DURABILITY EVALUATION OF WATTLE AND DAUB WALL PANELS: EXPERIMENTAL HOUSING BUILDINGS 001 AND 002 IN SÃO CARLOS - SP

AVALIAÇÃO DA DURABILIDADE DE PAINÉIS DE PAREDES DE PAU A PIQUE: EDIFÍCIOS EXPERIMENTAIS DE HABITAÇÃO 001 E 002 EM SÃO CARLOS - SP

EVALUACIÓN DE LA DURABILIDAD DE PANELES DE PARED DE BAHAREQUE: EDIFICIOS EXPERIMENTALES DE VIVIENDAS 001 Y 002 EN SÃO CARLOS - SP

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ABSTRACT

Between 1998 and 1999, two experimental housing units were built at USP São Carlos (SP) with the aim of researching the use of low-carbon technologies in social housing projects. In both units, prefabricated modular panels were designed and executed in wattle and daub, with a modular base of 75 cm and a height of 2.40 m, using sawn pine as one of their experimental sealing subsystems. This research proposes to evaluate the performance of the panels with a focus on durability, by defining and verifying the fulfillment of performance requirements and criteria, considering design and implementation detail characteristics. This verification is established through the visual identification of pathological manifestations, such as cracks, stains, and detachment on the surface of the panels, using photographs of the facade taken by drone flights.

KEYWORDS

Wattle and Daub; Earth construction; Durability Evaluation

RESUMO

Entre 1998 e 1999, duas unidades habitacionais experimentais foram construídas na USP São Carlos (SP) com o objetivo de pesquisar o uso de tecnologias de baixo carbono em projetos de habitação social. Em ambas as unidades, painéis modulares pré-fabricados foram projetados e executados em pau a pique, com uma base modular de 75 cm e uma altura de 2,40 m, utilizando pinho serrado como um de seus subsistemas experimentais de vedação. Esta pesquisa propõe avaliar o desempenho dos painéis com foco na durabilidade, definindo e verificando o cumprimento de requisitos e critérios de desempenho, considerando características de projeto e detalhes de execução. Essa verificação é estabelecida através da identificação visual de manifestações patológicas, como fissuras, manchas e descolamento na superfície dos painéis, utilizando fotografias da fachada tiradas por voos de drones.

PALAVRAS-CHAVE

Pau a Pique; Construção em terra; Avaliação de Durabilidade

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RESUMEN

Entre 1998 y 1999, se construyeron dos unidades habitacionales experimentales en la USP São Carlos (SP) con el objetivo de investigar el uso de tecnologías de bajo carbono en proyectos de vivienda social. En ambas unidades, se diseñaron y ejecutaron paneles modulares prefabricados de bahareque, con una base modular de 75 cm y una altura de 2,40 m, utilizando pino aserrado como uno de sus subsistemas experimentales de sellado. Esta investigación propone evaluar el rendimiento de los paneles con un enfoque en la durabilidad, definiendo y verificando el cumplimiento de los requisitos y criterios de rendimiento, considerando características de diseño y detalles de ejecución. Esta verificación se establece mediante la identificación visual de manifestaciones patológicas, tales como grietas, manchas y desprendimiento en la superficie de los paneles, utilizando fotografías de la fachada tomadas por vuelos de drones.

PALABRAS CLAVE

Bahareque; Construcción en tierra; Evaluación de Durabilidad

1. INTRODUCTION

Between 1998 and 1999, at the University of São Paulo, São Carlos Campus (SP), two Experimental Housing Units were constructed as part of the research project "Social Housing: Architectural Design and Production of Components in Reforestation Wood and Raw Earth,"funded by FAPESP (Proc. 95/9716-9).

The construction of these buildings aimed to research the use of low-carbon technologies in social housing, focusing on their construction processes and the performance of these systems over time. The two experimental housing units, 001 and 002, respectively (Figure 1), were constructed using a structural system of eucalyptus sawn timber pillars and beams, combined with three types of wall systems: straw clay, wattle and daub, and air cushion.

The wattle and daub, also known as "taipa de mão", "taipa de sopapo" and "pau-a-pique" in Brazil, according to the Ibero-American Network of Architecture and Construction with Earth (PROTERRA), is classified as a "mixed technique." This terminology is used to describe techniques that are characterized by the presence of a structural framework system made of wood or bamboo, which supports the infill and coating of earth (GARZÓN, 2011). As this technique utilizes abundant raw materials, does not produce waste in the absence of industrialized components, requires low energy, and has low carbon emissions during its production (JOAQUIM, 2015), it can be considered environmentally sustainable and a viable alternative for the construction sector. Due to these factors, the mixed technique was one of the construction techniques chosen to be tested in the experimental buildings, utilizing prefabrication processes of modular panels.

As initially proposed in 1995, this article aims to evaluate the durability of the 9 panels applied in Unit 001 and the 18 modular panels used in Unit 002, both employing the mixed technique.

2. METHODOLOGY

The methodology used was adapted from Souza (1981) and followed these steps:

a) Identification of User Requirements; Qualitative performance requirements and Quantitative performance criteria to be met;

b) Characterization of the buildings and their design conditions;

c) Characterization of the exposure conditions;

d) Development of spreadsheets for identifying pathological manifestations and analyzing their possible causes;

e) Performance evaluation with verification of compliance with the established requirements and criteria.

Figure 1: Experimental Housing Units 001 (Left - East view) and 002 (Right - West view)
Source: Elaborated by the Authors (2022)

2.1 Identification of performance parameters to be met

Among the various user requirements applicable to buildings listed by ISO/DO 6241, which serve as the basis for performance evaluation in SOUZA's (1981) method, the requirement defined for the present research was Durability Requirements.

To evaluate the durability of the mixed technique panels in the two buildings, qualitative requirements and quantitative criteria were defined. The established requirements focus on the integrity of the coating, where the presence of gaps between the panels and the main wooden structure and detachment of plaster exposing the internal structure of the framework are unacceptable. The acceptable criterion for the presence of cracks is that they must be less than 1mm in width.

2.2 Characterization of the buildings and their design conditions

To understand the performance of the buildings over their lifespan, it is necessary to list the set of actions that act upon them and how these relate to their specific design characteristics. For construction techniques involving raw earth, construction practices that address issues such as protection against weather conditions and site-specific characteristics related to moisture and sun exposition are essential to ensure that the buildings maintain their functionality and durability after occupation (LOPES, 1998). The relevant data were collected from technical visits, alongside the continuous reading and review of research reports prepared between 1996 and 2000 for FAPESP (Proc. 95/9716-9), which describe in detail the construction stages, establishing the characterization of the buildings, their design, and exposure conditions.

The mixed technique was used in both Housing Units through prefabricated panels. In Unit 001, panels measuring 3.00 x 2.40m and 1.50 x 2.40m, from pillar to pillar, were tested, with the interface (panel-pillar) filled with castor oil resin (Figure 2). In Unit 002, four modular panels measuring 0.75 x 2.40m were used to fill the 3m span. The interface (panel-pillar and panel-panel) with a dry joint was resolved by placing joint covers (2.5 x 5.0 cm) in wooden slats (Figure 3).

2.3 Characterization of the exposure conditions

Regarding the climatic conditions to which the mixed technique panels are subjected, it's possible to see in In Figure 4, that the yellow panels (001) have their faces oriented towards the East, West, and South. The blue panels (002), on the other hand, are oriented towards the North, South, and West, receiving sunlight in the afternoon and being exposed to greater temperature fluctuations throughout the day

Figure 5 refers to the average rainfall index of the city of São Carlos throughout the year, with a notable increase in rainfall between November and February.

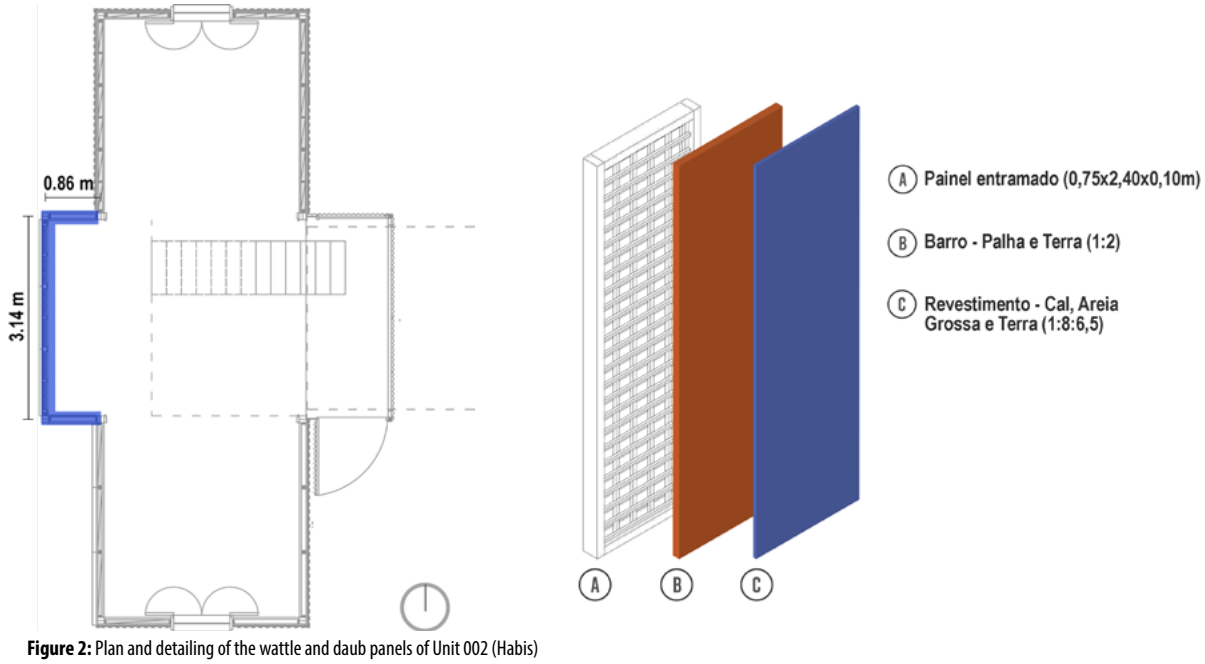


Figure 2: Plan and detailing of the wattle and daub panels of Unit 002 (Habis)
Source: elaborated by the Authors (2022)

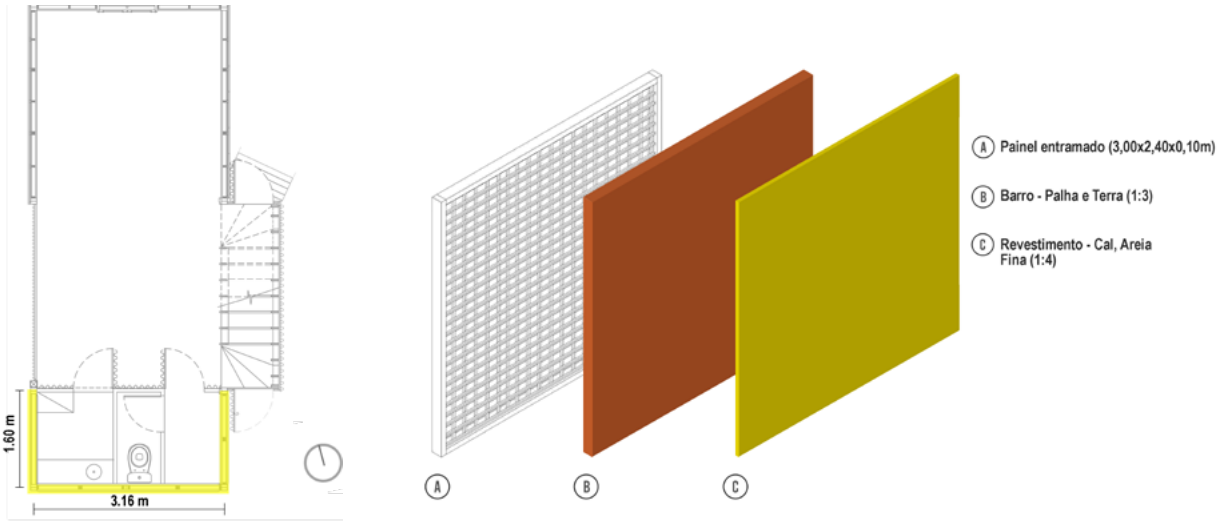


Figure 3: Plan and detailing of the wattle and daub panels of Unit 001 (Nomads)
Source: elaborated by the Authors (2022)

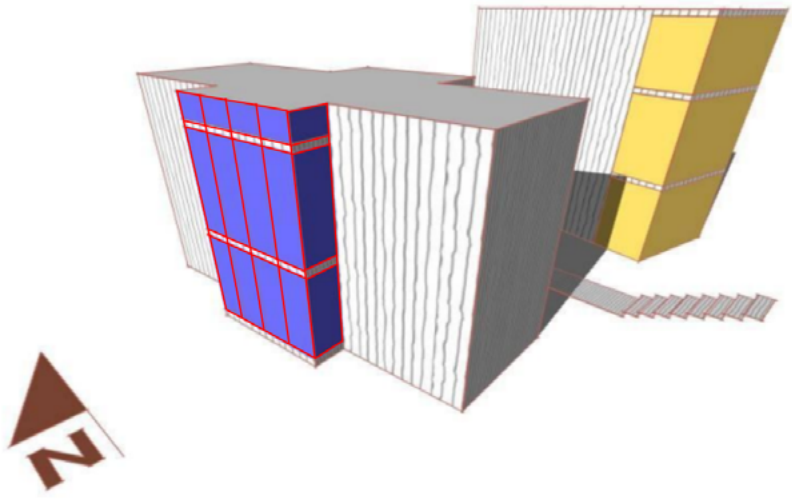


Figure 4: Orientation of the wattle and daub panels: UE1 (yellow) and UE2 (blue)
Source: (adapted in 2023 from Maia et al., 2009)

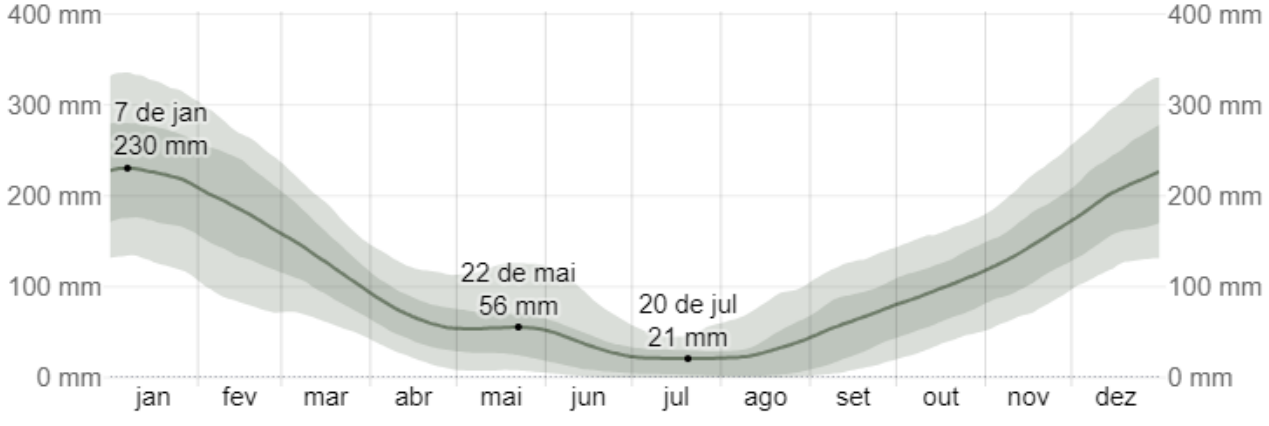


Figure 5: Average rainfall of the city of São Carlos, Brazil.
Source: Weathersparks (2024)

2.4 Identification of the pathological manifestations

The verification of the criteria and requirements is conducted through a visual analysis of pathological manifestations, including cracks, stains, and detachments. For this purpose, the "Dji Mavic Air 2" drone (Figure 4) was used to capture photographs of the facades of both buildings. Since the goal was to create a high-resolution photogrammetric 3D model of the buildings that could capture the smallest details on the facades, a total of 282 photographs were taken for Unit 001 and 269 for Unit 002.

The photogrammetry was carried out using the point cloud processing software Agisoft Metashape Pro (Figure 5) and was later edited in the Cloud Compare software (Figure 5) at the Digital Design Laboratory of the Institute of Architecture and Urbanism (IAU-USP).

Figure 6: Drone Mavic Air 2 capturing the façades of Unit 001 (Left), Photo captured (Right).
Source: Elaborated by the Authors (2022)

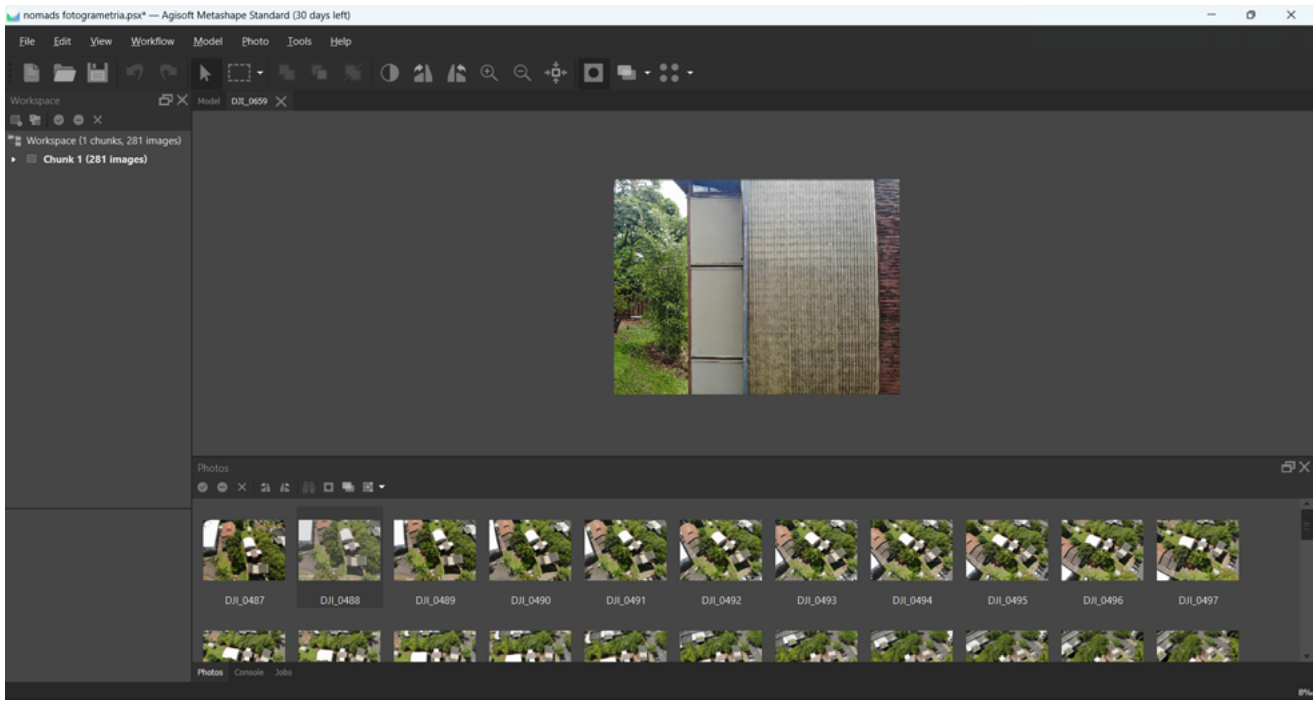


Figure 7: Interface of the Agisoft Metashape Pro point cloud processing software
Source: Elaborated by the Authors (2022)

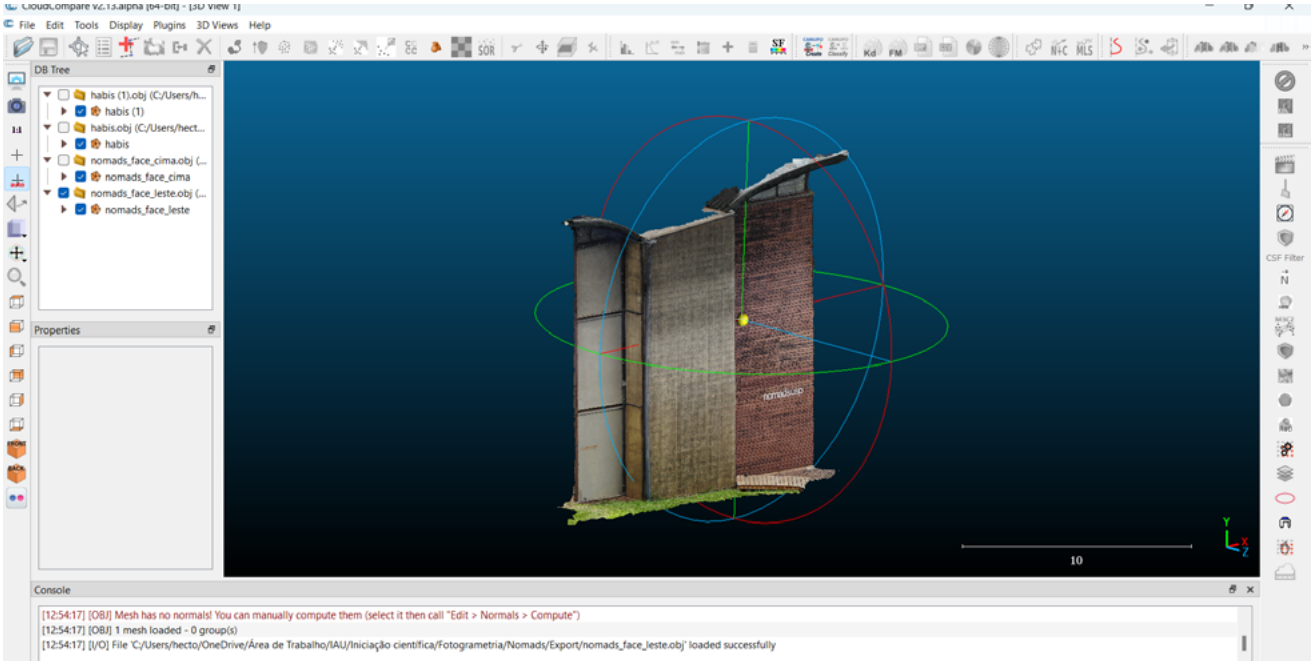


Figure 8: Three-dimensional model of the East face of 001 in Cloud Compare software.

Source: Elaborated by the Authors (2022)

Figure 9: Process of overlaying technical drawings and photogrammetry for pathology identification.

Source: Elaborated by the Authors (2022)

After exporting the facade images from the photogrammetry software, technicalelevation drawings of each building were superimposed to identify pathologicalmanifestations in each panel of mixed technique (Figure 6).

For the preparation of the Performance Evaluation Worksheet, for the identification ofthe pathological manifestations in the panels, the coding PXNY was created:

- **P:** represents the type of pathological manifestation identified, with Fissures (F) and Detachments (D).
- **X:** corresponds to the initials of the cardinal directions: North (N), South (S), East (L), and West (O).
- **N:** is the increasing numerical enumeration of the panels on each face, going from top to bottom.
- **Y:** is the alphabetical code (A, B, C...) assigned to each pathology from top to bottom.

Finally, a spreadsheet was developed with the identified pathological manifestations observed during the research, along with all collected data on site implementation and project details. Each panel was then subjected to a verification and classification process based on whether it met the defined requirements and criteria.

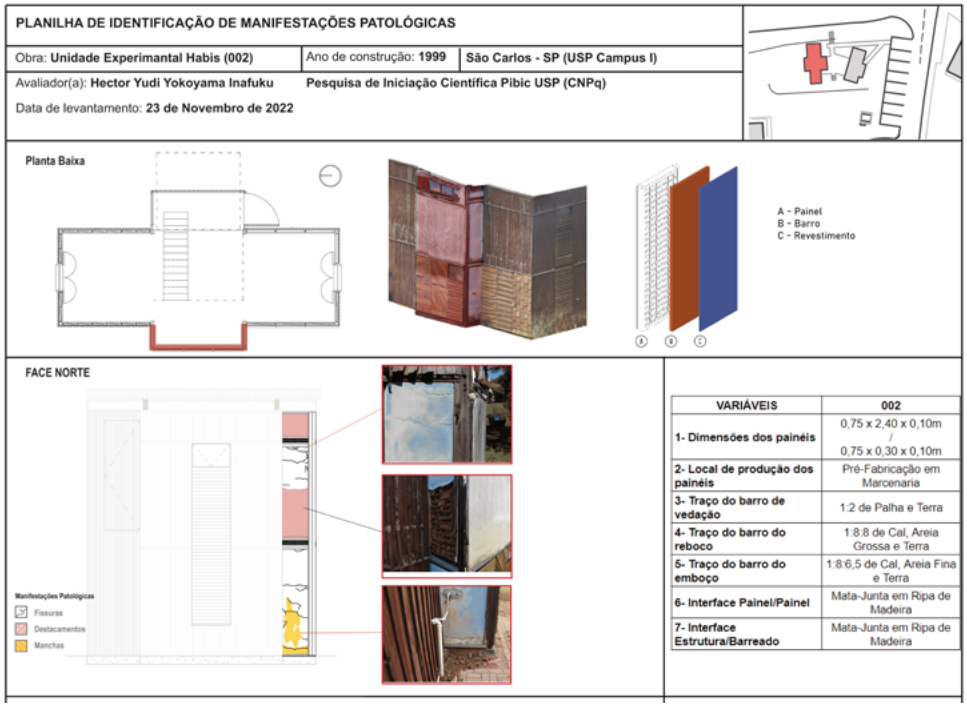
Figure 10: Pathological Manifestations of Unit 001 (East Façade)
Source: Elaborated by the Authors (2022)

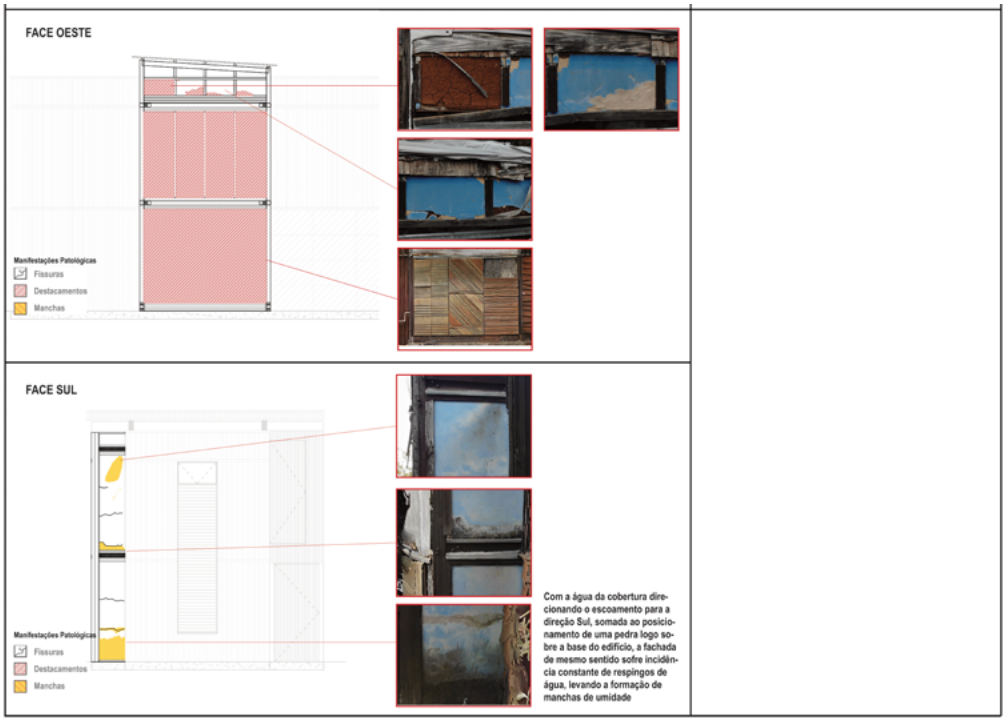
3. RESULTS

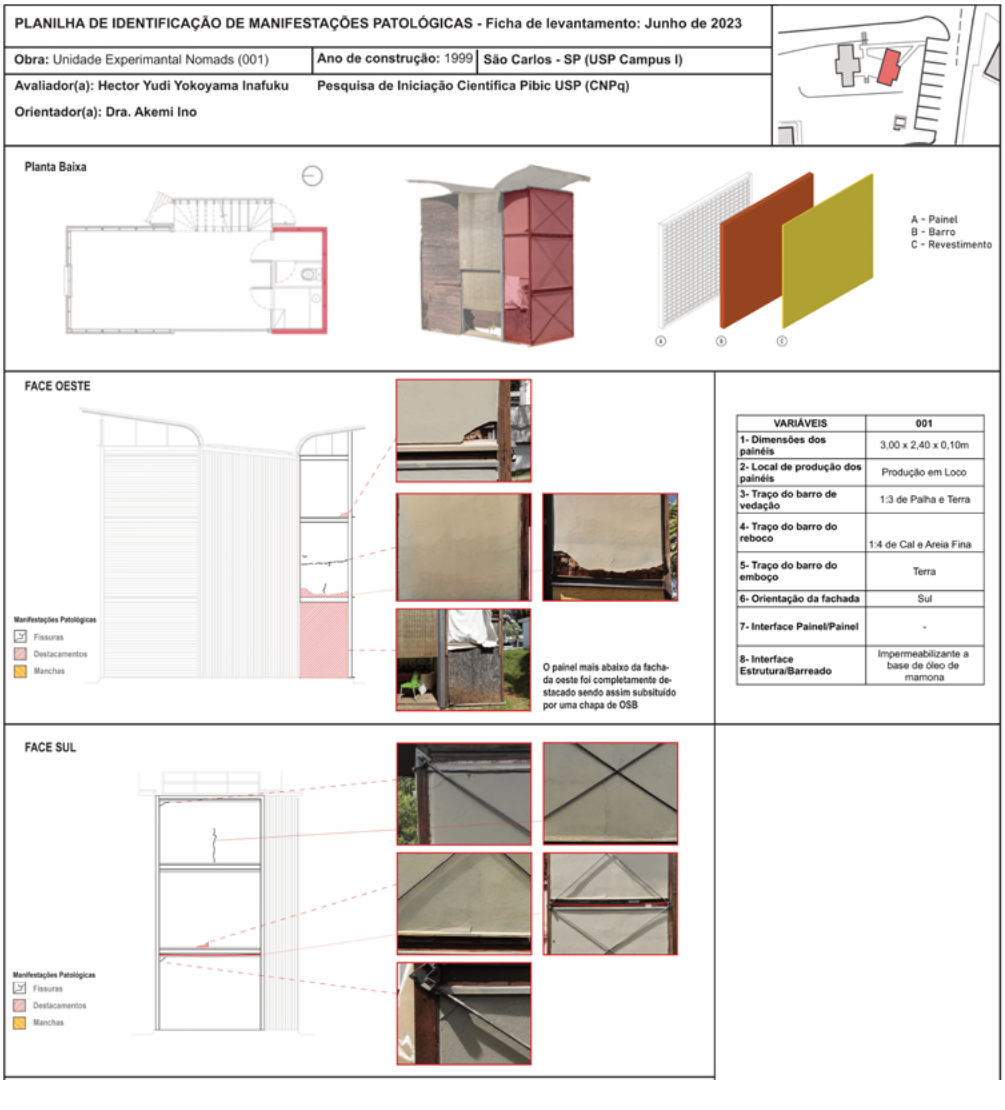
One of the products of the research is the pathlogy identification spreadsheet, which, in addition to recording the defects observed on each façade, includes data about the building to be evaluated, such as its location, floor plan, and perspective. The spreadsheet also contains the characterization of the panel design with its layered composition (Figure 11 and 12).

Of the nine panels evaluated in Unit 001, four met all the established requirements and criteria, with two located on the South face and two on the East face. The three panels on the West face did not meet the requirements.

In Unit 002, out of the 18 panels evaluated, only four met the defined requirements and criteria, with three on the South face and one on the North face. The panels on the West face were completely removed, and the lower floor wall was replaced with OSB paneling over the sawn timber frame.







VARIÁVEIS	001
1- Dimensões dos painéis	3,00 x 2,40 x 0,10m
2- Local de produção dos painéis	Produção em Loco
3- Traço do barro de vedação	1:3 de Palha e Terra
4- Traço do barro do reboco	1:4 de Cal e Areia Fina
5- Traço do barro do emboço	Terra
6- Orientação da fachada	Sul
7- Interface Painel/Painel	-
8- Interface Estrutura/Barreado	Impermeabilizante a base de óleo de mamona

Figure 12: Identification Sheets for Pathological Manifestations.
Source: Elaborated by the Authors (2022)

4. RESULTS ANALYSIS

In a comparative analysis, the dimensions and number of pathological manifestations innUnit 002 were significantly higher, with 6 stains, 13 cracks, and 14 detachments, compared to Unit 001, which had 5 stains, 6 cracks, and 5 detachments (Table 1). Overall, only 22% of the panels in Unit 002 met the established criteria and requirements, whereas in Unit 001, the percentage was 44%.

structure caused by under dimensioning, which, due to wind, may have contributed to the formation of cracks at the corners. Both FS1B and DS2A could be related to deformation in the lower beam, which is more noticeable in panel S2, as indicated by the horizontal line in Figure 13. This deformation may have led to the weight of the earth contributing to the formation of these cracks.

Building	Evaluated panels	Pathological Manifestations			Panels that met the established Criteria and Requirements
		Stains	Cracks	Detachments	
001	9	5	6	5	4 (44%)
002	18	6	13	14	4 (22%)

Table 1: Summary of Performance Evaluation of the wattle and daub Panels in Units 001 and 002.
Source: Elaborated by the Authors (2022)

4.1 Unit 001

In the panels facing the South side (S1; S2; S3) of Unit 001, shown in Figure 13, a total of four stains and two cracks were identified in panel S1, with one located at the upper left corner (FS1A) and another running vertically from the base towards the top of the panel (FS1B). In panels S2 and S3, a detachment (DS2A) was identified, similar to FS1B, also at the base of the panel on the beam structure, along with a crack (FS3A) found at the upper left corner of panel S3.

Among the possible causes for the formation of cracks FS1A and FS3A is potential movement in the

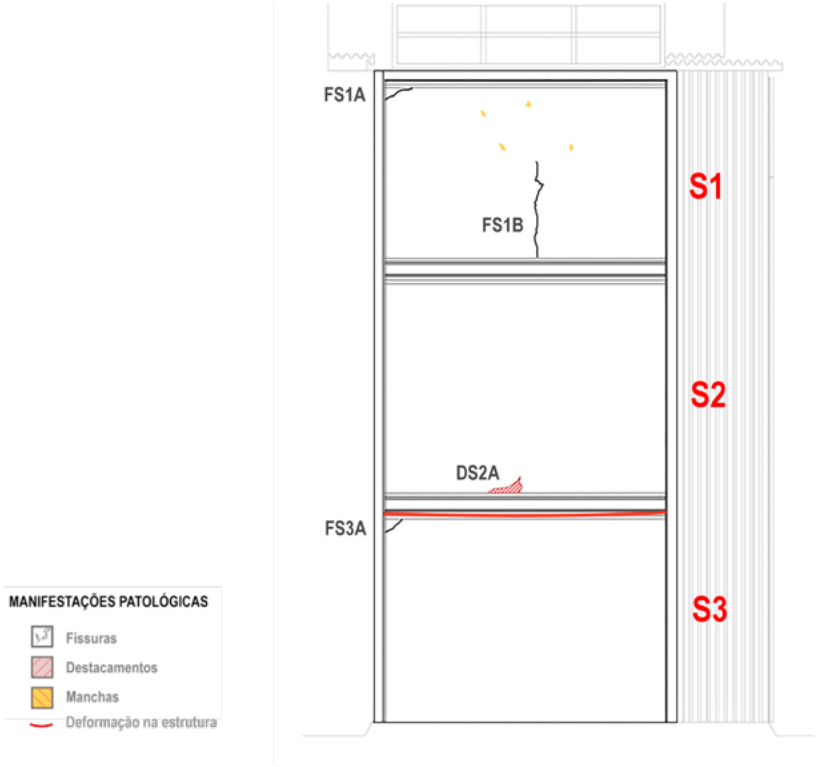


Figure 13: Pathological Manifestations on the South Façade (Unit 001).
Source: Elaborated by the Authors (2022)

Regarding the East face (L1; L2; L3), shown in Figure 14, the identified issues aremostly stains, with only one detachment (DL2A) located at the lower left corner of panel L2.

Both the East and West faces show good performance in terms of the interfaces between the earth and the wooden structure, which may be attributed to the castor oil resin applied in the mixed technique.

The West face stands out compared to the others due to the severity of its issues. In addition to the crack (FO1A), both panels O1 and O2 show significant detachments (DO1A; DO2B) concentrated in the lower region of the panel, as well as a detachment (DO2A) in panel O2 at the earth-structure interface. Panel O3 is notable for the complete removal of the earth and its coating (Figure 15).

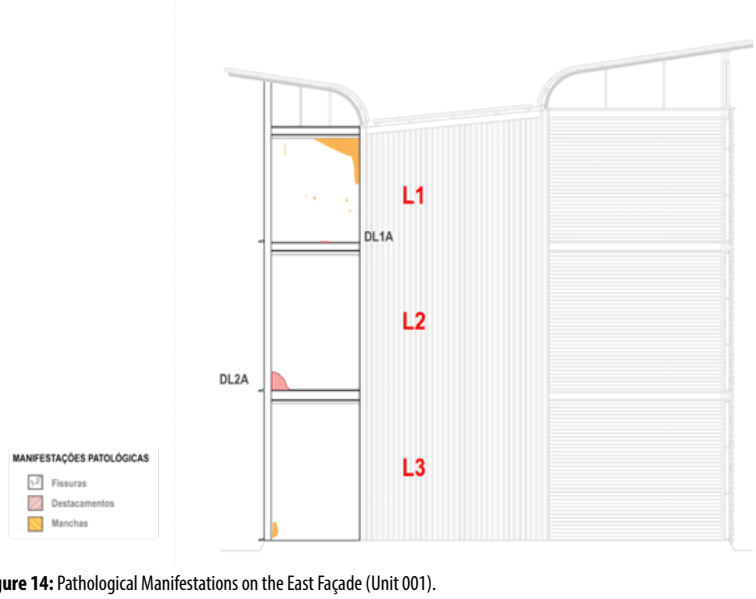


Figure 14: Pathological Manifestations on the East Façade (Unit 001).
Source: Elaborated by the Authors (2022)

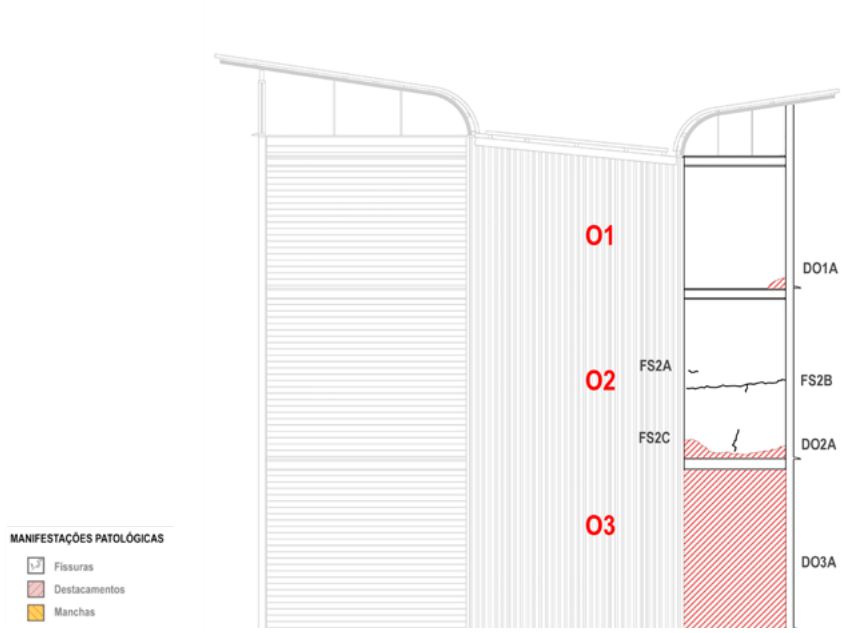


Figure 15: Pathological Manifestations on the South Façade (Unit 001).
Source: Elaborated by the Authors (2022)

When analyzing the three façades, a pattern of concentrated cracks and detachments at the corners of the panels (FS1A; FS3A; DL2A; DO1A; DO2A) becomes evident. A possible cause of this pattern is the movement of the structure due to wind, making the corner regions susceptible to cracking. Consequently, the presence of cracks and deformations facilitates water infiltration into the seal, leading to the rotting of the framework and detachment of the earth.

The temperature fluctuations experienced by the panels on the West face in the late afternoon may also be a possible reason for none of the panels meeting the established requirements. Combined with the previously mentioned issues, the identified pathologies manifestations could be related to the dimensional variation of the wood caused by temperature changes, affecting the material interfaces and contributing to water infiltration and accumulation in the wooden framework, leading to its decay.

Finally, it can be stated that only panels S1, S3, L1, and L3 meet the established criteria and requirements.

4.2 Unit 002

On the South face (Figure 16), there is a predominance of moisture stains caused by direct contact with water splashes. Despite this, it is the only face without any detachments, having only cracks with less than 1 mm of width.

The West face (Figure 17) has the highest number of sealant detachments, with faces O2 and O3 being completely detached.

The North face (Figure 18) shows complete detachment in panel N1 and partial detachment in panel N2, with a significant presence of cracks. Additionally, there isextensive moisture staining on panel N3, particularly near the ground.

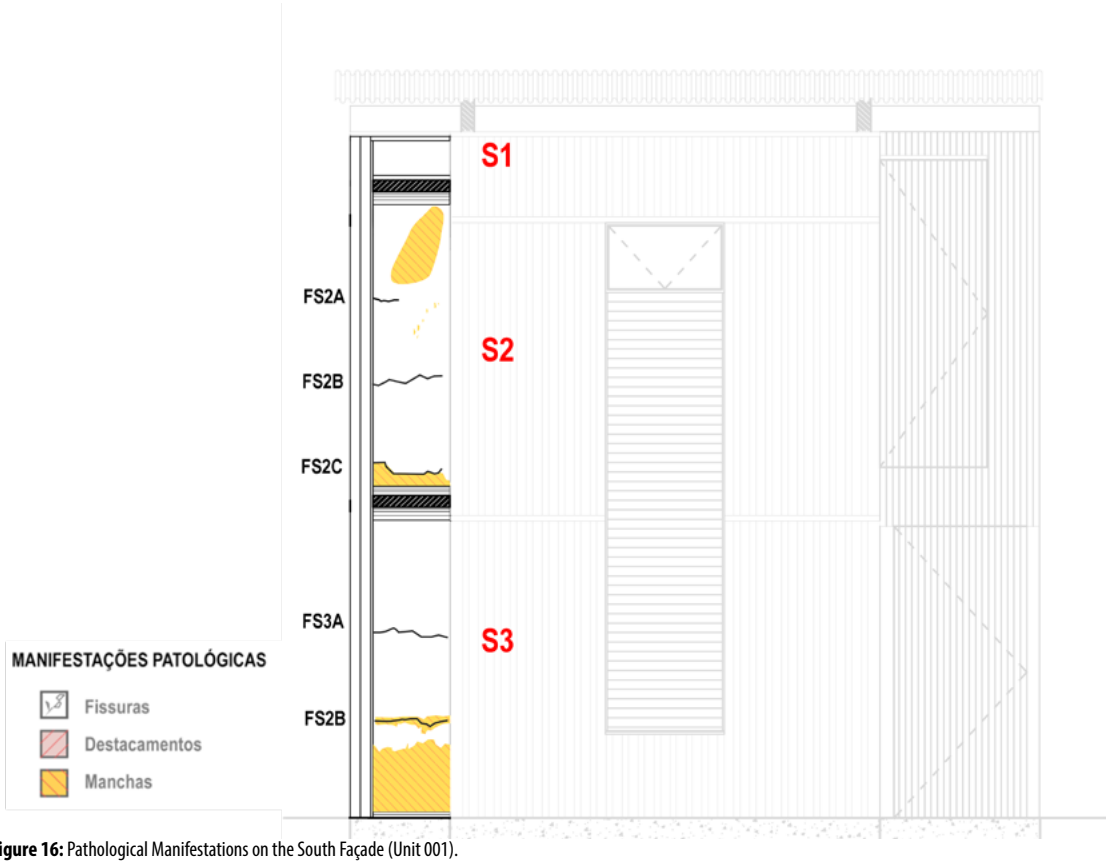


Figure 16: Pathological Manifestations on the South Façade (Unit 001).
Source: Elaborated by the Authors (2022)

Figure 17: Pathological Manifestations on the South Façade (Unit 001)
Source: Elaborated by the Authors (2022)

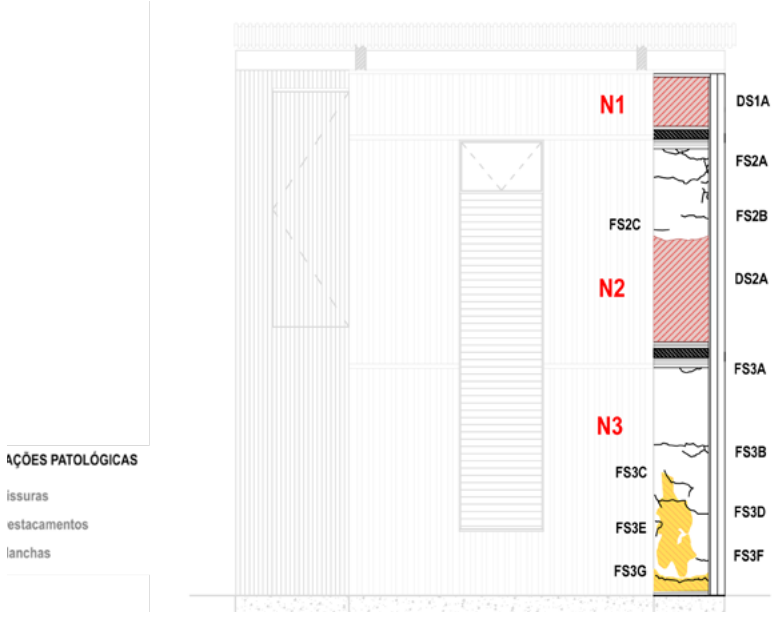


Figure 18: Pathological Manifestations on the South Façade (Unit 001).
Source: Elaborated by the Authors (2022)

4.3 Analysis of possible causes of the pathological manifestations

The durability of the wattle and daub technique heavily relies on the proper execution and detailing of the interfaces between the panels and the earth. Given that moisture is the primary factor in the deterioration of "taipa" (LOPES, 1998), the near-total detachment of the West façade of Unit 002 is related to the solution used for 75cm modular panels with exposed frame joints covered with wooden joint covers. Exposure to high solar radiation and dimensional variations in the wood led to formation of gaps, infiltration and accumulation of rainwater, initiating the rotting of the timber frame and consequent loss of support, causing detachment of the earth. Another moisture-related factor to consider as a cause of the wall detachments in Unit 002 is the lack of eaves, combined with the fact that the panels were elevated only 20 cm above the foundation, relative to ground level. Considering that the minimum foundation height to avoid wall deterioration due to moisture is 40 cm (LOPES, 1998), the proximity of the walls to the ground may have created conditions for water splashes and accumulation, which compromised the integrity of the walls.

Another noteworthy aspect of Unit 001 was the use of castor oil resin at the interface between the coating and the pillar. This flexible component allowed for the absorption of dynamic dimensional changes between the two materials, preventing the formation of gaps between the panel (earth) and the wooden pillar, and ensuring good performance over 25 years.

Thus, it can be concluded that the main cause of the performance difference between the two buildings is related to the design details concerning the protection of construction elements from contact with and accumulation of water and moisture at different interfaces between construction systems. This includes the adoption of 75 cm modular panels with exposed frames, compared to the single 3 m panel solution that covered the entire span from pillar to pillar, as used in Unit 001, along with the absence of eaves and a low-height foundation relative to ground level.

5. FINAL CONSIDERATIONS

The mixed technique, despite its numerous economic, technical, social, and environmental benefits, like any other construction process, requires careful prior planning. This includes conducting a site study and technical feasibility analysis to ensure optimal performance, durability, and functionality of the building (LOPES, 1998).

After about twenty-five years of use, the research that led to the creation of Experimental Housing Units 001 and 002 remains a valuable subject for investigation. It allows for numerous studies on the performance of the five subsystems (structure, cladding, joinery, roofing,

and installations) as proposed in the FAPESP Young Researchers in Emerging Centers project. It is important to note that exposure conditions were crucial for the performance of the mixed techniques in the cladding subsystem. Therefore, during the design phase, it is essential to develop tools, techniques, and construction processes that ensure the desired durability and performance of the "taipa de mão" walls, considering the exposure conditions they will face.

Understanding wattle and daub as a technique still stigmatized and often associated with "poverty and unsanitariness" by common perception in Brazil, scientific studies on this traditional technique can help combat these harmful and misguided views and open new perspectives for necessary changes in the construction industry, seeking more sustainable and less harmful solutions.

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CRediT Taxonomy (http://credit.niso.org/)

HYYI: conceptualization, formal analysis, visualization, writing - original draft, writing - review & editing and supervision.

AI: conceptualization, formal analysis, investigation, methodology, visualization, writing - original draft, writing - review & editing, data curation, resources and supervision.

Conflict declaration: nothing has been declared.