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Design In Guadua Angustifolia For A Pedestrian Bridge In Potreros Cocorná Antioquia

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Abstract The use of guadua has increased in importance as a construction material due to the implementation of sustainable materials in the construction sector. This material provides a good view to passersby of the typical mountainous landscapes of eastern Antioquia in Colombia. Furthermore, bridges are fundamental structures for connecting territories separated by streams, roads, or topographic depressions. The methodology of this research work considers in the first step the bibliographic compilation, the second step the main physical and mechanical properties of the guadua/bamboo, the three-step the analysis of the points and connections, and finally, the last step four the architectural design appropriately a structure that can be used as a Pedestrian Bridge in Antioquia in the most faraway locations. Also, specialized design software was used to obtain the conceptual design of the components and geometrical areas of the bridge and thus consider its use in real conditions. This works aims to present an architectural solution consisting of a bridge with a span of 12 m considering as the main component guadua Angustifolia elements that are interconnected design with metal elements being as support to obtain adequate and ecological structural characteristics contributing to the development of the sustainability in the civil engineering projects. Finally, the results exposed that considering the literature review and research consulted, it is possible to design a bridge with the appropriate structural conditions. It’s important to mention that this work was carried out from the architectural and functional point of view of the structure, prioritizing aesthetic and urban aspects, for which it is necessary to carry out structural modeling, obtaining the design parameters from laboratory tests on the guadua species of the zone.

Keywords: Bamboo, eco-construction, guadua, Pedestrian bridges, Ecological engineering.

1. Introduction

Construction is an activity that contributes to the socioeconomic development of a country; however, it has an impact on the environment, economy and society due to the occupation of space and landscape, resource extraction and generation of waste and pollutants [1]. Sustainable construction is an approach sought by governments, environmentalists and the general population [2], which seeks a favorable impact on the environment, stimulating research and the use of plant-based materials such as natural fibers due to their wide availability in nature, low cost, low weight, high mechanical strength and excellent physical properties [3].

Bamboo has been considered as an excellent component to replace polluting materials such as concrete and steel in a variety of uses in construction [4], which has been used as a structural material (columns or compression elements in structures) for centuries in northwestern South America [5]. Colombia has the second highest level of bamboo diversity in Latin America, with 24 endemic species including Guadua Angustifolia Kunth [6].

Guadua is composed of unidirectional cellulosic fibers, which harden or lignify as the stem matures, increasing density and mechanical properties [7]. In the coffee-growing region and the departments of Cundinamarca and Antioquia it is common to use Guadua Angustifolia Kunth in construction systems and in the manufacture of laminates, demonstrating outstanding mechanical properties of compression load, which is why it is used in the construction of houses, bridges and support structures, among others [8].

Bamboo pedestrian bridges are evidence of the competitiveness of the material in engineering and a work without environmental pollution, being an economic and ecological option [9]. The purpose of this article is to determine the application of Guadua as a structural element for the design of a pedestrian bridge, seeking to optimize or replace traditional materials with new, less polluting materials, with equal or better mechanical and structural properties, aiming at sustainable development.

2. Materials and Methods

The research is of an analytical and investigative nature, so no laboratory tests or trials on guadua will be carried out, but data on the physical and mechanical properties of previous research and available documentary information will be collected. Based on the qualitative and quantitative information obtained, an architectural design for a 12 m bridge is proposed. Figure 1 describes the steps of the research.

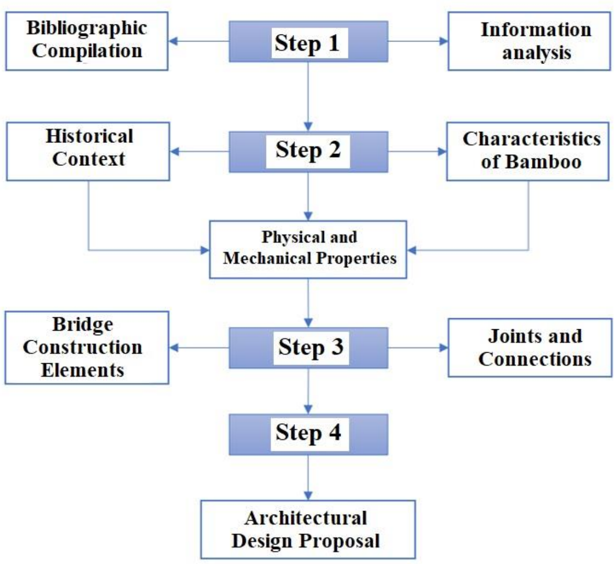

Figure 1. Methodology of work. Source. Authors

2.1. Study area - Municipality of Cocorná

The municipality of Cocorná is located in the eastern part of the Department of Antioquia, has an area of 210 km^2, an altitude of 1.300 m.a.s.l. and an average temperature of 23°C. Its main access is the Medellín-Bogotá highway, which tangentially touches the municipal seat [10].

2.2. Characteristics and properties of Guadua

Guadua is a woody bamboo species, listed as one of the 20 most sustainable bamboo species due to its rapid growth, size and capacity for CO2 sequestration [11], [12].Guadua is mainly constituted by cellulose and lignin (Table 1), where cellulose acts as reinforcement, similar to steel bars in reinforced concrete or fiberglass in fiber-reinforced plastic [13]; and lignin becomes the cell wall component, which represents between 20-35% of the plant biomass [11]. Mechanical properties are closely related to the proportion and distribution of fibers in the cross-section, where they are influenced by density, which depends on fiber content, fiber diameter and cell wall thickness [7].
Guadua is globally recognized for its physical characteristics due to the fact that it has specimens up to 30 meters high and 20 centimeters in diameter; and for its resistance to bending and compression, where it can have typical values in compression between 400 and 600 kg/cm2; However, these physical-mechanical properties present a considerable variation in their characteristic values due to cultivation factors [14], since it can present differences in terms of its development and growth due to the soils and climates where it is found, where soil quality, precipitation and temperature determine the development of the plant [12].

Table 1. Structural components of Guadua

Structural components of Guadua Angustifolia	% in weight
Cellulose	52.6
Hemicellulose	1.7
Lignin	27.6
Extractives	7.3

Source: [6]

Guadua has a specific weight of 0.5 to 0.6 and a specific gravity of 0.5 to 0.6, in addition to a high strength-to-weight ratio, energy absorption capacity and excellent flexibility that make it suitable for construction [15]. The parts of Guadua used in the construction of the structures are the Basa (center) and Sobrebasa (above), because their thickness and outer diameter are the most suitable from the point of view of resistance [16].
In a Guadua angustifolia the following parts can be distinguished: root, stem, leaves, flowers and fruits (Figure 2), where the stem is the culm, which has been used for different applications, which originates at the apex of the rhizome, being cylindrical, hollow and thin [17]. The diameter of Guadua varies widely, where in the more voluminous parts (lower section), it is from 10 to 18 cm, while in the thinner parts

(upper section) it is from 5 to 10 cm.

Guadua has a very efficient natural structural design, where the circular cross-section is composed of unidirectional cellulosic fibers (about 40% by volume) oriented parallel to the longitudinal axis of such, in a matrix of parenchymal tissue (50%; the remaining 10% are vessels for fluid transport) [7]. The properties of the material are comparable to those of conventional hardwood, then Table 2 and Figure 3 compare the different materials commonly used in construction with respect to guadua. However, is possible to observe in terms of the relationship between strength and stiffness with respect to the mass per volume of each material, guadua has a high performance considering its low weight.

Guadua is a material susceptible to interlaminar fracture [18], and has a low resistance to shear stress, a situation that requires an exhaustive analysis in the design of joints and connections, because it implies an additional risk due to the natural variability of the material, due to this each element of the construction must be subjected to a selection and inspection process following in detail the requirements established in the Colombian Seismic-Resistant Construction Regulation NSR-10 [19].

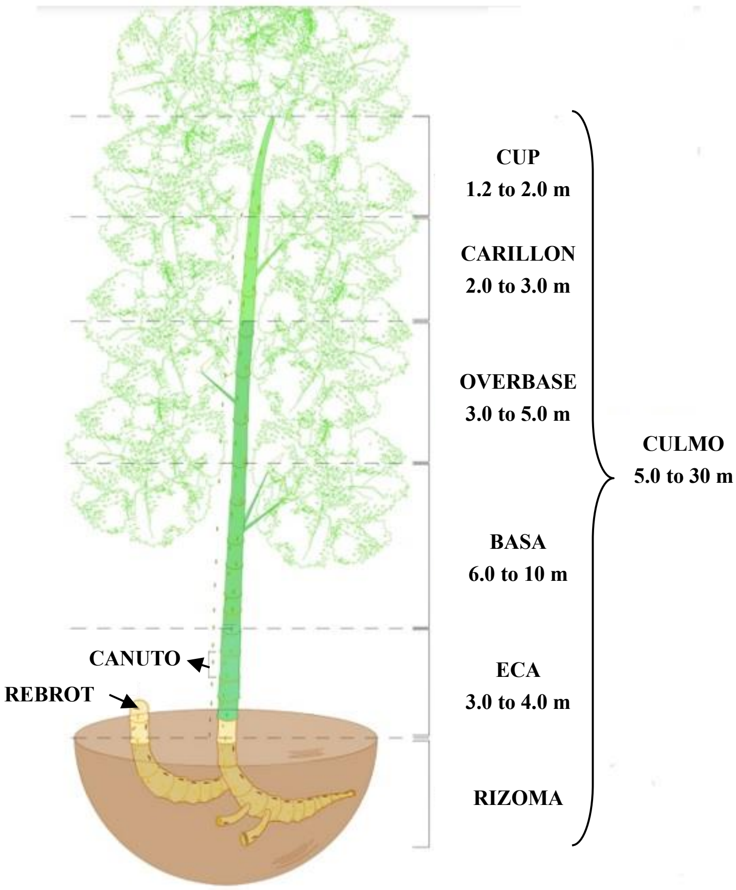

Figure 2. Components of Guadua.

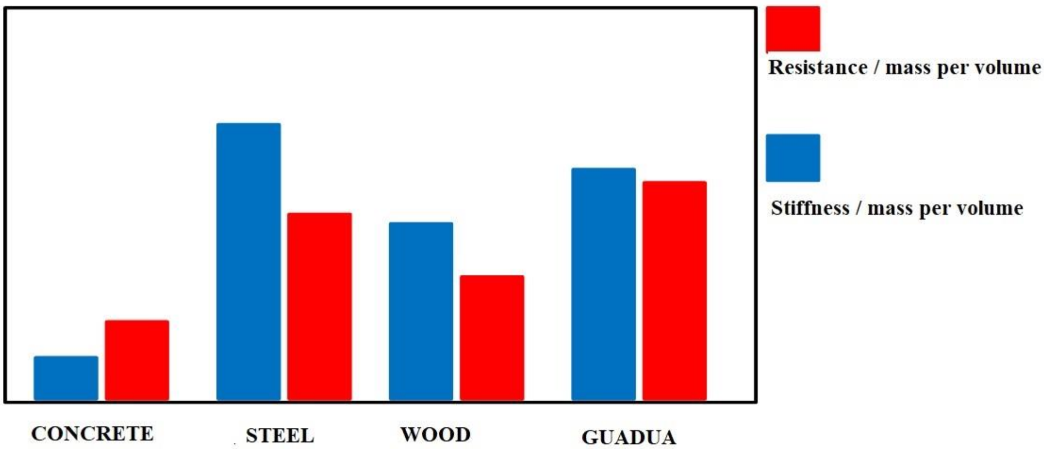

Figure 3. Comparison of the strength and stiffness of various building materials divided by their mass per volume. Source: Modification [20]

Table 2. Structural components of Guadua

Material	Design strength (kg/cm^2)	Mass per volume (kg/cm^2)	Resistance ratio (kg/cm^2)	Modulus of elasticity (kg/cm^2)	Stiffness ratio (kg/cm^2)
Concrete	82	2400	0.032	127400	53
Steel	1630	7800	0.209	214000	274
Wood	76	600	0.127	112000	187
Bamboo	102	600	0.170	203000	340

Source: [21].

3. Pedestrian Bridge Design

Ecological construction is an inevitable option for sustainable development, replacing materials such as steel and concrete with more environmentally friendly materials. The design proposal for the construction of the guadua pedestrian bridge in the municipality of Cocorná, will be based on the constructive elements, unions, and connections to reach the alternative architectural design of the bridge.

3.1. Construction elements, joints, and connections

The analysis and design of construction elements with guadua, as with wood, can be somewhat dangerous, since, even when the elements are sufficiently resistant for the calculated stresses, the joints and connections can become too weak, and in the case of guadua, these require special care. There are several traditional solutions for connections with this material, however, the fundamental problem lies in the low resistance of guadua to tensile stresses, a fact that is extrapolated to the trusses that can be configured with this material [22].
Figure 4 describes the main types of joints and connections used in the design of the pedestrian bridge.

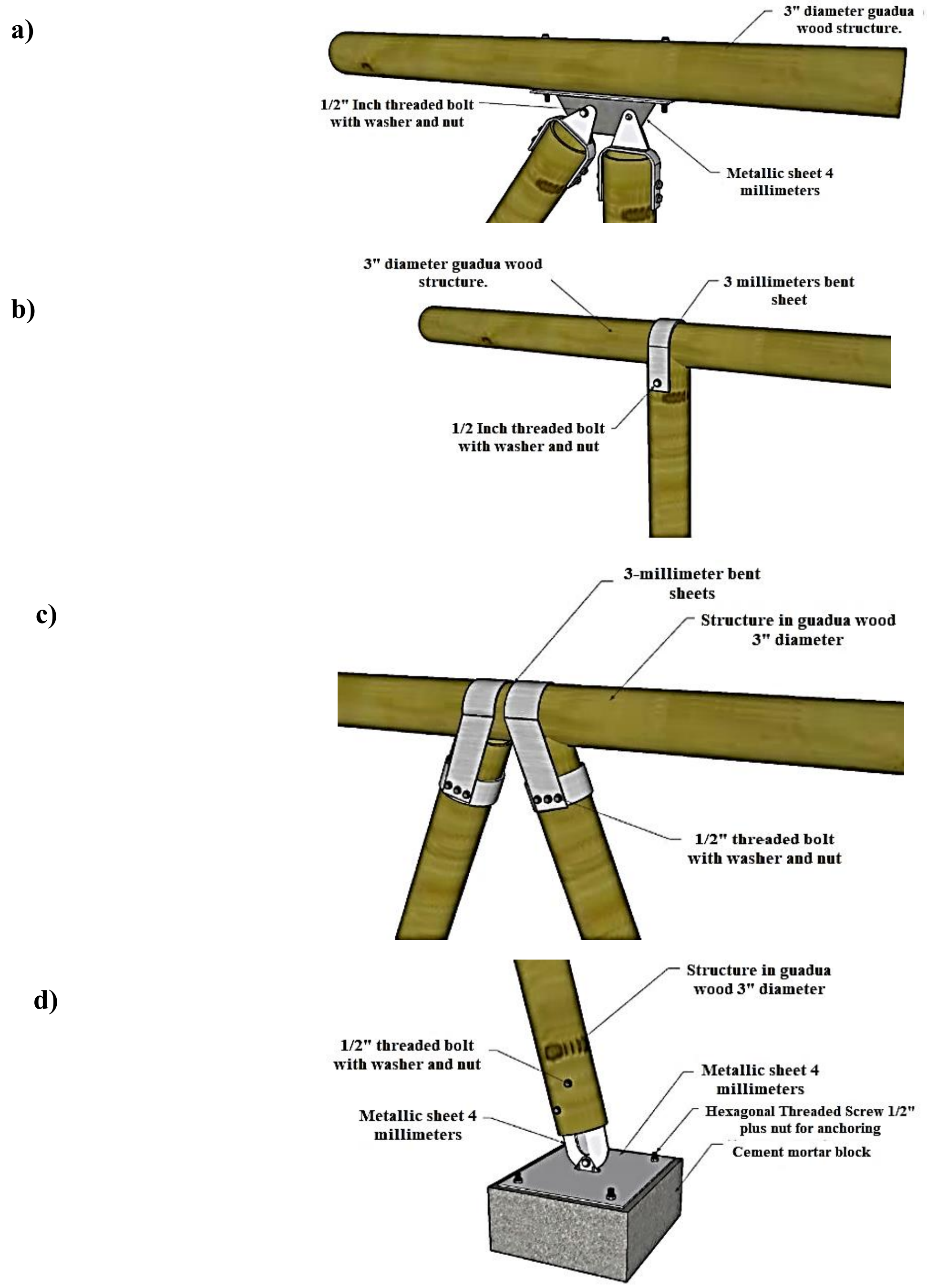

Figure 4. Main joints and connections of the bridge structure. a) join couple with the horizontal bar, b) Fixation, c) Reinforced union and d) Couple with the metallic sheet. Source. Authors

3.2. Bridge architectural design alternative

The main structure, as shown in Figure 5, consists of a 12.01 m long deck, composed of 192 bamboo units arranged transversely, which behave like beams with a length of 2.15 m and an average diameter of 4 inches. It has two trusses on each side of the deck, which consist of an arch composed of bamboo elements braced together by mechanical joints with heights varying between 3.0 m and 5.0 m.
The bridge has two access ramps as shown in Figure 6, and corresponding metal stairs, with an initial

section of 3.60 m, a 2.03 m landing and a second section of 2.36 m. The handrails are designed in guadua with an average diameter of 3 inches. In total, the pedestrian bridge has an effective length of 21.15 m from one end of the road to the other.

The deck is supported by four columns that converge in two pedestals respectively, which can be seen in the details of figure 7, the columns are composed of 8 guaduas joined together acting as a single structural element with dimensions of 0.26m and 0.13m respectively, and a length of 3.18m. The pedestal is a 0.40m long, 0.37m wide and 0.77m high concrete cube. Figure 9 shows the details of column C2, which supports the access stairs and corresponds to a 1.38m high metal I-profile embedded in a 0.40m long, 0.37m wide and 0.55m high die.

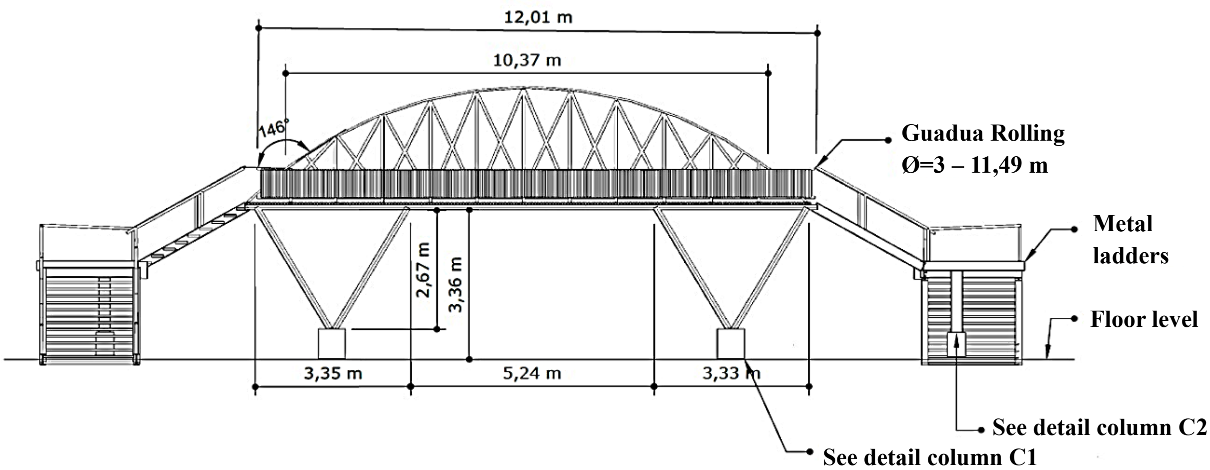

Figure 5. Front view of bridge. Source. Authors

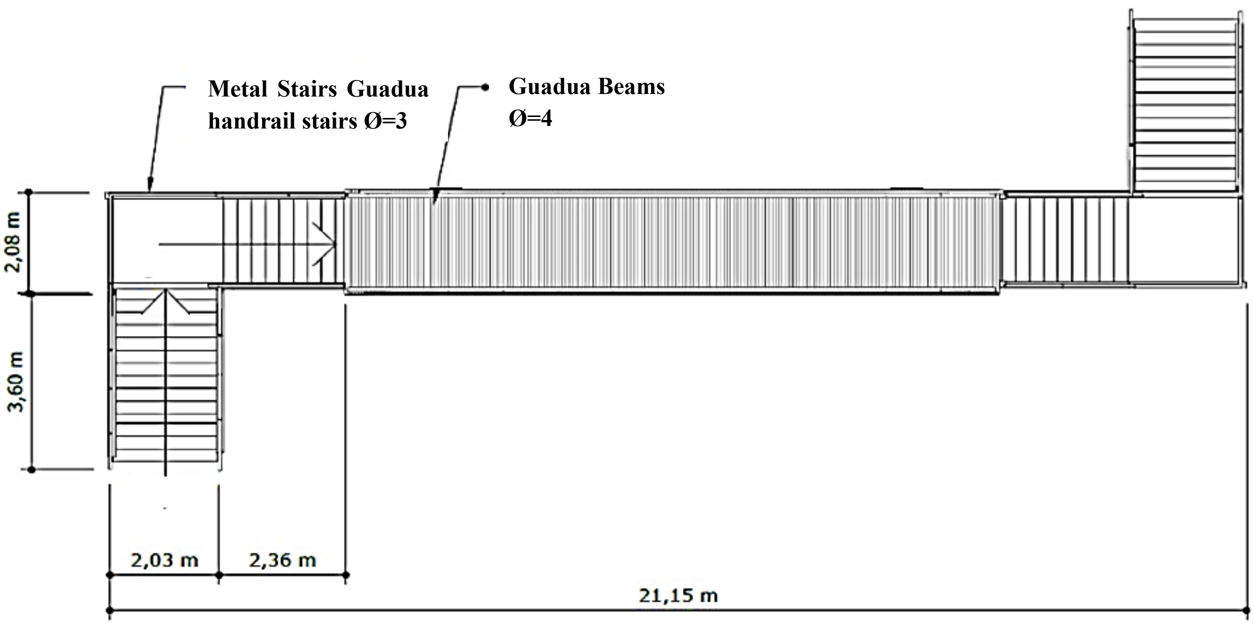

Figure 6. Plan view of the bridge.

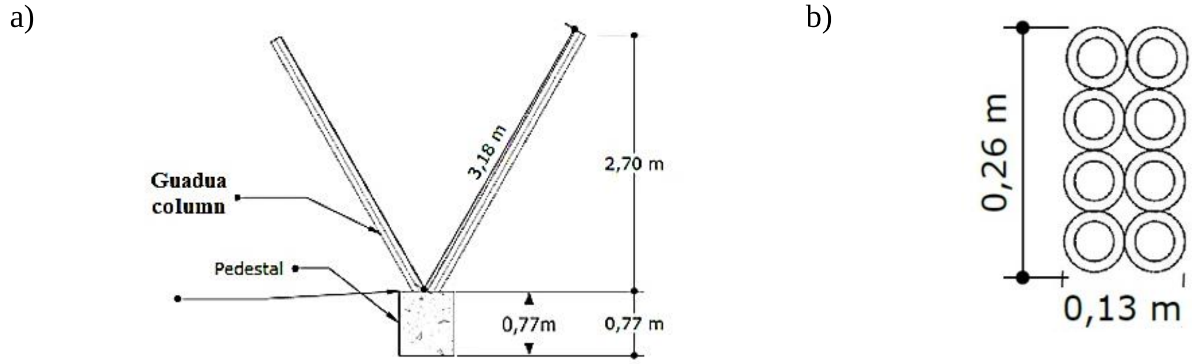

Figure 7. Column C1 (a) front view, (b) plan view.

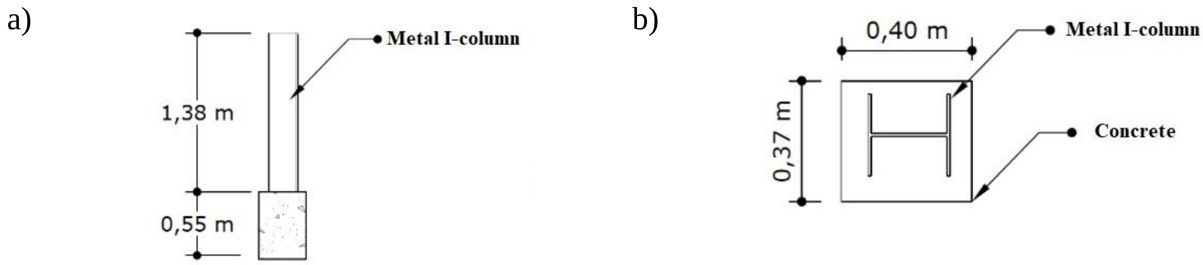

Figure 8. Column C2 (a) front view, (b) plan view.

Finally, Figure 9 shows the final design of the bridge in a 3D model. The main purpose of the proposed design was to harmonize the structure with the landscape context of the area, being an aesthetic and functional alternative that allows safe passage for pedestrians and provides a pleasant experience for users.

Figure 9. General design of the bridge. Source. Authors

4. CONCLUSIONS

In this work, a descriptive analysis of guadua as an alternative material for the construction of pedestrian bridges is carried out, motivated by the growing need to use materials that require less energy consumption and have a lower pollutant load. From the literature and research consulted, it is possible to assure that guadua is a material with an adequate structural behavior and with which different structures have already been built in Colombia.

Guadua as a construction material is a sustainable alternative to traditional materials and its use, besides being ecologically friendly as a substitute for wood, also imposes a new style in architecture.

Colombia ranks second in Latin America in the diversity of bamboo species, which is why it is pertinent to begin to include the use of this material more frequently in the urban design of cities. The pedestrian bridge designed for the municipality of Cocorná is an alternative framed within the ecological constructions, which in addition to providing a pleasant experience to users due to its aesthetics and finish is also functional to the extent that it offers a safe passage to passersby.

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