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Analyzing the Load-Bearing Capacity: Mechanical Properties of Guadua Cane Beams and Joists in Manabí

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Bamboo cane (Angustifolia Kunth) represents a valuable renewable resource in many rural areas of Ecuador, particularly in the province of Manabí, owing to its ecological significance and historical usage in construction. Despite its longstanding application in housing construction, the lack of technological advancements has hindered its industrialization. This limitation arises from inadequate knowledge regarding essential material characteristics, including age, moisture content, soil nutrients, and post-harvest treatment. The objective of the research is to analyze the load-bearing capacity of guadua cane beams and joists for the construction of sustainable homes with higher quality. By leveraging advanced technologies for cutting and sterilizing bamboo wood, the aim is to develop domestic solutions tailored for social housing projects. The anticipated outcomes include improved living conditions and enhanced structural quality, thereby positively impacting the livelihoods of communities in Manabí and beyond.

Keywords: Guadua Cane, Load-Bearing Capacity, Mechanical Properties, Beams, Joists.

1. Introduction

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format. The paper must be written in correct English. If the quality of the language is too poor, this can prevent your paper from being included in the Proceedings. For the good appearance of the Proceedings, it is of intrinsic importance that all full texts are of the same shape. The paper is to be written in two-column format on the paper size A4 and be right and left justified, using single spacing (Cambria 11 pt). The width of top, left, and right is 20 mm, and bottom margins is to be 25 mm. The width of each column is to be 80 mm, and the gap between columns should be 10 mm (Format>Columns).

The definition and function of beams in structural engineering are fundamental to understanding their importance in construction. Beams are horizontal structural elements that support vertical loads, redistributing them to the supports and foundations of the building. Its main purpose is to offer support and stability, ensuring the structural integrity of buildings. They work by transferring the loads received by the floors and ceilings to the columns or walls, thus preventing the collapse of the structure. The correct selection and design of beams are crucial to the success of any construction project, as their ability to support loads directly affects the safety and durability of the building. Beams play a crucial role in floor and ceiling structures, being key elements for the distribution and support of loads. In floors, beams work together with joists to support the weight of occupants, furniture and any other load, distributing it evenly to maintain the stability of the structure. On roofs, rafters not only support similar loads, but also face additional challenges such as the weight of snow or wind. The interaction between beams and joists is essential to create floor and ceiling surfaces that are both functional and safe, ensuring effective distribution of loads through the structure and into the foundation. The materials used for beams and joists vary significantly, each offering different advantages in terms of strength, durability and cost. Among the most common materials are: wood, traditionally used for its ease of handling and aesthetic properties, although its resistance can vary depending on the type of wood and its treatment. Steel that offers high strength and durability, being ideal for structures that require long distances between supports or heavy loads. Reinforced concrete that stands out for its fire resistance and its ability to form various shapes, although its installation requires specialized labour. Finally, guadua (Andean bamboo), recognized for its sustainability and mechanical properties, is gaining popularity as an ecological and resistant construction material, especially in regions where it is abundant. Choosing the right material for beams and joists depends on several factors, including the type of construction, environmental conditions, and available budget. Innovation in construction materials and techniques continues to expand the options available to engineers and architects, allowing them to design safer, more efficient and sustainable structures.

The Guadua Angustifolia Kunth cane has become an important plant in rural and peripheral areas around the world. This forest resource has not been used as such, due to the lack of a management culture oriented towards its industrialization has caused it to not be applied in its entirety. It is used in the field of construction, local development, environment and industry, its mechanical behaviour in structures makes it one of the most important alternative materials today for the construction of homes [1]

The Guadua cane has around 1,500 documented uses, such as: raw construction material, ornaments, chairs, mat walls, parquet floors, pharmaceuticals, toys and musical instruments. The reason for so many uses is that it is a species that has great versatility, lightness, flexibility,

hardness, seismic resistance, rapid growth, climatic adaptability, visual beauty and easy handling. Guadua is considered the vegetable steel of the future [2].

The Guadua cane existing in Ecuador belongs to the species "Guadua Angustifolia Kunth" or "Caña Brava" with thorns, is an excellent material used in the construction of homes due to its earthquake-resistant properties. The current plantations in the country reach approximately 645,000 hectares which represents a good alternative in the construction of social housing, due to its large number of longitudinal fibres as it has a high capacity to absorb energy and admit greater resistance to discharges resulting of external traction force and that is why it is called "vegetable steel" [3].

The potential areas in which guadua cane is grown in Ecuador are found on the coast in the provinces of Esmeraldas, Los Ríos, Guayas, El Oro, Santo Domingo de los Tsáchilas, Manabí, this provinces maintains an amount of 145,000 Has that gives 24.3% of the total hectares planted in the country, it occupies the first place in the diverse natural guadua plantations, it has a great potential for its use and its derivatives, a new development pole for the industry is created in the province of Manabí. [3].

This project presents the analysis of beams and joists which are made from guadua cane or "caña brava", its application in the construction of popular housing promotes the construction benefits of this material, promotes this type of industry, which promotes the development and innovation of different depressed areas, they are also very friendly to the environment in the province of Manabí. In Ecuador, the Guadua Angustifolia Kunth cane has been used mainly in the field of housing construction in urban and rural areas since colonial times, however, the lack of knowledge about the earthquake-resistant benefits has led to a little use of guadua, its industrialization has not fully developed which gives way to the presence of a monopoly in construction with conventional materials, the limited openness of institutions dedicated to the construction of ecological homes, the little dissemination of information about this material in higher education institutions of the country, have contributed to the fact that unconventional systems of new materials applied to construction such as guadua cane have not become widespread in this province and the country. [3].

In the province of Manabí there is only one native species of arborescent bamboo, which is the guadua cane Angustifolia Kunth GaK, locally there are known with different domestic names sucha as caña brava, caña mansa, cebolla, macana, cotuda o castilla, among others, all of these bamboos are from the same species Guadua Angustifolia Kunth, but they have different physical aspects, because they are ecotypes that respond to specific climatic and edaphic conditions, due to the origins of the mother plants. In the towns of the provinces of Manabí, wild cane with thorns predominates, which has better quality and resistance than the other varieties. [1].

During the development of this research project, the bending tests established by the NEC GaK - SE standard were carried out, compliance with them was verified, the mechanical bending resistance capacity of the bamboo cane beams and joists was determined, thus establishing resistance parameters that can be used in the design and construction of popular housing in the province of Manabí, as in other sectors of the country. The results of this project can serve as a basis for future research, the material can be incorporated in the massive construction of homes in both urban and rural areas in different areas of the country.

2. Literature Review

Guadua cane stands out in the world of construction for its unique characteristics that make it a highly valued material. First, its mechanical resistance to bending and compression makes it a robust option for structures that demand durability and firmness [4]. In addition, guadua presents notable flexibility, which allows its use in architectural designs with curvatures and organic shapes, thus expanding the creative possibilities in construction [5]. Its rapid growth and regeneration capacity make guadua a sustainable source, providing a renewable resource that recovers much faster than timber forests [6]. These characteristics not only underline the viability of guadua as a construction material but also highlight its potential to innovate the design and sustainability of architectural projects.

A comparative analysis between guadua cane and traditional construction materials reveals significant advantages that highlight its suitability for modern construction. In terms of mechanical resistance, studies have shown that guadua has properties comparable to those of steel and concrete in certain structural applications, particularly with respect to flexural resistance [4]. This comparison is revealing, considering the lower environmental impact and lower cost of guadua compared to these conventional materials. Furthermore, the ease of handling and versatility of guadua allow for a wide range of applications, from support structures to decorative finishes, offering a sustainable alternative without compromising aesthetics or functionality [7]. This analysis suggests that, beyond its ecological benefits, guadua is competitive in terms of performance and application with traditional construction materials.

The environmental benefits of using guadua cane in construction are multiple and have great impact. First, its cultivation contributes to the reduction of the carbon footprint, since guadua captures CO2 efficiently, thus helping to mitigate climate change [8]. Second, guadua promotes forest conservation by providing a sustainable alternative to wood, reducing pressure on natural forest resources [9]. Furthermore, the guadua production process has low energy consumption compared to the production of materials such as steel or concrete, which significantly reduces associated greenhouse gas emissions [9]. These environmental benefits not only highlight the importance of guadua as a sustainable construction material but also underline its role in the development of greener and more environmentally responsible construction practices.

Understanding the mechanical properties of construction materials is crucial for engineering and construction projects. Materials such as steel, concrete, wood and, increasingly, bamboo, have specific properties that make them suitable for various applications. Mechanical properties often considered include tensile strength, compressive strength, elasticity, and ductility. Bamboo, and specifically Guadua Angustifolia Kunth, has attracted attention for its notable mechanical properties, which include: - High tensile strength, which allows it to withstand significant stresses without breaking. - Superior compressive strength compared to concrete, making it a robust material for structural applications. - Remarkable elasticity and ductility, allowing it to flex under load without permanent deformation. This feature is particularly beneficial for creating structures resistant to seismic damage [10] [11]. These attributes position Guadua as a competitive and sustainable alternative to traditional construction materials, offering both environmental and structural advantages.

The flexural testing methodology to evaluate the strength of guadua cane material involves several systematic steps designed to accurately measure its flexural and stress resistance. Initially, guadua samples are prepared and conditioned following specific standards to ensure consistency and reliability in the testing process. Bending tests are then performed using a universal testing machine, which applies a controlled force to the sample until failure occurs. The main objectives of these tests are:

- Determine the flexural strength and rigidity of the Guadua samples.
- Characterize the behaviour of the material under load, including the yield point and ultimate failure [4] [12].

Calculate the modulus of elasticity, which is a measure of the material's elasticity or its ability to deform elastically when a force is applied. Through this experimental methodology, engineers and researchers can collect essential data on the mechanical properties of Guadua, allowing them to evaluate its suitability for various construction applications and innovate in the design of sustainable structures [13] [11].

The analysis of the results of the bending tests of Guadua cane offers revealing information about its mechanical performance and potential as a construction material. By evaluating the data obtained from these tests, researchers can draw conclusions about the strength, flexibility, and overall structural integrity of the material. Key findings often include: - Specific shear and flexural strength values, which indicate the material's ability to withstand forces that would cause it to shear or bend. - The modulus of elasticity, which provides information about the elasticity of the material and how it deforms under tension. - The behavior of Guadua under different loading conditions, including its ability to accept large deflections without failure, which is critical for earthquake-resistant construction [4] [5]. These results are crucial to develop guidelines and recommendations for the use of Guadua in construction. By understanding the mechanical properties of the material and how it behaves under various stresses, engineers can more effectively incorporate Guadua into sustainable building designs, taking advantage of its environmental benefits and mechanical strengths [11] [5].

2.1 Guadua cane as a construction element

Construction with Guadua Angustifolia Kunth has been growing in recent years, due to its mechanical properties, it has allowed the construction of structural elements that replace the characteristics of materials such as steel or concrete. Building with cane allows us to work with environmentally friendly, renewable materials, with low energy or economic costs, meeting fundamental aspects in construction [14].

Table 1: Energy rate for the production of construction materials (ECO-COST)

Material	Unit	Value
Concrete	MJ/m^3 por N/mm^2	240
Steel	MJ/m^3 por N/mm^2	1500
Wood	MJ/m^3 por N/mm^2	80
Bamboo	MJ/m^3 por N/mm^2	30

Source: Jules Janssen (Eindhiven University NL)

2.2Physical and mechanical properties

Mechanical: The mechanical characteristics of guadua are affected by factors such as: climate, soil, location, age, harvest time, humidity, etc. The density of the fibres is variable in the thickness of the guadua. Each guadua stem is different, so its geometry and behaviour cannot be standardized; these characteristics depend on the botanical species, location, age of the harvested stem, water content and the diameter and thickness of the wall [15].

Structure: The outer part of the microstructure of the cane stem is quite dense and only approximately 0.25 millimetres thick. This layer contains a large amount of silica, iron and aluminium, these elements being great protectors of the plant, but a great nuisance and problem for the tools used to cut them because they wear down their edges quickly. It also contains glasses, which are responsible for transporting liquid during the life of the reed, and cellulose fibres, which act as reinforcement in a similar way to steel rods in reinforced concrete or fiberglass in reinforced plastic fibres [16].

Lugares en Manabí donde se realizó el escogimiento de las muestras para los ensayos y pruebas Físico – Mecánicas de la GaK

Lugares donde se realizó el escogimiento de las muestras para los ensayos y pruebas Físico – Mecánicas (obtener resultados promedios) de la provincia de Manabí									
CANTÓN	Tensión de tracción (MPa)			Tensión de Compresión (MPa)			Tensión de flexión (MPa)		
	CEPA	BASA	SOBRE BASA	CEPA	BASA	SOBRE BASA	CEPA	BASA	SOBRE BASA
Santa Ana	27,48	25,20	24,80	18,20	15,25	11,23	4,25	2,6	2,28
Olmedo	29,72	25,62	25,30	18,84	16,60	12,42	4,32	2,45	2,43
Portoviejo Las Delicias	28,98	23,90	23,18	16,73	15,70	13,69	3,32	2,75	2,07
Portoviejo Santa Martha	24,25	23,49	21,03	15,70	13,77	12,51	2,86	2,47	2,09
Junín.	25,60	24,80	22,60	15,27	13,69	11,76	2,52	2,50	2,06
Chone	25,40	23,80	23,60	17,03	14,72	10,5	3,96	2,45	1,96

Fuente: Investigación realizada por el Ing. Alfredo Zambrano Rodríguez MSc, Docente UTM, Estudio de Doctorado en la Universidad del Oriente Santiago de Cuba – Cuba.
Elaborado por: Ing. Alfredo Zambrano Rodríguez MSc, Docente UTM.

Moisture content: GaK, like wood, decreases its resistance and rigidity as its moisture content increases, the values of allowable stress and moduli of elasticity which are reported by the moisture content of GaK is CH= 12% and if the environmental conditions where the project or construction will be carried out may vary the moisture content of the GaK above 12% [17].

Durability: Guadua cane is highly resistant to insect attacks, mold and rot, but it is worth protecting it against these same factors. The guadua has a cylindrical cross section made up of diaphragms that are cut with internodes of approximately 30 to 40 cm, which is equivalent to the buckling of the trunk [17].

Density: Guadua cane offers a very high strength-to-weight ratio, comparable to steel and high-resistance fibres whose value is considered around 1.75 and has a density of 700-800 kg/m^3. Although it may vary depending on the quality of the growing site, position of the stem, etc. Density turns out to be an extremely important property and indicates some valuable relationships, such as the bending stress for failure in kg/cm^2, can be estimated as 1.43 times the density in kg/m^3 [17].

Bending: The bending failure of the guadua cane is not a failure per se, because there are no cracks or breaks of the specimen in two parts as in wooden beams or other material. Likewise, through tests carried out over several years it has been shown that delayed deformation in

guadua cane does not occur. What happens in the specimens of guadua cane tested in bending is that the bond between the fibres is broken which leads to the circular shape of the section losing strength. However, none of the fibres along the stem suffer any damage meaning that once the load is removed, the guadua cane beam returns to its original shape, that is, it has an elastic behaviour [17].

Modulus of elasticity: An advantage can be observed in the use of thin tubes in relation to their cross section. The accumulation of high resistance fibres in the external parts of the guadua wall also works positively in favour of the elastic modules as it does for the tensile and flexural strengths. Like solid wood models, those made of guadua decrease between 5 to 10% with increasing stress, the high elasticity of guadua makes it a potential material to be used in areas with high seismic risk [2].

2.3 Design of the beams and joists

It is extremely important to take into account that the beams of a structure, after assembly, are completely joined to the vertical support or column. It is necessary that the cuts for joint pieces that are made fit or mold perfectly to the diameter of the round cane.

Fig. 1. Beams composed of latillas (analysis beam)

Fig. 1. Single element cane beams

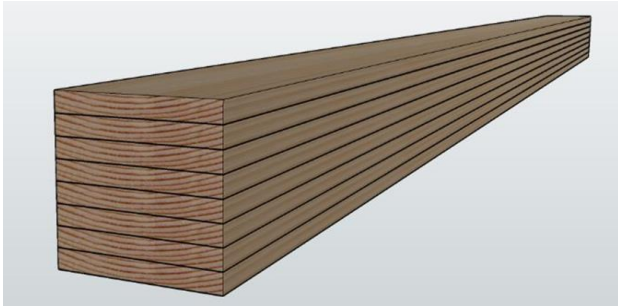

Fig. 1. Diseño de viga de latilla cepillada

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3. Conclusion

Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

The province of Manabí has an area of 145,000 hectares of guadua cane crops, for this reason it is necessary to generate projects for the application and use of this material as an element of housing construction, because it has excellent structural resistance and contains less sugar and starch which makes it less palatable to insects and pests.

The respective assembly processes were carried out with the designs of beams and joists using the necessary machines and procedures for cutting, drying and curing the guadua cane, in this way complying with the quality requirements mentioned in the Ecuadorian Gak standard. Three beams were made with measurements of 8.5 cm thick and 8.5 cm wide by 2.50 m long, in the same way three joists of 5.5 cm *5.5 cm were made, with the same length measurements as the beam.

The prepared beams and joists were subjected to the respective tests using the university's reaction framework. First, the bending test was carried out on three beams and three joists. The average bending limit at which the beam breaks is of 13.49 KN and an average deformation of 54.96 mm, in the case of the joists it gives us an average bending limit of 3.34 KN and an average deformation of 63.75 mm. Next, the resistance test was carried out for both the beams and joists, where the value of the resistant moment could be determined.

The guadua cane is a very versatile plant adapted to the agro-ecological conditions of the coastal sector of Ecuador, for this reason its use and commercialization is very recurrent, at an international level the Ecuadorian guadua is considered one of the best canes in the world, this Thanks to its physical, mechanical and botanical characteristics, guadua angustifolia is present in the country in the coastal, mountainous and eastern regions, mainly in provinces such as El Oro, Guayas, Los Ríos, Pichincha, Santo Domingo and Manabí.

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