graphic of the general data (Casa do Horto)

Table 05. General Data: Imaflora

Number of modules	7
Total parts	143
Rotted parts	0
Detachments	3
Wood knots	0
Cracks	33
Woodplanks	0
Sill failure	3

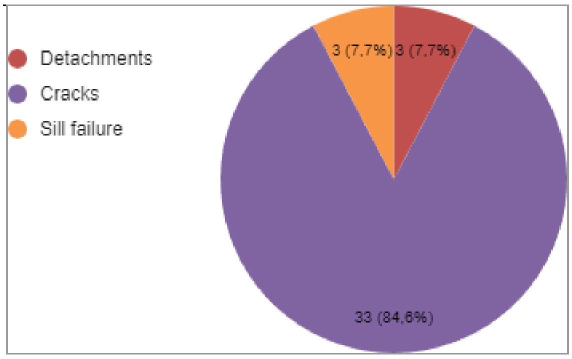


Figure 15. Graphic of the general data (Imaflora)

Table 06. General Data: Mananciais

Number of modules	6
Total parts	412
Rotted parts	23
Detachments	3
Wood knots	103
Cracks	8
Woodplanks	0
Sill failure	0

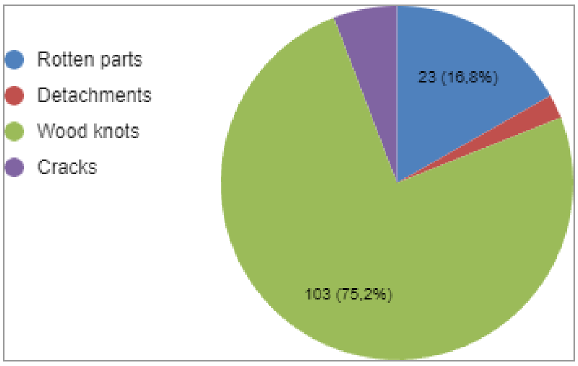


Figure 16. Graphic of the general data (Mananciais)

Throughout the research stage, the analysis focused on understanding the reasons for the occurrence or non-occurrence of the defects listed. During data processing, it was noted that the field survey "Intensity" and "Frequency" classifications were directly associated with the number of affected parts and their degree of deterioration. However, these classifications made the analysis and the comparative study complicated because it was necessary to study a lot of different variants – quantitative and qualitative – which were interesting at first, but to sum up the analysis, were not. Therefore, it was decided to use the percentage of parts affected and the percentage of parts to be replaced in relation to the total of evaluated parts, this way, the whole analysis would be based on percentage, facilitating the data produced.

Moreover, the panels were grouped and compared according to the building's facade solar orientation. This systematisation was done to investigate the influence of solar incidence and other facade attributes on panel performance. For instance, the presence of eaves may affect performance. Finally, we analysed the panels both quantitatively and qualitatively. We used graphs and tables to interpret the data collected in the field and checked photographic records and notes on defects. This mixed approach allowed us to diagnose each panel.

5) The comparative study between the five external cladding panels: Fachin (2006) [3] defines comparative study as the investigation of things or facts by comparing their similarities and differences

through the analysis of concrete data. This confirms diagnoses based on the deduction of similarities and divergences of constant elements, abstract and general. The method was applied to diagnose the five sealing system projects. The aim was to verify similarities and differences in panel performance and relate them to the specificities of design, construction, use, and maintenance of the external cladding panel. This procedure is justified because it compares the results obtained through the analysis of five timber panels, under conditions of similar exposure or not, thus providing a more comprehensive assessment of the range of external timber panels. For example, Tables 07 – 08 and Figure 17 illustrate the data collected and analysed on the rotted parts. Each analysed defect has similar tables and graphics, in order to form a coherent database.

Table 07. Total parts evaluated in all facades of all buildings

Building	Analysed parts (East facade)	Analysed parts (West facade)	Analysed parts (North facade)	Analysed parts (South facade)	Total parts analysed
001 – Nomads	82	82	145	0	309
002 – HABIS	96	72	44	44	256
Casa do Horto	50	38	25	50	163
Imaflora	50	49	21	23	143
Mananciais	52	31	42	81	206

Table 08. Rotted parts from each building

Building	Total parts evaluated	Number of affected parts		Number of parts to be substituted		Affected parts to be substituted
001 – Nomads	309	3	1,0%	3	1,0%	100,0%
002 – HABIS	256	209	81,6%	196	76,6%	93,8%
Casa do Horto	163	7	4,3%	6	3,7%	85,7%
Imaflora	143	0	0,0%	0	0,0%	0,0%
Mananciais	206	23	11,2%	7	3,4%	30,4%

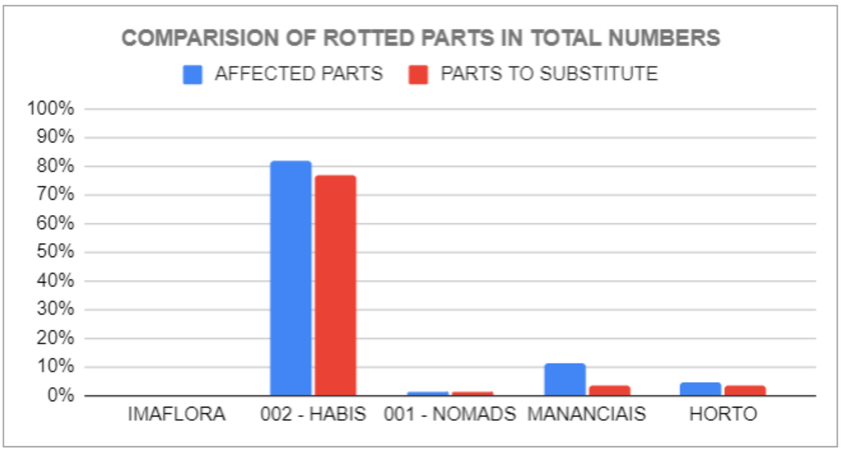


Figure 17. Graphic of the comparision of rotted parts in total numbers

The method developed showed that the construction techniques used significantly affect the durability of external cladding panels. Factors such as the type of wood species used, maintenance routine and frequency, material treatment, solar exposure, presence of eaves, and correct project directions all play a crucial role. It is essential to consider these factors to ensure the longevity of the cladding panels.

Also, it is important to add that, during the development and application of the method, some difficulties were encountered, especially regarding the standardisation of the criteria adopted and the form of assessment of durability of the external panels. This is because the criteria of evaluation was supposed to register the performance of different panels, with their own specificities each. Furthermore, the comprehension of the fragilities and potentials of the assessment method took place gradually, along with the field studies. Therefore, it is recommended that further research using similar methods predict field tests in the building evaluated before carrying out the official field studies, in order to adapt the tool to the specificity of the construction.

4. Conclusion

Considering the current scenario of civil construction, the Assessment Method presented in this article can serve as a fundamental tool to contribute to the scientific framework on the performance of wooden constructions. Therefore, the method was developed based on real constructions to extract conclusions capable of supporting the decision making of planning, building and managing timber constructions. It can also support the decision-making process of researchers interested in optimising timber projects.

It is worth mentioning that this work only evaluated external cladding panels of five experimental buildings built with reforestation wood, all located in São Paulo, Brazil and, on average, with 20 years of construction. To further expand scientific knowledge about long-term behaviour of buildings constructed with low carbon construction technologies, such as timber, a greater scientific production in this field is necessary, such as: studies that evaluate the performance of other subsystems of experimental buildings (floor, structure and roof, for example), studies that evaluate constructions in other regions with different climatic conditions and studies thar evaluate these same buildings after longer periods of time.

Acknowledgments

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