

Pathological Manifestations in Wood Structures of Amazonian Stilt Houses: A Case Study in Itaituba, PA, Brazil

Maria Tamiris Fonseca de Lima ^a, José Renato Lima Aguiar ^a,
Victor De Araujo ^b, Thiago Augusto de Sousa Moreira ^c,
and Matheus Viana de Souza ^{a,*}

*Corresponding author: matheus.souza@ufopa.edu.br

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GRAPHICAL ABSTRACT



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Maria Tamiris Fonseca de Lima ^a, José Renato Lima Aguiar ^a,
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Wood structures used in stilt houses are exposed to environmental conditions in the Amazon that favor degradation processes. Such degradation may compromise durability, performance, and safety. This study evaluated pathological manifestations in the wood structures of stilt houses located in the Jardim das Araras neighborhood in Itaituba, Pará state, Brazil, to analyze the maintenance conditions and practices adopted by residents. The research was designed as a qualitative, descriptive case study based on *in situ* visual inspection of 10 stilt houses, photographic records, structured interviews with housing users, and prioritization using the GUT Matrix (Gravity, Urgency, and Trend). Eleven pathological manifestations were identified, including mold fungi, degradation at the bases and tops of pillars, longitudinal cracks, decay fungi, rupture and displacement of structural elements, visible beam deformation, and member instability. The questionnaire results showed the predominance of corrective maintenance, with 70% of residents reporting that they replace components only after visible defects appear. Moisture exposure, biological agents, and insufficient preventive maintenance were associated with the deterioration observed. Periodic inspections and preventive actions were recommended to the users, with priority given to critical support elements.

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Contact information: a: Federal University of Western Pará (UFOPA), Itaituba Campus, Universitária, S/N, Maria Magdalena, CEP 68183-300, Itaituba, Pará, Brazil; b: Postgraduate Program in Civil Engineering, Faculty of Engineering of Ilha Solteira, São Paulo State University “Júlio de Mesquita Filho” (UNESP), 550 Alameda Bahia, Ilha Solteira, Brazil; c: Federal University of Western Pará (UFOPA), Santarém Campus, Engineering and Earth Sciences Institute, Rua Vera Paz, s/n, 68040-255, Santarém, Pará, Brazil; *Corresponding author: matheus.souza@ufopa.edu.br

INTRODUCTION

In civil engineering, pathological manifestations correspond to anomalies, failures, or defects capable of compromising the performance, durability, and safety of buildings. In wood structures, these manifestations are especially relevant because of the organic origin and hygroscopic nature of wood, which promotes moisture exchange with the environment and affects its physical and mechanical properties (Brito 2014; Shimbo and Ino 2024).

Wood degradation results from an interaction among construction-related, environmental, and use-related factors. Detailing failures, prolonged moisture exposure, lack of preservative treatment, and insufficient maintenance can favor symptoms such as cracks, deformations, staining, decay, and loss of mechanical resistance of structural members (Brito 2014; De Paula *et al.* 2021).

Among deterioration agents, biotic agents are particularly important, especially decay fungi and xylophagous insects. These organisms degrade the main constituents of wood (cellulose, hemicellulose, and lignin), reducing wood mass, stiffness, and load-bearing capacity (Dumankaya *et al.* 2025; Silva *et al.* 2024). Fungal decay can occur in different forms, such as brown rot, associated mainly with cellulose degradation, and white rot, associated with lignin consumption. In parallel, xylophagous insects, such as subterranean termites and powderpost beetles, may attack the internal portions of members by opening galleries, which makes early identification of the damage more difficult (Brito 2014). Table 1 shows the risk classes of xylophagous organisms according to the wood use conditions.

Table 1. Risk Classes for Visual Inspection of Wood Structures According to Environmental Exposure Conditions

Risk Class (RC)	Wood Use Condition	Main Xylophagous Organisms
1	Indoor use, out of contact with soil, foundations, or masonry; protected from weathering, internal moisture sources, and access by subterranean or arboreal termites.	Drywood termites; wood-boring beetles
2	Indoor use, in contact with masonry, but without contact with soil or foundations; protected from weathering and internal moisture sources.	Drywood termites; wood-boring beetles; subterranean termites; arboreal termites
3	Indoor use, out of contact with soil and protected from weathering, but occasionally exposed to moisture sources.	Drywood termites; wood-boring beetles; subterranean termites; arboreal termites; mold/staining fungi; decay fungi
4	Outdoor use, out of contact with soil, and exposed to weathering.	Drywood termites; wood-boring beetles; subterranean termites; arboreal termites; mold/staining fungi; decay fungi
5	Contact with soil, freshwater, or other situations favorable to deterioration, including embedment in concrete and/or masonry.	Drywood termites; wood-boring beetles; subterranean termites; arboreal termites; mold/staining fungi; decay fungi
6	Exposure to saltwater or brackish water.	Marine borers; mold/staining fungi; decay fungi

Source: Adapted from Brito (2014)

Abiotic agents, including solar radiation, thermal variations, excessive moisture, and weathering, also contribute to surface changes, cracking, roughness, and increased permeability. Although such factors do not always destroy wood by themselves, they increase susceptibility to biological attack and accelerate mass loss and the reduction of physical and mechanical properties (Martins and Fioriti 2016; Castro and Guimarães 2018).

In the Amazonian context, stilt houses represent a vernacular housing typology that is adapted to the dynamics of water, allowing occupation of flood-prone and floodplain areas. However, their primary structural elements-especially pillars, piles, and beams-are frequently exposed to moisture, soil, and freshwater. According to the risk classification proposed by Brito (2014), this condition corresponds to a high-risk exposure class for biodeterioration.

Beyond environmental exposure, the vulnerability of stilt houses is related to precarious construction, deficient urban infrastructure, and the accumulation of residues in areas where moisture is retained. Under such conditions, preventive maintenance and the control of biodeteriorating agents become essential strategies to preserve safety, performance, and service life (Brito 2014; Grecco 2024).

Interventions in wood structures may include corrective actions, such as replacement of members with substantial loss of cross section, local reinforcement, and rehabilitation of deteriorated components, as well as preventive measures such as moisture control, periodic cleaning, drainage improvement, separation of wood from permanent water sources, and the use of preservative treatments compatible with the exposure class (Brito 2014).

Although studies have addressed wood deterioration, structural pathology, and Amazonian stilt-house architecture, few investigations integrate, in the same analytical procedure, visual inspection of wood members, residents' perceptions, and hierarchical prioritization of pathological manifestations to guide maintenance actions in urban Amazonian stilt houses. This gap is relevant because maintenance in these dwellings often occurs reactively and is conditioned by community resources and practical knowledge.

Based on this gap, the objective of this study was to diagnose and prioritize pathological manifestations in wood structures of stilt houses located in the Jardim das Araras neighborhood, Itaituba, Pará, Brazil, through *in situ* visual inspection, photographic records, questionnaires applied to residents, and the GUT Matrix. The study also sought to relate the observed damage to maintenance conditions and to propose intervention priorities compatible with the Amazonian floodplain context.

EXPERIMENTAL

Study Design

This study was designed as qualitative, descriptive, and applied research conducted through a case study. The methodological procedure was structured to allow the diagnosis to be reproduced in other stilt-house areas. It included spatial delimitation, unit selection, non-destructive visual inspection, photographic recording, questionnaire application, classification of pathological manifestations, and prioritization using the GUT Matrix. Table 2 summarizes the adopted stages.

Spatial Delimitation of the Study Area

The Jardim das Araras neighborhood (Fig. 1a), located in a riverine floodplain area in the municipality of Itaituba, Pará, Brazil, was selected as the spatial scope of this research. The neighborhood was intentionally selected because of the presence of traditional and hybrid stilt houses, proximity to the Tapajós River, and recurrent exposure to moisture and flooding conditions, all of which are directly associated with the deterioration of wood structures.

Table 2. Summary of the Methodological Procedure Adopted in the Study

Stage	Procedure	Output
1	Delimitation of the Jardim das Araras neighborhood and identification of stilt houses near the water body.	Spatial scope of the study
2	Selection of 10 stilt houses by intentional and accessibility sampling, considering access authorization and the presence of exposed wood elements.	Sample P1 to P10
3	Non-destructive visual inspection of pillars, piles, beams, floors, guardrails, enclosures, and wood-soil/water interfaces.	List of pathological manifestations and photographic records
4	Face-to-face questionnaire applied to residents, without nominal identification of participants.	Data on maintenance, materials, treatment, and risk perception
5	Tabulation of occurrences and association between manifestations and evaluated houses.	Frequency of manifestations per unit
6	Assignment of Gravity, Urgency, and Trend scores and calculation of $G \times U \times T$.	Ranking of manifestation criticality
7	Integration of inspection, GUT Matrix, and questionnaire results.	Prioritization and preventive maintenance guidelines

Source: Authors (2026)



Fig. 1. Aerial photos of Jardim das Araras neighborhood, Itaituba, Brazil: (a) spatial delimitation and (b) stilt-house sample. Source: Google Earth, adapted by the authors (2026)

The sample consisted of 10 housing units (Fig. 1b), identified as P1 to P10. The selection considered the presence of wood structural elements accessible to visual inspection, proximity to areas influenced by water, and the possibility of interviewing the resident. Because this is a qualitative case study, the results are not intended for statistical generalization, but they allow the identification of deterioration and maintenance patterns in a representative local context.

All 10 units used timber as the primary load-bearing material and presented an elevated post-and-beam structural arrangement, with floor and roof loads transferred through timber members and beams to vertical pillars or piles and then to the supporting ground. This load path was interpreted qualitatively from the visible structural arrangement; no structural load calculations were performed. Localized construction hybridization was recorded in six units: five had masonry bathrooms and one had a

masonry cesspit, whereas four remained entirely timber. These masonry components were localized and did not replace the primary timber support system.

Although the questionnaire asked how long each stilt house had existed, exact construction dates were not independently verified by documentary records. Construction period was therefore not used as a quantitative comparison variable, and this is treated as a limitation of the sample characterization.

The hydrological behavior of the Tapajós River was considered as an environmental contextual variable. According to Santos *et al.* (2025), the flood period occurs between January and May, when the river level may reach approximately 10.0 m, while the falling-water period extends from July to November, with minimum levels close to 2.5 m. Such oscillation favors wetting and drying cycles in wood members, especially in the lower portions of the stilt houses.

***In Situ* Visual Inspection**

The *in situ* visual inspection was performed as a non-destructive procedure based on a protocol adapted from Brito (2014) and Lucena and Lima (2024). In each unit, pillars, piles, beams, floors, guardrails, enclosures, wood-soil/water interfaces, and areas with moisture accumulation were prioritized (Fig. 2a). The evidence was recorded photographically and linked to the corresponding stilt-house identification. Height measurements (Fig. 2b) were made with a measuring tape, allowing an approximate altimetric variation to be observed among the structures: stilt houses in areas more prone to flooding had heights between 4 m and 6 m, whereas units in less affected areas had heights between 1.5 m and 3 m.



(a)



(b)

Fig. 2. Assessment in stilt house sample: (a) visual inspection of lower elements and (b) altimetric measurement. Source: Authors (2026)

Questionnaire Application

Using the same sample adopted for the visual inspection, a structured questionnaire was applied to residents of the 10 evaluated units (Appendix). The instrument included questions on length of residence, wood used, origin of the material, frequency of replacement of boards and pillars, period of repairs, parts considered most critical, treatments applied to new wood, presence of mixed materials, and residue accumulation. The interviews were conducted face-to-face, individually, and without nominal

identification of respondents. The answers were tabulated as absolute and relative frequencies, always considering the small sample size ($n = 10$). Therefore, the percentages presented are descriptive and are used to support the qualitative interpretation of the maintenance and conservation patterns observed during the inspections.

GUT Matrix and Data Processing

After the inspection, the pathological manifestations were cataloged according to their occurrence in the evaluated units and associated with the photographic records in the Appendix. The GUT Matrix was then applied, following procedures used in studies that prioritize pathological manifestations (De Paula *et al.* 2021; Brito 2023). This tool ranks problems according to three criteria: Gravity, Urgency, and Trend (Table 3).

Table 3. GUT Matrix Scoring Criteria

Score	Gravity (consequence)	Urgency (time to intervene)	Trend (expected progression)
1	Negligible consequence for performance or safety	Routine monitoring; no near-term action	No progression expected
2	Minor, localized consequence	Intervention may be scheduled	Worsens in the long term
3	Moderate consequence or functional impairment	Repair should be planned promptly	Worsens in the medium term
4	Serious consequence for durability or structural performance	Urgent intervention required	Worsens in the short term
5	Critical consequence; potential loss of load-bearing capacity or stability	Immediate technical intervention required	Rapid progression or active aggravating condition

Source: Adapted from Periard (2011) and operationalized by the authors for the present timber-structure assessment

In the present study, Gravity and Urgency were treated as distinct dimensions. Gravity expresses the potential consequence of an observed condition for durability, functionality, or structural safety if it remains unresolved, whereas Urgency expresses the time available before technical intervention is required. Thus, a condition may have high gravity without requiring immediate action, while another may warrant urgent action because of active progression. Trend represents the expected rate of worsening under the observed exposure conditions.

Each manifestation was evaluated based on the available visual evidence, considering the potential damage, the affected element, the possibility of progression, and the consequence for building performance. Because the same manifestation was observed in different stilt houses, the GUT score was assigned by type of pathological manifestation rather than by isolated photograph, which allowed the criticality of the damage to be compared in a standardized way.

The criticality index was calculated as the product $G \times U \times T$. In addition, an accumulated index was calculated for each stilt house by summing the GUT scores of all manifestations present in that unit. This procedure does not replace a detailed structural assessment, but it provides an indication of the units that require priority technical inspection.

To reduce classification subjectivity, uniform operational criteria were adopted: Gravity received a higher score when there were indications of compromised load-bearing elements, loss of section, rupture, deformation, or instability; Urgency increased when the

damage indicated the need for short-term repair; and Trend received a higher score when active moisture, infestation, progressive cracking, or environmental conditions favorable to aggravation were observed. Thus, manifestations scoring 125 were classified as critical and requiring priority intervention; scores from 64 to 80 indicated high criticality and the need for monitoring and repair planning; and scores below 64 were interpreted as lower relative priority, without excluding the need for periodic follow-up.

The GUT scores were assigned from the technical visual inspection by the research team and were not derived from the residents' questionnaire responses. Resident perceptions were used only as complementary information for triangulation with the field diagnosis.

RESULTS AND DISCUSSION

Mapping of Pathological Manifestations in Stilt Houses

Eleven pathological manifestations were identified and cataloged in wood elements. These manifestations were associated with 28 photographic records obtained during the visual inspection and presented in the Appendix. Table 4 lists the manifestations observed in the evaluated stilt houses.

Table 4. Pathological Manifestations Identified in the Stilt Houses

Pathological Manifestation	Stilt Houses Observed
Visible subterranean termite tunnels	P1, P2, P3, P4, P5, P7
Decay fungi in beams and pillars	P1, P2, P3, P4, P5, P8, P9
Staining/mold fungi	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10
Rupture/displacement in apparent structural elements	P2, P3, P4, P6, P10
Degraded, hollow, or partially missing pillar bases and tops	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10
Deep longitudinal cracks in pillars	P1, P2, P3, P4, P6, P7, P8, P9
Floor gaps larger than 5 mm	P2, P3, P4, P5, P7, P9
Visible deformation in beams	P5, P7
Member instability	P4, P6, P10
Guardrails/enclosures with decay at the base	P5, P6, P9, P10
Deterioration due to excessive moisture	P9, P10

The most frequent occurrences were staining/mold fungi and degraded bases and tops of pillars. Both of these were recorded in all 10 units evaluated (10/10). This result indicates generalized action of moisture and biological agents in zones of contact with soil, water, and exposed surfaces. Deep longitudinal cracks in pillars (8/10) and decay fungi in beams and pillars (7/10) were also frequent, indicating progressive impairment of load-bearing elements.

Visible beam deformation (2/10), member instability (3/10), and deterioration due to excessive moisture (2/10) occurred less frequently, but not necessarily with lower relevance because they were associated with localized structural risk. Thus, recurrence

analysis was interpreted together with the GUT Matrix criticality scores, avoiding underestimation of severe but less frequent damage.

Representative field photographs of six of the identified manifestations are shown in Fig. 3; the complete photographic record of all 11 manifestations is retained in the Appendix.



Fig. 3. Representative pathological manifestations documented in the evaluated stilt houses: (a) decay fungi in beams and pillars; (b) rupture/displacement in apparent structural elements; (c) degraded, hollow, or partially missing pillar bases and tops; (d) member instability; (e) visible subterranean termite tunnels; and (f) staining/mold fungi. Source: Authors (2026)

GUT Matrix Application

Table 5 presents the prioritization of pathological manifestations based on Gravity, Urgency, and Trend. Higher values indicate greater criticality and, therefore, higher priority for intervention. The criteria used for the evaluation of each manifestation are detailed in the Appendix. Table 6 shows accumulated criticality index by stilt house.

The P4 stilt house presented the highest accumulated index (723), followed by P5 (626), P10 (599), P2 (598), and P3 (598). This result indicates that maintenance prioritization should consider not only the severity of each manifestation, but also its concentration by housing unit. Stilt houses with the highest accumulated scores should be subjected to more detailed technical inspection, especially in support elements and structural connections.

The highest scores were concentrated in manifestations associated with severe structural damage and advanced biodeterioration, such as decay fungi in beams and pillars, rupture or displacement, degradation at pillar bases and tops, beam deformation, and

member instability. These manifestations reached 125 points and were classified as critical. Termite tunnels, staining/mold fungi, and deterioration due to excessive moisture scored 80 points, indicating conditions favorable to the progression of biodeterioration and reinforcing the need to combine moisture control, preservative treatment, and planned replacement of compromised components (Brito 2014; Castro and Guimarães 2018).

Table 5. GUT Classification of the Pathological Manifestations Identified in the Photographic Records

Photo	Pathological Manifestation	G	U	T	Total
1	Decay fungi in beams and pillars	5	5	5	125
2	Rupture/displacement in apparent structural elements	5	5	5	125
3	Degraded, hollow, or partially missing pillar bases and tops	5	5	5	125
4	Visible deformation in beams	5	5	5	125
5	Member instability	5	5	5	125
6	Visible subterranean termite tunnels	4	4	5	80
7	Staining/mold fungi	4	4	5	80
8	Deterioration due to excessive moisture	4	4	5	80
9	Guardrails/enclosures with decay at the base	4	4	4	64
10	Deep longitudinal cracks in pillars	3	3	4	36
11	Floor gaps larger than 5 mm	3	3	3	27

Table 6. Accumulated Criticality Index by Stilt House

Stilt House	Number of Manifestations Observed	Accumulated GUT Index
P4	8	723
P5	7	626
P10	6	599
P2	7	598
P3	7	598
P6	6	555
P9	7	537
P7	6	473
P1	5	446
P8	4	366

Decay Fungi in Beams and Pillars

The occurrence of decay fungi in beams and pillars received the maximum GUT Matrix score (125), reflecting the high criticality of this pathological manifestation in the stilt-house structures. Zeni *et al.* (2005) experimentally documented wood degradation caused by white-rot fungi. In buildings, persistent moisture and water infiltration can favor decay and compromise the integrity and mechanical resistance of wood structural members (Brito 2014; Martins and Fioriti 2016).

This pattern is consistent with Martins and Fioriti (2016), who evaluated wood structures at the IBC Events Center and identified a high incidence of decay affecting pillar bases, pillars, and beams. In that case, the emergence of pathological manifestations was strongly intensified by high relative humidity and rainwater infiltration, compromising the integrity and mechanical resistance of the structural system.

A similar pattern of degradation in support members was reported by Silva *et al.* (2024) in a rural building, where continuous moisture exposure caused by leaks and the absence of preservative treatment favored mold, mildew, and decay in structural members, resulting in visible signs of rupture. Field tests conducted by Corassa *et al.* (2019) also showed that forest environments favored greater deterioration of evaluated woods, resulting in loss of mechanical resistance and lower natural durability, especially for species more susceptible to termite attack.

Rupture or Displacement in Apparent Structural Elements

Rupture or displacement in apparent structural elements received the maximum GUT score (125), ranking among the most critical manifestations in the evaluated stilt houses (Fig. 3b). Gomes *et al.* (2021) showed that variability in the modulus of elasticity of wood members can lead to larger-than-expected roof displacements, which may contribute to pathological manifestations. In wood structures, overloads may cause excessive deformation or even failure of structural members. Inadequate use, accidental overloads, and lack of maintenance may also aggravate degradation (Brito 2014). Deformations, displacements, and deflections may indicate changes in structural behavior, while instability may manifest itself as buckling of pillars (Brito 2014). Cracks and drying defects may compromise the mechanical resistance of wood members because of internal stresses and fiber discontinuity, affecting structural behavior (Pfeil and Pfeil 2014). In stilt houses, support elements such as pillars and piles are fundamental to the support of the building (Ribeiro 2011; Oliveira Junior 2009). Therefore, fractures and displacements must be monitored, particularly in connection regions, because failures in these zones may compromise safety and, in some situations, contribute to structural collapse (Brito 2014). Similar conditions were described by De Paula *et al.* (2021), who reported that design and dimensional failures, excessive spacing between support beams, and irregular wood elements changed the original roof slope and caused cracks along the fibers at member joints.

The displacement and misalignment observed in the case-study structures should not be interpreted as evidence of a single biological mechanism. Visual inspection alone cannot distinguish among loss of support caused by member deterioration, connection irregularities, geometric defects, or movement/settlement at the pillar base in saturated soil. Accordingly, settlement in soft floodplain soil is a plausible mechanism, but it was not measured and cannot be confirmed from the present data. The manifestation was therefore treated as a structural condition requiring technical inspection rather than being attributed exclusively to biodeterioration. Parra *et al.* (2022) documented an analogous loss of contact between a beam and its supporting pillar, in which geometric irregularities and loading contributed to instability and required emergency shoring.

Degraded, Hollow, or Partially Missing Pillar Bases and Tops

Degraded or hollow pillar bases received the maximum GUT score (125), which confirms their high criticality. Pillar ends are particularly vulnerable when they remain

exposed to persistent moisture and biodeteriorating agents, increasing the susceptibility of the bases and tops to progressive deterioration (Brito 2014).

Continuous moisture favors the development of decay fungi and is one of the main factors associated with biological deterioration and reduced durability of structural members (Milani and Kripka 2012). As a consequence, wood loses mass internally and progressively, causing hollow sections and missing parts that significantly reduce the compressive resistance of members parallel to the grain (Brito 2014).

From a construction perspective, this degradation at member ends is aggravated by execution failures and the absence of details that prevent direct contact between wood and permanent moisture sources or water accumulation at the bases (Altoé and Alvarez 2009). When a pillar reaches this level of section loss or internal hollowing, the stability of the stilt-house superstructure is compromised, increasing the risk of localized or even global collapse.

The occurrence of deterioration at both pillar bases and tops indicates that the moisture source is not necessarily limited to floodwater or water beneath the house. Lower ends are compatible with exposure to saturated soil, floodwater, and retained moisture, whereas deterioration at upper ends may also result from rainwater, roof leakage, splash, or local water accumulation at connections, as reported for other timber structures (Martins and Fioriti 2016; Parra *et al.* 2022). The field observations therefore support rainwater as a plausible contributing mechanism, particularly at upper ends; however, the study did not measure moisture sources separately and cannot quantify their relative contributions.

The accumulation of waste and debris under stilt houses also contributes to accelerating degradation of pillar bases because retained residues impair water circulation and favor organic matter accumulation (Grecco 2024). In Amazonian rural communities, deficiencies in solid-waste collection and management have been associated with improper disposal practices and consequent environmental and public-health concerns (Oliveira *et al.* 2024).

Navarro (2022) emphasizes that stilt dwellings are a historical form of ecological adaptation to riverine areas and tropical-forest floodplains. In this context, it can be inferred that continual water-level oscillation favors high moisture contents at the bases and ends of piles, creating conditions suitable for decay fungi and other biodeteriorating agents (Milani and Kripka 2012). These organisms progressively compromise the mechanical resistance and durability of wood, thereby reducing service life (Brito 2014).

Visible Deformation in Beams

Visible deformation in stilt-house beams received the maximum GUT score (125), classifying it as a high-severity pathology. This condition results from the combination of applied loads and creep, which, according to Silva (1989), is characterized by the progressive increase in deformation over time under constant loading.

Biotic degradation also reduces the resistant cross section of the member, compromising flexural stiffness. Although Souza and Ripper (1998) address the pathology of concrete structures, their concept that structural deterioration compromises overall performance and reduces the capacity of a building to perform its intended functions also applies to wood structures. In this case, loss of resistant material leads to reduced load-bearing capacity and safety. In this regard, ABNT NBR 7190-1 (2022) establishes that excessive displacements correspond to failure to meet serviceability limit state criteria.

Mattos Junior *et al.* (2017) identified marked flexural deformation in roof structural elements, with excessive deflections and severe deformations that changed the original

slope of the system. The weakening and loss of stiffness were aggravated by damaged members resulting from inadequate interventions and lack of corrective maintenance. The authors emphasized that geometric irregularities, excessive deflections, and stress concentrations, associated with weathering and xylophagous attack, compromised the roof structural performance and increased the risk of collapse.

Member Instability

Member instability also received the maximum GUT score (125), confirming its criticality in stilt houses. Instability results from loss of structural integrity, changes in support conditions, and progressive deterioration of resistant elements, all of which compromise global equilibrium (Brito 2014). In the observed cases, this condition was evidenced by pillar misalignment, visible inclination, and apparent loss of plumb, indicating that the structure no longer maintained its original stable position.

The impairment of bases and support connections changes the internal distribution of forces in wood members, introducing eccentricities and additional demands that accelerate displacements and increase the risk of structural collapse (Pfeil and Pfeil 2014). Similar instability and lateral displacements were reported by Lucena and Lima (2024) in walkways made of round eucalyptus wood. They identified nonconformities in knee-brace connections, mainly attributed to poor fastening, failures in notched joints, and corrosion of metal connectors. As a consequence, excessive lateral displacements occurred during pedestrian traffic and under wind action, associated with irregularities in bracing and lateral restraint.

Visible Subterranean Termite Tunnels

Visible subterranean termite tunnels received a score of 80 in the GUT Matrix because of their high potential to compromise stilt houses. This manifestation results from prospecting channels composed of soil, feces, and saliva, which protect insects against desiccation as they move toward wood. Fontes (1995) reported that subterranean termites have a high capacity to build tunnels and galleries in different materials and use these structures to spread through buildings and reach new food sources, favoring infestation progression.

According to Brito (2014), these structures are essential for maintaining the moisture content required for colony survival, allowing access to wood even when it is not in direct contact with wet soil. This foraging strategy is particularly aggressive in the Amazonian environment, where saturated soils may favor numerous colonies. Because subterranean termite attack can progress internally, substantial section loss and reduced resistance may occur before damage becomes readily visible during routine observation (Brito 2014).

The occurrence of xylophagous insect attacks, especially subterranean termites, is recurrent in wood structures. Mattos Junior *et al.* (2017) identified consumed and fractured roof members attributed to xylophagous insects and the absence or loss of effectiveness of preventive immunization. Parra *et al.* (2022) also identified termites in wood structural elements and highlighted the need for corrective interventions. In stilt houses, Oliveira *et al.* (2021) recorded floor damage caused by active termite infestation, loss of structural resistance, and compromised resident safety.

Because many dwellings are arranged in rows, the short distance between houses and continuity of favorable moist soil may facilitate subterranean termite foraging across the local built environment. However, the questionnaire did not investigate neighboring

households' maintenance practices, and the study did not identify colonies or track termite movement between houses. Therefore, the occurrence recorded in P1, P2, P3, P4, P5, and P7 cannot be attributed to transmission from a specific neighboring house. No wood-boring beetle damage was recorded as a distinct pathological manifestation in the 10 inspected units. Spatial and entomological monitoring would be required to test inter-house infestation pathways (Fontes 1995; Brito 2014).

Staining and Mold Fungi

Staining and mold fungi scored 80 in the GUT Matrix because of the risk of aesthetic and functional deterioration of wood under high moisture conditions. These fungi proliferate in wood with moisture content above 20%, a condition common in Amazonian stilt houses exposed to saturated soils and seasonal floods. This visual manifestation signals critical environmental conditions that may compromise wood durability and require moisture control to prevent progression to more severe pathologies (Brito 2014).

Although staining/mold fungi were recorded in all 10 units, the inspection protocol recorded occurrence rather than severity as a function of elevation, and wood moisture content was not measured at different heights. Consequently, the present evidence did not demonstrate a specific vertical gradient of mold severity relative to the seasonal water level. The widespread occurrence is instead consistent with generalized high-humidity exposure and multiple moisture pathways. Future work should combine elevation-referenced observations with repeated wood-moisture measurements through flood and falling-water periods.

Parra *et al.* (2022) also observed pathological manifestations caused by weathering and biodeterioration in a timber structure at the Federal University of Tocantins, in Gurupi, Brazil. The authors reported deterioration of wood structural pillars associated with water infiltration from roof failures, which maintained high moisture levels and favored biodegrading agents.

Deterioration Due to Excessive Moisture

Deterioration due to excessive moisture under the structure scored 80 in the GUT Matrix, demonstrating its impact on the integrity of the stilt-house system. Continuous exposure to high moisture favors wood biodeterioration and creates conditions suitable for the development of decay fungi, which can degrade lignocellulosic material (Zeni *et al.* 2005; Brito 2014).

Similarly, Lopes and Schmitz (2023) observed that during periods of intense rainfall, the evaluated bridge was exposed to water levels above the safety elevation, subjecting wood structural members to severe moisture conditions. During the inspection, the authors also identified cracks and other pathological manifestations in the bridge structural elements. Therefore, the condition observed in the present study is incompatible with durability and service-performance requirements provided in ABNT NBR 7190-1 (2022), which requires the design to consider exposure conditions and mechanisms capable of ensuring structural durability.

Guardrails and Enclosures with Decay at the Base

Decay at the base of guardrails and enclosures in stilt houses scored 64 in the GUT Matrix. According to Brito (2014), this manifestation mainly results from continuous exposure of wood to moisture from saturated soil and the action of xylophagous fungi, which find favorable development conditions in the soil-air interface. The absence of

preservative treatment, combined with moisture exposure and deficient maintenance, promotes biological deterioration and compromises durability and performance. Silva *et al.* (2014) stated that wood deterioration caused by xylophagous fungi is directly related to degradation of the main chemical constituents of wood. The authors observed that Basidiomycete fungi showed greater capacity to deteriorate both heartwood and sapwood, with sapwood being more susceptible to biological attack. This indicates a reduction in the natural durability of wood throughout the biodeterioration process. Oliveira *et al.* (2021) also showed that water-level variation and constant moisture have harmful effects on wood elements in stilt houses in Cametá, Pará. Direct and continuous contact with river water was identified as a critical factor for foundation deterioration and decay of structural members. Successive wetting and drying cycles caused cracks and created an environment highly favorable to fungi and other xylophagous agents, leading to loss of mechanical strength and deformation of stilt-house profiles.

Deep Longitudinal Cracks in Pillars

Deep longitudinal cracks in pillars scored 36 in the GUT Matrix, indicating moderate criticality. This pathological manifestation may be related to internal stresses caused by differential shrinkage of wood during successive moisture-loss cycles, a process intensified by the anisotropy of the material.

Pfeil and Pfeil (2014) noted that dimensional variations in the radial and tangential directions generate internal stresses capable of producing longitudinal cracks in wood members. Although moisture exposure and contact with soil may not immediately cause substantial loss of integrity, these conditions favor biodeterioration agents and increase wood susceptibility to biological attack (Farias *et al.* 2023). Therefore, preventive monitoring is essential to avoid progression and preserve structural performance.

Formaio *et al.* (2023) also reported the impacts of climatic variations and weather exposure on wood structural elements. Solar radiation, wind, rain, and moisture promoted physical deterioration of exposed wood, causing surface changes, cracks, and checking. The authors also identified fungi in the inspected structure and emphasized the importance of periodic inspections and maintenance to prevent pathological manifestations from worsening and to extend service life.

Floor Gaps Larger Than 5 mm

Floor gaps larger than 5 mm scored 27 in the GUT Matrix and were classified as a pathological manifestation of low structural severity. This manifestation is related to wood hygroscopicity, in which moisture variations toward equilibrium with the environment cause dimensional changes, expressed as shrinkage or swelling (Logsdon 1998).

Although these openings do not compromise the stability of the stilt house, they reduce functional performance by allowing debris and insects to pass through the underfloor void. This defect highlights the importance of adequate construction details and preventive maintenance because these factors directly influence the durability and performance of wood structures (Brito 2014).

Questionnaire Results from Residents

The questionnaire applied to residents was used to triangulate visual-inspection data with use practices, maintenance routines, and risk perception. Because the sample comprised 10 units, the results are presented as absolute and relative frequencies and have a descriptive character. Priority was given to questions with higher response rates and

stronger relationships with the conservation of wood members.

The first aspect assessed was the frequency of interventions performed by residents, especially replacement of boards and pillars (Fig. 4). This information is relevant because literature on wood structures indicates that periodic inspections and maintenance are essential for controlling moisture, biodeterioration, and performance loss (Brito 2014; Vidal *et al.* 2015).

Figure 4 indicates that 7 of the 10 residents (70%) replace components only when a visible problem occurs. Only 1 resident (10%) reported replacement every two years, while the others reported replacements performed four years ago or more than two years ago. This result suggests an association between the predominance of corrective maintenance and the high frequency of pathological manifestations observed during inspections, without establishing a direct causal relationship because of the small sample size. The perception of residents regarding the most vulnerable elements was then analyzed. This information is important because users follow the behavior of the building over time and can indicate recurrent deterioration.

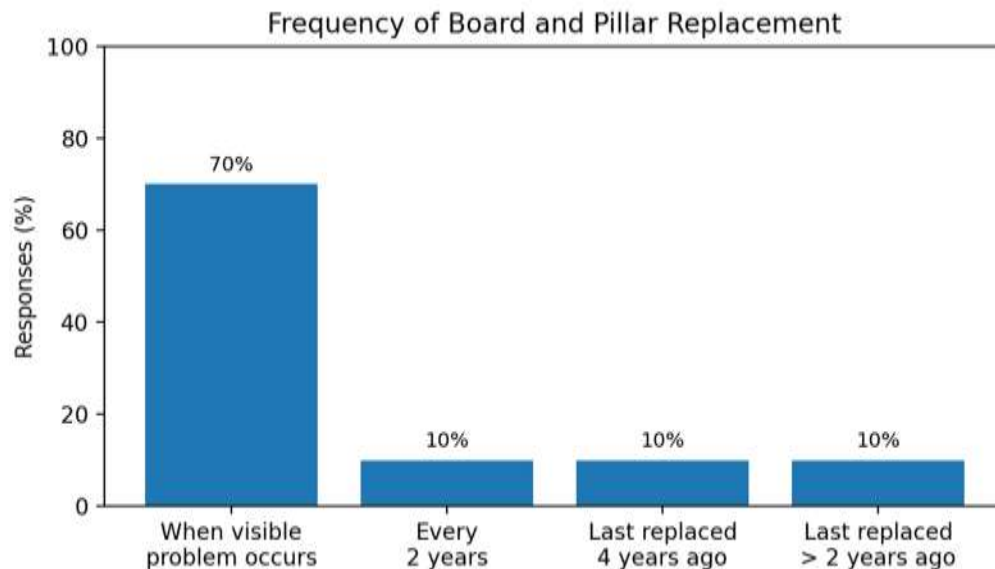


Fig. 4. Frequency of board and pillar replacement

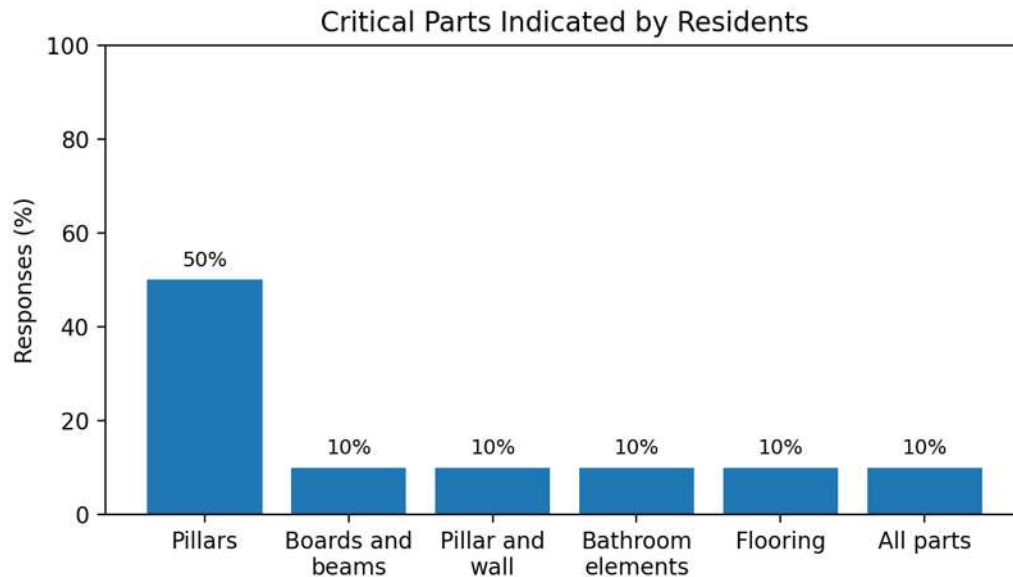


Fig. 5. Critical parts of the stilt houses indicated by residents

Figure 5 shows that 5 of the 10 users (50%) identified pillars as the most critical part of the stilt house. This perception converges with the visual-inspection findings because degraded bases and tops of pillars were identified in all evaluated units. Thus, pillars represent the main point of convergence between the technical diagnosis and the residents' perception.

The vulnerability of pillars and other components is associated with the absence or inefficiency of protective barriers against moisture and biological agents. Figure 6 summarizes responses regarding substances or finishes applied by residents to new wood before installation.

Figure 6 shows that 5 of the 10 stilt houses (50%) receive no protective treatment on new wood. In 3 units (30%), residents reported the use of used engine oil and/or diesel. Pereira *et al.* (2015) found, under controlled experimental conditions, that used engine oil increased the resistance of Amazonian woods to termite attack. However, this empirical practice should not be regarded as equivalent to standardized preservative treatments selected according to wood species, exposure conditions, and intended use (Vidal *et al.* 2015). Oil-based paint was reported in 2 units (20%). Although it may function as a surface finish, it does not replace preservative treatments suitable for wood exposed to moisture, fungi, and termites. Controlled studies have shown that preservative treatment can improve wood resistance to xylophagous organisms (Paes *et al.* 2008), reinforcing the importance of appropriate treatment in the evaluated stilt houses.

None of the residents reported use of a standardized industrial preservative treatment. For highly exposed structural members, preventive maintenance should combine moisture-control detailing with preservative treatment selected according to wood species, treatability, exposure class, and applicable environmental requirements. In Brazil, pressure impregnation with registered water-borne preservatives, including CCA- or CCB-based systems, is an established approach for wood subject to biological attack, and experimental evidence has shown improved resistance to xylophagous organisms after preservative treatment (Paes *et al.* 2008; Vidal *et al.* 2015). The present study did not test the performance of preservative systems *in situ*.

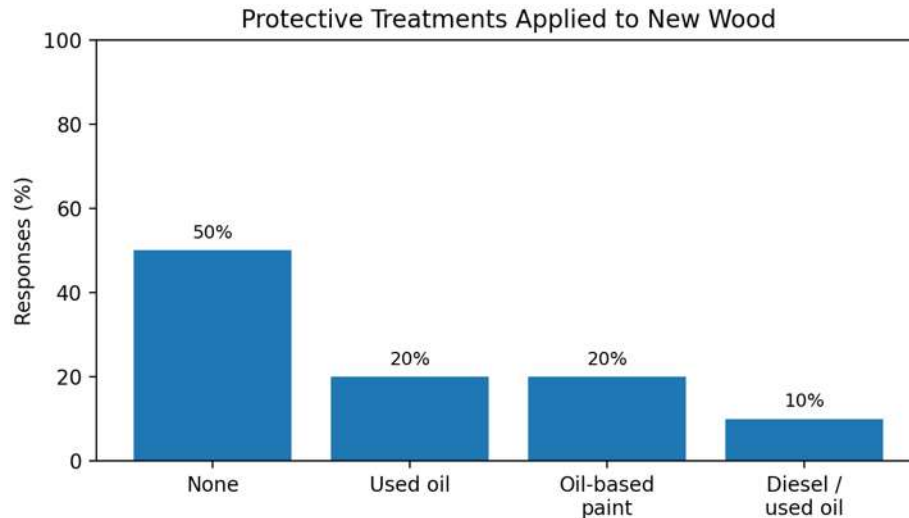


Fig. 6. Protective treatments applied to new wood

Another aspect identified in the questionnaires was the incorporation of mixed materials, especially concrete and masonry, as an empirical strategy to increase durability in wet areas. The presence and distribution of these solutions are shown in Fig. 7. Figure 7 indicates that 5 of the 10 stilt houses (50%) have masonry bathrooms, 1 unit (10%) has a masonry cesspit, and 4 units (40%) remain entirely made of wood. This result reveals a process of construction hybridization in which residents seek greater resistance in areas exposed to moisture, especially sanitary spaces. Although the association between wood and concrete can increase local stiffness and durability, it requires adequate detailing at interfaces to avoid moisture transfer, stress concentration, and incompatibilities arising from differential deformation. Therefore, the use of mixed materials should be accompanied by waterproofing, ventilation, and physical separation between materials (Ceccotti 2002; ABNT NBR 7190-1 2022).

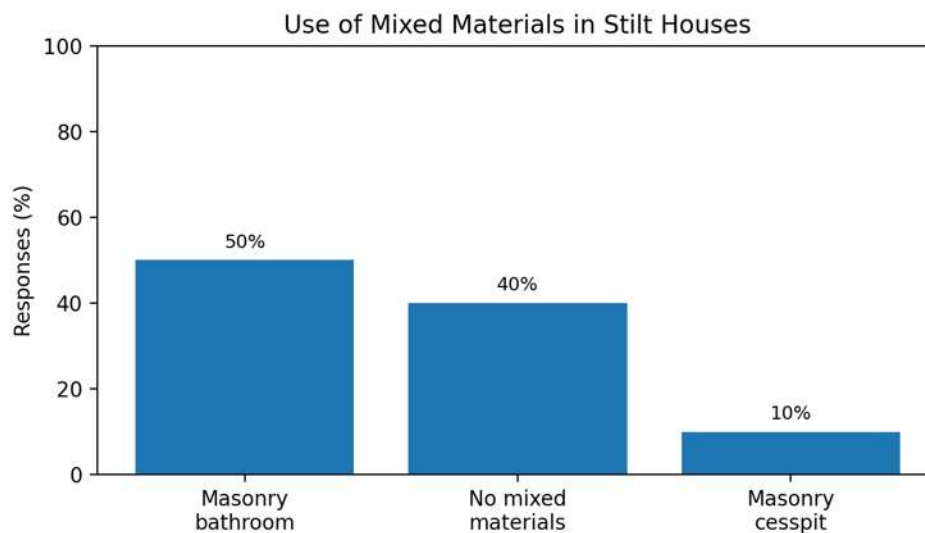


Fig. 7. Presence of mixed materials (concrete/masonry) in the stilt houses

Finally, the residents' knowledge of the wood species used in the structures was

investigated. This information is important for defining maintenance strategies, selecting preservative treatments, and assessing the natural durability of the material.

Figure 8 shows that 9 of the 10 residents (90%) did not know how to identify the wood species used in the structure. Only 1 resident (10%) indicated the use of amarelão and angelim-pedra, native species recognized for high density and natural durability. This lack of knowledge makes it more difficult to adopt specific preventive measures because different species have distinct levels of resistance to moisture, permeability, and attack by xylophagous organisms (Zenid 2009; Brito 2014).

Because the field protocol was intentionally non-destructive, no wood specimens were removed for anatomical identification. The common names reported by residents were therefore treated as self-reported information and not as taxonomically confirmed species identifications. Future studies should include anatomical identification or another validated species-identification procedure before relating deterioration rates to specific wood species.

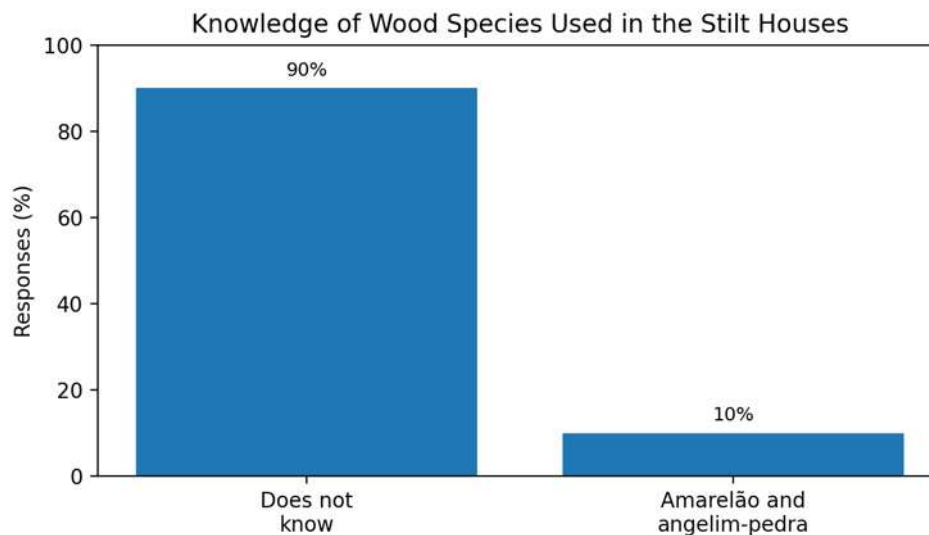


Fig. 8. Knowledge of the wood species used in the stilt houses

In summary, the questionnaires reinforce that deterioration observed during inspections did not depend only on environmental conditions. It was also associated with predominantly corrective maintenance practices, empirical treatments, construction hybridization without technical detailing, and lack of knowledge regarding the wood used. These factors should guide technical-assistance programs and preventive maintenance strategies for Amazonian stilt houses.

The main limitation of the study was the small sample size and qualitative design, which did not allow statistical generalization to all Amazonian stilt houses. Additional limitations include the absence of documentary verification of construction dates, anatomical confirmation of wood species, moisture-content profiles by elevation, geotechnical measurements of pillar-base settlement, and entomological tracing between neighboring houses. Nevertheless, the adopted protocol proved useful for integrating visual inspection, residents' perceptions, and prioritization by the GUT Matrix. Future research may expand the number of evaluated units, include non-destructive testing, monitor wood moisture at different elevations and hydrological periods, perform anatomical identification of the wood species used, and investigate spatial pathways of xylophagous infestation.

CONCLUSIONS

1. This research diagnosed 11 pathological manifestations in the wood structures of 10 stilt houses located in the Jardim das Araras neighborhood, Itaituba, Brazil. The results confirmed that the floodplain environment, characterized by high moisture, contact with freshwater, flood and falling-water cycles, and exposure to biological agents, is a critical condition for the durability of these buildings.
2. The most recurrent manifestations were staining/mold fungi and degradation of pillar bases and tops, both observed in all evaluated units. Deep longitudinal cracks in pillars, decay fungi in beams and pillars, ruptures and displacements of structural elements, beam deformation, member instability, subterranean termite tunnels, decay in guardrails, deterioration due to excessive moisture, and floor gaps were also identified. Visible subterranean termite tunnels were recorded in 6 of the 10 houses (60%; P1, P2, P3, P4, P5, and P7). This was a frequent manifestation, but it was less recurrent than staining/mold fungi and degradation of pillar bases and tops, which occurred in all 10 units.
3. The GUT Matrix ranked the manifestations according to Gravity, Urgency, and Trend. The highest scores were assigned to decay fungi in beams and pillars, ruptures or displacements of structural elements, degraded bases and tops of pillars, visible deformation in beams, and member instability, all classified as critical. The accumulated index by stilt house indicated higher priority for units P4, P5, P10, P2, and P3, which concentrated the highest sum of damage.
4. The questionnaires showed the predominance of corrective maintenance: 7 of the 10 residents stated that they replace components only after visible problems appear. In addition, 5 residents identified pillars as the most critical elements. This perception converged with the technical visual inspection by the research team, which identified degraded pillar bases and tops in all 10 houses and classified this manifestation as critical (GUT = 125). Resident opinions were used as complementary evidence and did not determine the GUT scores. Half of the stilt houses received no treatment on new wood, whereas part of the residents employed used oil, diesel, or oil-based paint, practices that do not replace adequate preservative solutions for exposed wood.
5. Five of the 10 stilt houses had masonry bathrooms, indicating construction hybridization as an attempt to increase durability in wet areas. However, the association between wood and masonry/concrete requires technical care at interfaces, especially regarding waterproofing, ventilation, and prevention of moisture transfer. Furthermore, 9 of the 10 residents did not know the wood species used, which limits the definition of specific preservation and maintenance strategies. Because no anatomical identification was performed, the species information should be interpreted as resident-reported rather than as taxonomically confirmed.
6. Based on these results, periodic inspection routines are recommended, with priority given to pillars, piles, beams, and connections; control of moisture and residues under the buildings; planned replacement of members with section loss; use of preservative treatments compatible with the exposure class; and technical guidance for residents regarding wood selection, risks from xylophagous agents, and appropriate preventive maintenance practices.

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APPENDIX

Stilt-House Inspection and Interview Questionnaire

Questionnaire for inspection and interviews in stilt houses (Jardim das Araras neighborhood, Itaituba, PA, Brazil).

Section	Fields / Questions
I. Building and location data	Stilt-house identification; inspection date; geographic coordinates (GPS); proximity to water; type of foundation/support.
II. Housing context and history	1. How long has this stilt house existed? 2. Which wood species were used to build the house, especially the pillars in contact with water? 3. Was the wood new, reused from other houses, or mixed?
III. Maintenance and structural life cycle	4. How often have you needed to replace the main boards or pillars? 5. In what period of the month/year is wood most often replaced or repaired (low-water or flood season)? 6. Which part of the house usually deteriorates fastest? 7. Does the new wood receive any paint, oil, or special treatment before installation? If yes, which one?
IV. Perception of pathology and risk (GUT Matrix)	8. Have you noticed any part of the house that became hollow or spongy due to decay? 9. If someone steps on or places weight on this member, do you feel that it is still safe or could it break?
V. Environmental factors and hybrid construction	10. Is there concrete, brick, or masonry in any part of the house (walls or floor)? 11. Is there any place under or beside the house where waste or dirt accumulates and retains water?

Visual Record of Occurrences Identified in the Case Study

The following visual records show the pathological manifestations observed during the visual inspection of the stilt houses.



Fig. A1. Occurrence 1. Decay fungi in beams and pillars. GUT score: 125



Fig. A2. Occurrence 2. Rupture/displacement in apparent structural elements. GUT score: 125



Fig. A3. Occurrence 3. Degraded, hollow, or partially missing pillar bases and tops. GUT score: 125



Fig. A4. Occurrence 4. Visible deformation in beams and pillars. GUT score: 125



Fig. A5. Occurrence 5. Member instability. GUT score: 125



Fig. A6. Occurrence 6. Visible subterranean termite tunnels. GUT score: 80



Fig. A7. Occurrence 7. Staining/mold fungi. GUT score: 80



Fig. A8. Occurrence 8. Deterioration due to excessive moisture. GUT score: 80



Fig. A9. Occurrence 9. Guardrails/enclosures with decay at the base. GUT score: 64



Fig. A10. Occurrence 10. Deep longitudinal cracks in pillars. GUT score: 36



Fig. A11. Occurrence 11. Floor gaps larger than 5 mm. GUT score: 27