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WOODEN BRIDGES IN AMAZONIA: RECOMMENDING REGIONAL FOREST SPECIES FOR STRUCTURAL MAINTENANCE

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ABSTRACT

Wooden bridges are essential structures for communities, especially in the Amazon region, where they have played a crucial role in territorial unification. Most were built without the supervision of specialized technicians. Maintenance of these structures is essential to ensure their durability, given the use of different wood species and the challenges of natural degradation. This study aims to list suitable Amazonian species for each structural element of DNIT-type bridges (Brazilian National Department of Transport Infrastructure), taking into account natural durability, mechanical strength and dimensional stability. The justification lies in the need to increase the useful life of these structures, taking into account factors such as environmental degradation and biological attacks. To this end, bibliographic data on the species identified in two bridges on the BR319 was studied, selecting and separating them into groups, for use at points most susceptible to attack and points subject to the weather, which meet the structural calculation, and also have good dimensional stability. The results listed eigth possible forest species for appropriate use in the maintenance of DNIT-type Amazonian wooden bridges.

Keywords: Sustainable forest management; Natural durability; Species grouping

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PONTES DE MADEIRAS NA AMAZÔNIA: RECOMENDAÇÃO DE ESPÉCIES FLORESTAIS REGIONAIS PARA A MANUTENÇÃO ESTRUTURAL

RESUMO As pontes de madeira são estruturas essenciais para as comunidades e especialmente na região Amazônia, onde desempenharam um papel crucial na unificação territorial. A maioria foi construída sem a supervisão de técnicos especializados. A manutenção dessas estruturas é fundamental para garantir sua durabilidade, dado o uso de diferentes espécies de madeira e os desafios com a degradação natural. Este estudo visou elencar espécies amazônicas adequadas para cada elemento estrutural das pontes tipo DNIT (Departamento Nacional de Infraestrutura de Transporte), considerando durabilidade natural, resistência mecânica e estabilidade dimensional. A justificativa está na necessidade de aumentar a vida útil dessas estruturas, levando em conta fatores como degradação ambiental e ataques biológicos. Para isso foram estudados dados bibliográficos das espécies identificadas em duas pontes na BR319, selecionando e separando-as em grupos, para uso em pontos mais suscetíveis a ataques e pontos sujeitos às intempéries, que atendam ao cálculo estrutural, e além disso, possuam boa estabilidade dimensional. Os resultados elencaram oito espécies florestais possíveis para uso adequado na manutenção das pontes de madeira amazônicas tipo DNIT.

Palavras-Chave: Manejo florestal sustentável; Durabilidade natural; Agrupamento de espécies

1. INTRODUCTION

Bridges are fundamental structures for the development of communities, as they connect cities and shorten distances, facilitating the movement of people and goods. Despite some good examples of properly designed and executed wooden bridges, which guarantee them good durability and use, most of Brazil's wooden bridges were not built by technicians specialized in wood, which can compromise the quality and durability of these works (Calil Junior et al., 2008; Scaliante, 2014).

To promote the territorial unification of the Amazon region by land in the 1970s, hundreds of wooden bridges had to be built, overcoming the numerous natural obstacles, especially the region's abundant waterways (Munhoz, 2023). The use of wood as a construction material for bridges in the Amazon was a natural choice, due to the great availability of this resource in the region (Vasconcelos, 1993).

There are dozens of wooden bridges on the BR 319 highway linking Manaus (AM) to Porto Velho (RO). The maintenance of these bridges is essential for the local connection and with around fifty years of use, they require an analysis of their structural design and the materials used. An analysis of two bridges identified twelve species of wood in the structures and recorded 95 macrofungi, mainly from the Polyporaceae family, as well as the presence of xylophagous insects in less resistant wood. These findings highlight the diversity of the materials used and the need for specific strategies for their conservation (Paula et al., 2021).

The use of several species in the same structure is not the main factor for structural problems, but it is economically unviable to opt for a single species due to the irregular distribution of trees in the management areas, and the abundance of species in the region, which can reach around 6700 species (Cardoso et al., 2017).

The Amazon is home to between 40 and 400 species per hectare, many of which play a crucial role in climate regulation, although their density is relatively low (Jardim & Hosokawa, 1987; Tello, 1994; Oliveira, 1997; Higuchi et al., 1998; Carneiro, 2004).

Through the use of Sustainable Forest

Management (SFM), it is possible to exploit timber resources in a balanced way, guaranteeing their regeneration and ecological preservation (Higuchi, 1994).

In terms of structural design for bridges, the Brazilian standard for Timber Structure Projects NBR 7190 (ABNT, 2022) encourages the grouping of species based on mechanical strength, but requires care to avoid technological problems. In the case of timber bridges, such as the DNIT type in the Amazon, the structural design allows the use of different species without compromising the integrity of the construction.

The Amazonian environment is extremely favorable to wood degradation, whether due to abiotic factors (temperature, humidity, luminosity, acidity, etc.) or xylophagous organisms, mainly fungi and insects (Jankowsky, 1990). Respect for special care in the project design phase minimizes wood degradation, and it is essential to choose the right species for the exposure environment. The Brazilian standard NBR 16143 Preservation of wood - System of categories of use (ABNT, 2013) establishes categories of use for wood according to its exposure, prioritizing more resistant species for external applications. Similarly, the Brazilian standard for Wooden Structure Projects NBR 7190 (ABNT, 2022) recommends the use of more durable woods in areas vulnerable to insects and fungi, ensuring greater longevity for the structure.

The study is justified by the fact that in order to increase the useful life of a structure, it is crucial not only to assess the strength and rigidity of the material in relation to the loads it supports, but also to consider that certain elements may be more susceptible to degradation due to exposure to adverse climatic conditions or environments that are conducive to attack by organisms such as fungi and insects. It is essential to take into account the environment in which the structure will be used and this study points out the critical points of degradation in the design of DNIT-type bridges installed on highways in the Amazon region.

In this context, the aim of this study is to list native Amazonian species, with data available in the literature, that are suitable for each structural element that makes up the DNIT-type bridge, taking into account natural durability, the necessary mechanical strength and dimensional stability.

2. MATERIAL AND METHODS

2.1 Material

The target material for this study is data related to the mechanical properties, natural durability and anisotropy coefficient of trees from the Amazon region, Where DNIT-type bridges are built. Due to the large number of species, the most commonly found species were chosen, taking as a parameter the study carried out by INCT Madeiras da Amazonia (National Institute of Science and Technology) and INPA (National Research Institute of Amazonas), through Projeto de Desenvolvimento Sustentável PDS-Morena, located in the city of Presidente Figueiredo, State of Amazonas, between 2014 and 2017.

In this project, a sample forest inventory was carried out covering an area of 20 ha and four areas of 10 ha each for a forest inventory (census) with a DBH of $\geq$ 20 cm, with a view to the area of effective exploitation. Only one 10 ha area was used for the case study. In this area, 1,535 individuals with DBH $\geq$ 20 cm were found, totaling 2,439 m³ of timber in logs, while for trees with the minimum cutting diameter (MCD) allowed by law (MCD > 50 cm) and commercially available, 98 trees were found.

2.2 Methods

Information on the 98 species was collected using databases, but not all of them have their characterization available in the literature. The online databases consulted were from the Forest Products Laboratory (LPF) of the Institute for Technological Research (IPT), and from books and forestry and timber information portals.

Due to the availability of rough sawn timber, the Cardeiro species (*Scleronema*

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micranthum) was tested in the laboratory following the minimum characterization method of ABNT NBR 7190-3 Design of timber structures - Part 3: Test methods for defect-free specimens for timber from native forests.

Based on the design of the DNIT-type bridge analyzed by Paula et al. (2021), illustrated in Figure 1, and on the load simulations carried out by Munhoz (2023), in the light of item 12.2 of the NBR 7190-1 (ABNT, 2022) standard for the Design of Timber Structures, which deals with the Systems and Categories of Use of Timber, the points and elements of the bridge most susceptible to biological attack and rot were identified. By cross-referencing this data with existing literature, taking into account the resistance class, natural durability and anisotropy coefficient, a list of recommended wood species was generated for each part of the bridge structure.

Figure 1. a) Side view of the bridge over the Igarapé Bandeirão; b) Detail of the pillars. Source: Paula et al. (2021)
Figura 1. a) Vista lateral da ponte sobre o Igarapé Bandeirão; b) Detalhe dos pilares. Fonte: Paula et al. (2021)

3. RESULTS

3.1 Natural durability

Table 1 shows the division of the species into three levels of natural durability: High, Medium and Low durability for the 141 species listed in the Morena PDS that have data catalogued in the literature. The same table shows the data found in the literature regarding the resistance class and the anisotropy coefficient, which is related to the dimensional stability of the species.

3.2 Durability of wood and category of use of DNIT-type bridge components

By comparing the information presented in Table 1, which details the natural durability of Amazonian wood species, with the data in Table 25 of the NBR 7190-1 (ABNT, 2022) standard for Wooden Structure Projects, which classifies the categories of wood use, it was possible to identify relevant patterns and correlations between the natural resistance of the woods and their recommended applications. Based on this analysis, the consolidated results were organized and presented in Table 2, providing a clearer and more structured view of the suitability of the different species for specific conditions of use.

Based on the reference in item 12.2 of standard NBR 7190-1 - Design of Timber Structures (ABNT, 2022), which deals with systems and categories of use for timber, and the analysis of the results consolidated in Table 2, it was possible to determine the most appropriate category of use for each component of the DNIT-type bridge. These classifications were established taking into

Table 1. Natural durability, strength class, and anisotropy coefficient of selected Amazonian species

Tabela 1. Durabilidade natural, classe de resistência e coeficiente de anisotropia de algumas espécies amazônicas

Common names	Scientific names	Natural durability	Strength class	Anisotropy Coefficient
Macucu chiador	*Licania* sp.	Low	D60 (4)	1,98 (6)
Macucu de sangue	*Mabea speciosa*	Low	D60 (1)	1,98 (6)
Louro rosa	*Nectandra rubra*	Medium	D50 (2)	2,50 (5)
Pequiarana	*Caryocar glabrum*	Medium	D40 (2)	-
Guariuba	*Clarisia racemosa*	Medium	D60 (1)	-
Sucupira amarela	*Vatairea sericea*	Medium	D60 (1,2)	-
Sucupira vermelha	*Hymenolobium pulcherrimum*	Medium	D60 (1,2)	-
Tauari	*Couratari stellata*	Medium	D40 (2)	1,35 (6)
Ucuuba puna	*Iryanthera* sp.	Medium	D60 (4)	1,61 (4)
Abiurana branca	*Micropholis guyanensis*	High	D50 (4)	2,24 (5)
Abiurana casca fina	*Pouteria fimbriata*	High	-	-
Abiurana ferro	*Pouteria pachycarpa*	High	-	-
Abiurana roxa	*Micropholis guyanensis*	High	-	-
Acariquara	*Minquartia guianensis*	High	D60 (5)	1,55 (5)
Acariquara branca	*Geissospermum argenteum*	High	-	-
Anani	*Symphonia globulifera*	High	-	1,75 (6)
Angelim rajado	*Zygia racemosa*	High	D60 (1)	1,57 (6)
Angelim pedra	*Dinizia excelsa*	High	D60 (2)	1,61 (5)
Cardeiro	*Scleronema micranthum*	High	D30 (3)	-
Caroba	*Jacaranda copaia*	High	D20 (1)	-
Casca doce	*Pradosia verticillata*	High	D40 (1)	-
Castanha de cotia	*Aptandra tubicina*	High	D60 (4)	-
Castanha jacaré	*Corythophora rimosa*	High	D60 (1)	-
Castanha sapucaia	*Lecythis pisonis*	High	D60 (5)	1,62 (5)
Castanha vermelha	*Cariniana micrantha*	High	D50 (4)	-
Cumaru roxo	*Dipteryx* sp.	High	D60 (1)	1,55 (6)
Cumarurana	*Dipteryx magnifica*	High	D60 (1)	-
Cupiúba	*Goupia glabra*	High	D60 (1)	1,78 (6)
Gito vermelho	*Guarea convergens*	High	D60 (1)	-
Itaúba	*Mezilaurus itauba*	High	D50 (1)	2,27 (6)
Louro amarelo	*Ocotea* sp.	High	D60 (1)	1,71 (6)
Louro gamela	*Ocotea* sp.	High	D40 (1)	-
Louro inhamui	*Ocotea* sp.	High	D50 (1)	2,07 (5)
Louro japura	*Ocotea* sp.	High	-	-
Louro preto	*Ocotea* sp.	High	D40 (4)	1,84 (6)

Sources: (1) Instituto Nacional de Pesquisas da Amazônia – INPA (1991); (2) Instituto de Pesquisas Tecnológicas – IPT (2025); (3) Ensaio em laboratório; (4) Laboratório de Produtos Florestais – LPF (2021); (5) REMADE (2025); (6) Siqueira (2022).

account the specific conditions of exposure and durability required for each structural element, as illustrated in Figure 2. In the figure it can be seen that the gauges used in the bridges are excessively large, which has contributed to the durability of the structures.

3.3 Strength classes of DNIT-type bridge components

Munhoz (2023) carried out simulations to assess the performance of bridges under the action of standard loads, represented by a 45-

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Table 2. Usage categories and wood durability recommendations
Tabela 2. Categorias de uso e recomendação da durabilidade da madeira

Use category	Wood service condition	Wood durability recommendation
1	Interior of buildings, not in contact with the ground, foundations, or masonry; protected from weather and internal moisture sources; inaccessible to subterranean or arboreal termites.	Low
2	Interior of buildings, in contact with masonry but not with the ground or foundations; protected from weather and internal moisture sources.	Medium
3	Interior of buildings, not in contact with the ground and protected from weather, but occasionally exposed to moisture sources.	Medium
4	Outdoor use, not in contact with the ground and exposed to the weather.	High
5	In contact with soil, fresh water, or other conditions favorable to deterioration, such as being embedded in concrete or masonry.	High
6	Exposure to saltwater or brackish water.	High

ton standard train, determining the necessary resistance for each structural element. Based on these results, by applying them to DNIT-type bridges, it was possible to define the corresponding structural classes for each bridge component, as illustrated in Figure 3. Based on this analysis, wood species were selected that simultaneously meet the criteria of mechanical strength, dimensional stability and natural durability, ensuring greater efficiency and longevity for the structure. Once again, the oversizing of the sections used in the construction of the bridges stands out, indicating the possibility of optimization. In the event of a more comprehensive renovation or complete replacement of the structure, rather than just a partial replacement of parts, the reduction in dimensions could result in a more efficient use of materials, while maintaining the safety and durability of the construction.

3.4 Species selected for maintenance of DNIT-type wooden bridges

Considering the category of use, i.e. natural durability for all bridge elements, a more restricted list was obtained from Table 2. Filtering further, taking into account only species with an anisotropy coefficient of less than 2, resulted in the list of species shown in Table 3.

4. DISCUSSION

This study showed that timber bridge projects need to be concerned about their durability and dimensional stability right from the design stage. The on-site inspection of bridges on the BR 319 highway carried out by Paula et al. (2021) showed that at the time the structures in question were built, there were no criteria for selecting and allocating the species for each structural element.

In this case, the designer of wooden

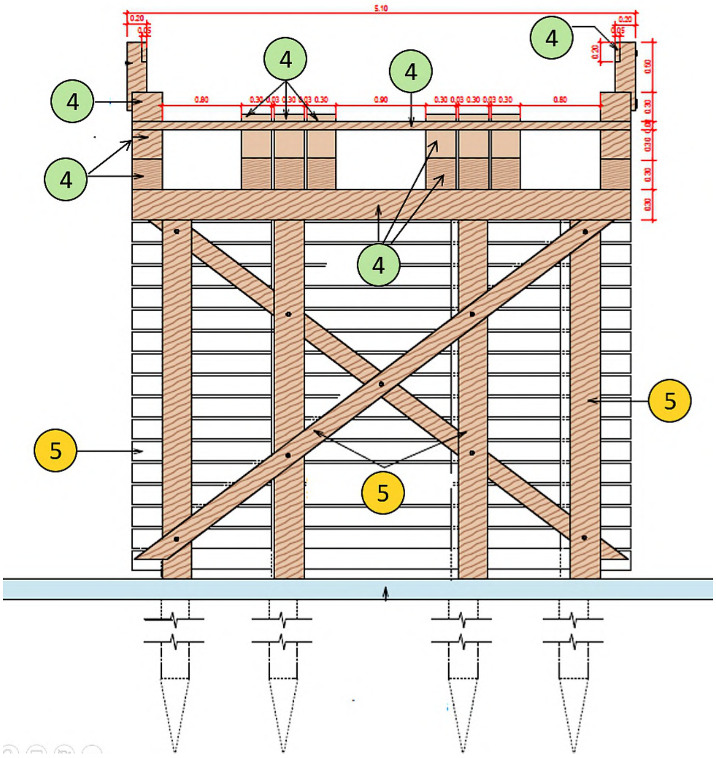

Figure 2. Indication of usage categories for each component of the DNIT-type bridge**.** The numbers indicate the categories of use listed in Table 2

Figura 2. Indicação das categorias de uso para cada componente da ponte tipo DNIT. Os números indicam as categorias de uso listadas na Tabela 2

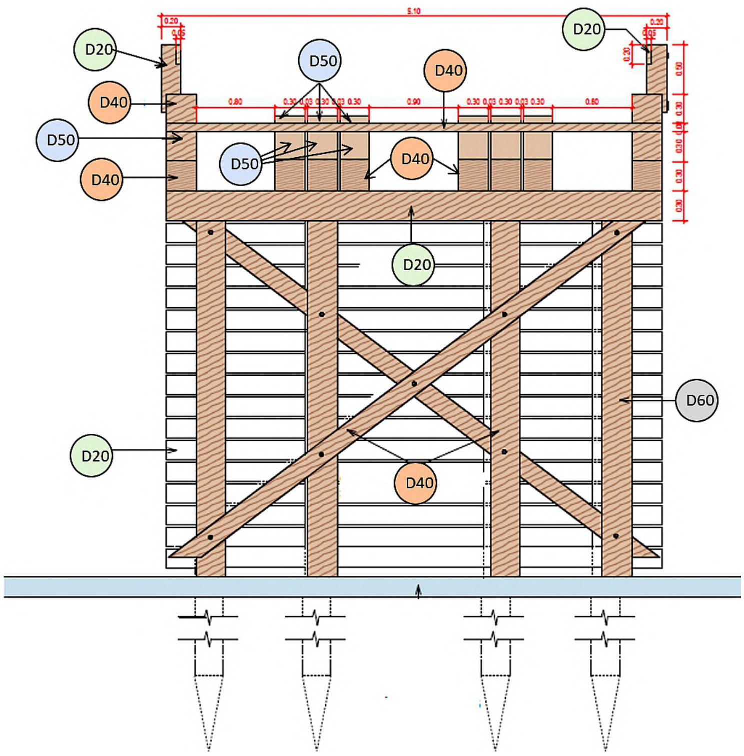

Figure 3. Strength classes for the bridge components. The codes indicate the wood strength classes listed in Table 3

Figura 3. Classes de resistência para os componentes da ponte. Os códigos indicam as classes de resistência da madeira listadas na Tabela 3

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Table 3. Selected species for DNIT-type bridge components
Tabela 3. Algumas espécies selecionadas para componentes de pontes tipo DNIT

Common names	Scientific names	Natural durability	Strength class	Anisotropy Coefficient
Acariquara	*Minquartia guianensis*	High	D60 (5)	1,55 (5)
Angelim rajado	*Zygia racemosa*	High	D60 (1)	1,57 (6)
Angelim pedra	*Dinizia excelsa*	High	D60 (2)	1,61 (5)
Castanha sapucaia	*Lecythis pisonis*	High	D60 (5)	1,62 (5)
Cumaru roxo	*Dipteryx* sp.	High	D60 (1)	1,55 (6)
Cupiúba	*Goupia glabra*	High	D60 (1)	1,78 (6)
Louro amarelo	*Ocotea* sp.	High	D60 (5)	1,71 (6)
Louro preto	*Ocotea* sp.	High	D40 (4)	1,84 (6)

Sources: (1) Instituto Nacional de Pesquisas da Amazônia – INPA (1991); (2) Instituto de Pesquisas Tecnológicas – IPT (2025); (3) Ensaio em laboratório; (4) Laboratório de Produtos Florestais – LPF (2021); (5) REMADE (2025); (6) Siqueira (2022).

structures must not only take into account the mechanical strength of the wood, but also prescribe species according to their mechanical strength, dimensional stability and natural resistance. This requires more complete data on Brazilian forest species, specifically Amazonian species.

Paula et al. (2021) presented the identification of 12 species in a single bridge, which includes species that are used intensively in the sawn timber market, such as cumaru (*Dipteryx* sp.), cupiúba (*Goupia glabra* Aubl.), jatobá (*Hymenaea courbaril* sp), maçaranduba (*Manilkara* sp.), sucupira (*Andira parviflora* Ducke) and tauari (*Couratari* sp.). Categorization by resistance class, combined with natural resistance and a low anisotropy coefficient, helps to replace the use of these species with other alternatives that are more abundant and of less commercial interest.

According to Higuchi (2015), species such as matá-matá amarelo (*Eschweilera wachenheimii* (Benoist) Sandwith), breu vermelho (*Protium* sp.) and ucuuba punã (*Iryanthera* sp. (Benth.)) are abundant in the state of Amazonas and commercially unknown. Depending on their resistance classes, natural durability and anisotropy, they could be good substitutes for the species traditionally more accepted for structures.

Although Table 3 shows a limited number of species, there are hundreds of Amazonian species that have not yet been mechanically characterized, but which have the potential to meet the regional demand for renovation or replacement of current wooden bridges. Similarly, as shown in Table 2, research into little-known species should cover not only their mechanical characterization, but also the assessment of their natural durability, following the approach adopted by Santos et al. (2019). This scenario reinforces the importance of ongoing research aimed at studying and characterizing these lesser-known woods, allowing for more efficient and sustainable use of the resources available in the region.

In addition to the criteria pointed out in this study, it is important to note that current forestry legislation imposes rules that initially make the use of some species unfeasible. In short, the Brazilian Forest Code, governed by Law No. 12,651 of May 25, 2012, MMA Normative Instruction No. 5 of December 11, 2006 and Resolution No. 406 of February 2, 2009 of the National Environmental Council (CONAMA), establishes forest exploitation for timber purposes based on a Sustainable Forest Management Plan (PMFS) (BRASIL, 2012). In addition to stipulating cutting cycles and logging intensities, the minimum cutting diameter (DBH) is set at 50 cm.

The acariquara species (*Minquartia guianensis*) was one of the eight indicated in this study but has low diametric growth, with not all adult individuals reaching the minimum DBH. Andrade et al. (2017) assessed the growth of *M. guianensis* for 31 years and observed a decrease in diametric growth from DBH ≥ 50 cm, concluding that trees with DBH between 35 and 45 cm have the potential to be managed.

With an appropriate management plan, using the design criteria, it is possible to select species that can be used to maintain existing bridges or can be used for new wooden bridges. In the case of new bridges, it is recommended to develop a structural design with the appropriate dimensioning, as the one adopted at the time of highway construction in the region used cross-sections that were exaggerated for the acting loads, wasting financial and forestry resources. Other non-commercial or little-known species could be listed in future work based on the characterization of these species.

In terms of comparison with other studies, the literature review shows a significant gap in the current state of wooden bridges in the Amazon region. Most of the available publications discuss the existence of these structures and emphasize the need to replace them with concrete bridges, on the grounds that they are more durable and require less maintenance. However, there is a lack of studies that analyze in detail the current condition of these bridges, the challenges faced in their conservation and sustainable alternatives for their maintenance.

The proposal to replace it with concrete, although apparently beneficial, raises important environmental issues. Concrete, unlike wood, has a high environmental impact due to the extraction of its inputs and the high energy consumption in the manufacturing process. In contrast, wood is a renewable resource that is widely available in the Amazon and, when used within proper forest management practices, can provide a sustainable building material that is easy to replace.

This study makes a unique contribution by highlighting that, instead of prioritizing concrete replacement alone, it is essential to consider sustainable wood management strategies, enabling the gradual maintenance and replacement of structures over the years. In this way, as well as preserving the economic viability of buildings, this approach contributes to reducing environmental impact, in line with sustainable development principles.

5. CONCLUSION

The first conclusion drawn is that there is a lack of complete data on the characterization of Amazonian species, especially with regard to shrinkage tests to determine the anisotropy coefficient, as well as more tests on the natural durability of wood. This is reflected in the fact that only 36 of the 141 species analyzed have information available in the literature or in databases, representing around 25% of the total.

Secondly, it was found that of the 36 species with available data, only 8 (22.5%) meet the criteria of high durability, high strength class and low anisotropy coefficient. If this trend is confirmed for all 141 species, we could have a list of approximately 32 species suitable for use in DNIT-type bridge structures in the Amazon region, which is still a limited number compared to the approximately 6,000 species mentioned in the literature.

The compilation of bibliographic data, combined with normative criteria, proved to be essential for prescribing species, helping to ensure that new projects or renovations of existing bridges result in safer and more durable timber structures.

The identification and characterization of the mechanical properties and durability of woods with potential for efficient and sustainable use in timber bridges is fundamental. Therefore, further studies should be encouraged in future technical and academic research, contributing to the development of safer and more durable solutions.

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AUTHOR CONTRIBUTIONS

I. D. M.: Conceptualization, Investigation; M. C. M. P.: Methodology, Formal Analysis, Investigation, Writing - review and editing; A. J. N. L.: Methodology, Review, Writing - review and editing; E. V. C. M. de P.: Methodology, Writing - review and editing, Supervision.

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