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Topological stereotomic structure with the use of palm rachis applying material physics to architectural design

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Abstract. The use of ancestral construction techniques in wood has evolved throughout history, but consequently many species have been disappearing after indiscriminate logging; but the use of renewable materials is what is needed in the present and in the future after the global pollution and the ecological footprint of materials such as iron or concrete, so it is necessary to glimpse new building materials from a renewable approach. To this end, this research focuses on the application of physicochemistry and physics of materials to establish the feasibility of using Attalca Butyracea palm rachis as a sustainable material with a novel application in the field of architecture. For this purpose, a methodology of morphological configuration is applied that appropriates the identification of specific physical properties together with notions of geometry and topology applying the concept of topological stereotomic configuration from the operational tools and morphological actions of the Lucas Períes fold, resulting in a proposal for a topological stereotomic structure applied to the architectural design of buildings in the municipality of Pelaya, Colombia.

1. Introduction

The research focuses on the study of the Attalca Butyracea palm the study of its physicochemical properties due to the mechanical characteristics of its rachis for construction and its wide presence throughout the Colombian territory and specifically for the study in the department of Cesar [1]. Traditionally, palm rachis has been used in the construction of ecological bricks used in the construction of mezzanines [2,3] and paper [4], however, this research proposes the use of palm rachis in the elaboration of strips to be used in construction, with the advantage of offering in this way, materials of very low price, but of great resistance, that facilitate the construction of houses in regions with low-income inhabitants.

The use of renewable materials for construction in the current context becomes completely necessary after the environmental emergency that is presented either by climate change, or the ecological footprint left by our buildings [5-7]. But the use of renewable materials such as wood leaves the door open to indiscriminate and uncontrolled illegal logging since, according to the World Wildlife Fund, there are 796 endangered plant species in Colombia due to problems such as climate change, deforestation, and illegal timber extraction [8], making it necessary to find new building materials that can have a renewable approach and allow their cultivation and mass production without affecting their population.

The rachis is a type of spine or column that articulates the leaves of a palm tree, which together give shape to the leaf or stalk of the palm. It can be used to make slats with different mechanical properties according to the stage of development of the stalk [9]. The study is carried out with the Attalea butyracea plant, which is characterized by a stipe of 4 meter to 10 meter in height depending on the age of the plant and 35 cm to 75 cm in diameter. It has between 25 and 40 leaves, with a rachis 4 m to 6 m long and each leaf with 180 pairs 240 pairs of pinnae and shedding fruit pods 1m to 1.5 m long by 30 cm to 45 cm wide.

The study leads to good results in the topological modulation of architectural structures and suggests the use of palm rachis as a material of good application in architecture, with very low costs, which allows a favorable approach to its sustainability and ecological benefits and presents good resistance to tension and bending.

2. Materials and method

The research articulates a documentary investigation for the postulation of the palm rachis as a construction element, in which the design process evolves, applying creative processes in which experiments are carried out with the palm rachis and modular proposals are executed where a methodology of morphological configuration is applied that appropriates the notion of geometry and topology applying the concept of topological stereotomic configuration from the operational tools and morphological actions of the fold where the formal result is that of irregular polyhedral hollow bodies, with topological properties of transformation, provided by the folding, folding and unfolding [10,11].

Tensile test is performed according to ASTM D6-38 [12] procedure using a speed of 5 mm/min, flexural test according to ASTM D7-90 [13] procedure with a speed of 1.74 mm/min, impact test using TMI 43-1 pendulum, bulk density measured according to ASTM D7-92 [14] procedure, and failure of specimens of upper section of panel (exposed to radiation) and another specimen of lower section (less exposed to radiation).

Of the various elements that the plant presents and the numerous utilities they can have, the rachis has been scarcely explored in architectural application, maintaining a limited theoretical source of this element. The rachis of the wine palm (Attalea butyracea) is a fibrous longitudinal element that maintains excellent characteristics of elasticity when green, and hardness and resistance when dry. Its thickness varies from its beginning 8 cm, 10 cm to its end 1 cm, 0.5 cm, changing morphologically in the process, becoming wider at the beginning and more refined at the end. For constructive use, values from 9 cm in its thickest parts up to 2.5 cm are used due to its mechanical capacity and resistance.

3. Results and discussion

The palm rachis manifests itself as a strip of specific measures in which it can be used from the multiplicity for the creation of modular panels.

3.1. Physical-mechanical properties of palm rachis

In this phase of the research, palm rachis ribbons are elaborated and the variables that affect the elaboration process are defined. The following variables were analyzed: area of the strip section, mass, humidity, temperature, pressure, and time, following the parameters of previous research [15,16]. Three values were set for each variable, minimum, maximum and an intermediate one, under the realization of tests on different slats, the results are shown in Table 1.

The mass of the lath is expressed as the apparent density defined as the ratio between the weight and the volume including the voids or pores that it may have. The influence of each variable is determined by qualitative analysis of the quality of the material obtained.

Table 1. Values of variables in the thermocompression process.

Variable	Minimum value	Intermediate value	Maximum value
Cross-sectional area (cm^2)	40	50	60
Mass (g/cm^2)	0.6	0.8	1
Humidity (%)	8	12	15
Temperature (°C)	160	180	220
Pressure (MPa)	14	22	30
Operating time (min)	4	10	20

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3.2. Structural modulation from the ribbon
In the context of self-construction in the municipality of Pelaya Cesar, earthen construction is an alternative that is manifested in low-income housing because its ease of acquiring resources makes it a tentative alternative, but these buildings in most cases do not comply with the structural regulations of the region due to the lack of structural notions in its conception, However, even so, the use of vernacular materials such as guadua, can palm, or palm rachis can be seen in the design of walls with wattle and daub systems, which are still structural modulation panels that allow for self-construction and although they do not meet the standards, they provide protection from the weather and offer a provisional solution to the need for housing.

For the modular analysis, prototypes are used to study the possible arrangements and topologies that can be achieved by arranging the slats on surfaces that can range from simple to complex geometric compositions. One of the examples analyzed presents a skin arrangement with hyperbolic paraboloid modules joined together, generating a self-supporting structure that can be transposed to a real architectural space as a type of pergola, or flat or living roof structure Figure 1.

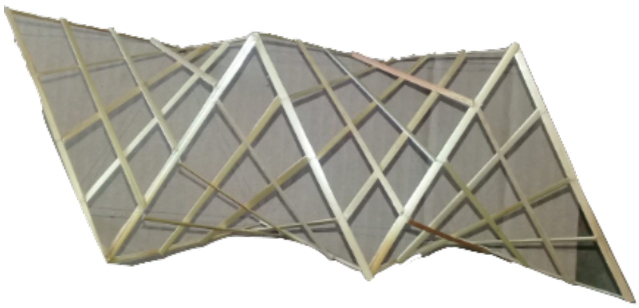

Figure 1. Modular prototype from the arrangement of joined hyperbolic paraboloids.

3.3. Structural optimization from topological geometry
The topological geometry can be analyzed from the theory of Lucas Períes for the purposes of this study from the fold, in which the topology of an element could undergo transformations without losing the initial topological property [17,18], which can be reflected in the design of an architectural space from the transformation of a conventional parallelepiped to the transformation of a space more topologically optimized to the use that can be given to its interior spaces [19]. Clear examples in architecture are evidenced as the Té house vreeland-Netherlands, UN Studios, 2004; house of music Porto-Portugal, New COAG Headquarters, Vigo Spain, Zon-E 2005; or the case of Microtower, Tel Aviv PIPO 2012 in which the topological transformation from the fold is evident in the final presentation of the design.

From this approach, a decomposition of an initial element is made from the articulation of breaks generating a new topological conception [20], therefore, it is proposed as a building skin and begins to determine an internal structure that supports the building to finally have an architectural design prototype that starts with a parallelepiped and that is topologically transformed to generate an optimization in the use of heights and spaces from the concept of fold applied Figure 2. The result is an architectural space that can be applied in real contexts such as plazas, parking lots, sports complexes and many more examples contextualized in large spaces.

3.4. The fold as an optimized topological structure for construction systems with rachis
Based on the modulation defined above, the construction process is defined, and four important characteristics are defined for direct application in the building Figure 3:

- ⇨ Modulation: different panels are defined and coupled to each other for the parametric generation of the project.

- ⇨ Structural frame: the materiality can vary according to the structural requirements and the spans to be met in the project to give it the necessary strength.
- ⇨ Skin or envelope: the skin can be executed in different materials, either in earth for interior areas for comfort reasons, or with more contemporary materials, such as Draywall, Super Board, wood sheets, among others.
- ⇨ Palm rachis: It becomes the heart of the module that replaces more expensive materials and fulfills the same objective of modular structuring to be applied in real projections.

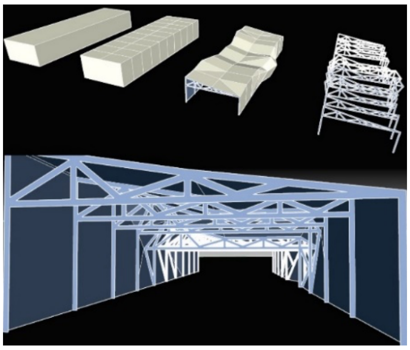

Figure 2. Diameter variation in the rachis.

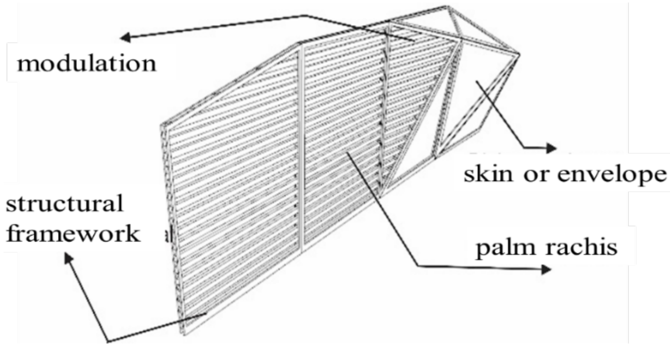

Figure 3. Application of the fold for topological modification in a project.

3.5. Deformation at panel fracture
Deformation tests of the panel built with the palm rachis are carried out, the results obtained in the tests are shown in Table 2.

The tensile strength obtained was 35 MPa, which is higher than other composites and to a greater extent than oil palm rachis, Young's modulus obtained values of 2.3 GPa and 1.98 GPa, about the modulus of elasticity, it remains at the average value of materials exceeding 0.3 GPa material of panels with oil palm composite, in the same way, in the flexural strength the percentage of elongation at fracture in 15 MPa tests fluctuated between 1.8 MPa and 2.1 MPa and flexural strength 60 MPa. the material also shows high ductility and densities ranging between 1 g/cm^3 and 1.4 g/cm^3.

Table 2. Panel fracture deformation results.

	Tensile strength (MPa)	Young's modulus of the panel (GPa)	Percentage of elongation at fracture
Down	35	2.30	2.1
Up	25	1.98	1.5

4. Conclusions
The application of the palm rachis in effect generates positive results in the topological modulation of architectural structures that can be applied in the Colombian context.

Tensile and flexural strength has higher values than palm kernel fiber composite material.

In the municipality of Pelaya it is possible to execute these constructive systems that articulate the palm rachis due to its properties for the multiplicity of modular elements. The use of palm rachis is a material of novel application in architecture that promises for further research and applicability in various scenarios of current architecture, which responds to issues of sustainability and reduction of the ecological footprint of commonly used materials.

The research is of great contribution to the knowledge of the physicist as well as to the physics teacher and student because it allows linking several sciences in an applied way, giving the opportunity to understand such abstract concepts of mathematics through its application in natural sciences, specifically physics, and artistic sciences, reflected in this case in architecture. The contribution of research to physics is reflected in the incorporation of this science in the solution of architectural problems, linking in the process the sciences of art, the exact sciences, and the engineering sciences.

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