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THE TENDOM SYSTEM AND THE EVOLUTION OF ITS CONSTRUCTION TECHNOLOGY: A REVIEW

EL SISTEMA TENDINOSO Y LA EVOLUCIÓN DE SU TECNOLOGÍA CONSTRUCTIVA: UNA REVISIÓN

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ABSTRACT

Abstract. This research proposal integrates the existing relationship between construction technology and the environment, to be used in the construction of housing using the system of non-structural light walls. With this construction system, it is intended to publicize this new non-traditional construction technology, by integrating materials of regional origin and low ecological impact, in order to achieve construction sustainability at an environmental, economic and social level. Theoretically, it is based on Cardellach's philosophical principle, by incorporating the term of tendinous systems in the structures, as constructive forms that have their origin in the zoological architecture of vertebrates, where these structural and constructive forms are at a higher level of mechanical sensitivity and naturally inspired. Subsequently, Thomas integrates design, technology and culture, in an unconventional construction alternative called sinewy walls. The typology of this construction system consists of the on-site manufacture of flat rectangular modular panels, reinforced inside with a barbed wire mesh that acts as integrated tendons, covered on both sides with a mixture of mortar, to form a rigid structural frame, composed of sawn wood, guadua, in metal angle or concrete structure, thus constituting a monolithic structural element that will behave like a confined wall, which will give consistency and finish to the wall.

Keywords:
non-conventional construction techniques, sustainable environment, sinewy wall, unreinforced masonry.

RESUMEN

La presente investigación integra la relación existente entre tecnología constructiva y medio ambiente, para ser utilizada en la construcción de vivienda empleando el sistema de muros aligerados no estructurales. Con este sistema constructivo, se da a conocer esta nueva tecnología constructiva no tradicional, ya que integrar materiales de origen regional y de bajo impacto ecológico, con el objeto de alcanzar sostenibilidad constructiva a nivel ambiental, económico y social. Teóricamente, el principio filosófico de

Palabras clave:
técnicas constructivas no convencionales, medio ambiente sostenible, muro tendinoso, mampostería no reforzada.

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	Cardellach, incorpora el término de sistemas tendinosos en las estructuras, como formas constructivas que tienen su origen en la arquitectura zoológica de los vertebrados, donde estas formas estructurales y constructivas están en un nivel superior de sensibilidad mecánica y de inspiración natural. En el 2002, Thomas integra diseño, tecnología y cultura, en una alternativa constructiva no convencional llamada muros tendinosos. La tipología de este sistema constructivo consiste en la fabricación in situ de paneles modulares rectangulares planos, reforzados en su interior con una malla de alambre de púas que hace las veces de tendones integrados, recubierta en sus dos caras por una mezcla de mortero, para conformar un marco estructural rígido, compuesto por alguno de las siguientes clases de materiales: madera aserrada, por bambú o guadua angustifolia (Colombia), por ángulo metálico o por estructura en hormigón; constituyendo de esta manera un elemento estructural monolítico que se comportará como un muro confinado, que le dará consistencia y acabado al muro.

Introduction

This research is part of a project that will develop the design of a constructive system of non-structural lightened tendon walls, with a matrix of environmentally friendly recycled cardboard tubes, emulating the zoological architecture of bees in their hives, forming a matrix as a whole. The research is framed in the field of Materials Engineering and Construction Techniques, and is approached from the environmental point of view in the area of recycling of construction materials. The proposed model investigated consists of a new construction system, composed of light tendinous walls for non-structural use, since it is necessary to search for alternatives and mainly for non-traditional raw materials, with the purpose of proposing technological solutions that optimize the use of these available resources, resulting in the welfare of the community, from the economic point of view, and the improvement of the environment.

With the delimitation of the research topic to a specific and restricted subject within the non-structural masonry, the attainment of the sources of information and bibliographic references also becomes less frequent and reduced, particularly because this subject was born exclusively in the department of Valle del Cauca, Colombia, Municipality of Santiago de Cali, Corregimiento de Pance, Vereda La Viga, (Thomas, 2002); that due to its constructive and geographical versatility has been extended to the coffee axis of the country and has been implemented by some universities of the Andean area. According to the various researches carried out on this subject in the region, it is feasible to find these research resources, which will be the bibliographic sources of consultation to answer and solve the problem. Derived from the above, it is necessary to perform not only a bibliographic analysis of the subject, but also a structural analysis of the proposals and prototypes that have been presented mainly in Latin America, for example, the study by Casas (2011) where he assures that the tendon wall construction system has been successfully used in the construction of one and two-story houses and in complementary buildings in rural and peri-urban areas of southwestern Colombia.

Method

Research Design

The existence of a proven objective reality, such as stone and brick masonry walls as a construction method since millenary times, has been transformed with the invention of new materials and construction methodologies. In modern times, this boom of new technologies in the construction sector is causing an environmental problem of incalculable proportions, as it is using large quantities of raw materials composed of non-renewable natural materials (Ramírez 2022). In order to solve this environmental problem, new construction alternatives that are more environmentally friendly are being developed.

The development and modification of traditional construction techniques need to evolve and adapt to the needs of societies, but are directly related to safeguarding the integrity of their inhabitants and the right to decent housing; however, we must consider the increase in climate changes such as floods, increased extreme temperatures, and droughts that have occurred in the last 10 years (Management Solutions, 2020). As a result of the above, it is necessary to design and propose new construction techniques that meet the structural requirements to reduce the high housing deficit in Colombia (Perera, 2012). In addition to meeting the challenge of structural requirements, it is necessary that these proposals reduce the construction time of a project and maintain an optimal performance between materials, labor and equipment with proper planning and execution of its construction elements. Finally, a proposal for a lightweight wall system is presented, which consists of the on-site fabrication of flat rectangular modular panels, reinforced on the inside with a barbed wire mesh that serves as integrated tendons, covered on both sides with a mortar mixture, to form a rigid structural frame, composed of one of the following types of materials: sawn wood, bamboo or guadua angustifolia (Colombia), metal angle or concrete structure; thus constituting a monolithic structural element that will behave as a confined wall, which will give consistency and finish to the wall.

Instruments

For the definition of the structural evolution, updates and innovations of the tendon walls, a bibliographic search was carried out in the known specialized information systems, Google Scholar and Scopus or Reserach Gate. The search included keywords such as sinewy structures, ecology of sinewy walls, nonstructural masonry walls using sinewy systems, etc. Next, the selection of the scientific products to be studied was made from their origin to the year 2023, since this research will mark the importance of using this type of structural systems, their limitations and variables, which need constant updates to guarantee an optimal sustainable performance. A matrix was made using the purpose of each of the selected academic/scientific products to begin to trace a timeline in the evolution of constructive tendon systems. With the selection of the study area, the delimitation of the scientific products that marked the results and analysis of this research was completed. Derived from the type of construction system to which they respond, the type of society to be served and the infrastructure system for which they are designed, we proceeded to make a hierarchy of recommendations so that the tendinous systems, especially the nonstructural walls, are a first option in different constructions, whether for housing, commerce, educational facilities, urban or rural.

Results

The need for a paradigm shifts regarding traditional construction methods and the handling of materials from the technological point of view in order to implement and build more economical and efficient environmental housing, the non-traditional construction system of tendon walls, is not a new methodology, but it offers a viable and sustainable alternative through the analysis and chronological account of the technical and constructive evolution of the tendon wall.

Tendon Systems

Cardellach in 1910 expresses that man must be contemplative of nature, which is the great truth of all the material world that surrounds him; helped by his imagination he argues and reasons expressing his phenomena "in the form of geometric concepts and analytical mathematical expressions, constituting a spiritual gear of rational deductions that lead us quickly to the discovery of new truths", (1970, p. 1).

All structures are subject to the laws of external forces of nature, calling it the general mechanical principle, which must be satisfied by simplifying the complexity of natural phenomena by establishing simple hypotheses, to be possible the stability and strength of the structure, this he calls the principle of the structure. In nature we have an example, the zoological architecture of vertebrates formed by the animal skeleton.

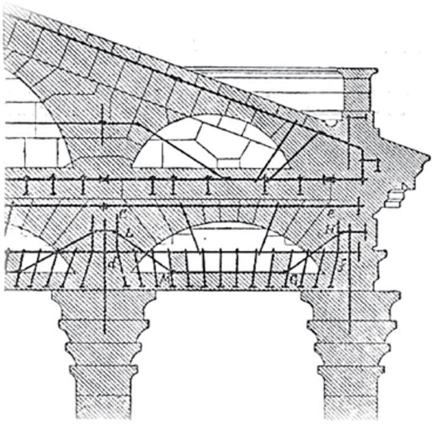
Concluding in this way that the engineer with this innovative spirit, must discover new forms of resistant frames for the present construction; the only origin of these structural and constructive forms is in a superior level of mechanical sensibility and natural inspiration, which are innate in man (architect, engineer) and which have constituted an important characteristic of his development, (Cardellach, 1970, p. 8-10). He synthesizes that structural forms should be classified or grouped by harmony of texture, mechanics and construction into two main groups:

1. Bi-resistant forms, suitable to withstand compressive and tensile stresses, are used in construction systems of steel tendons in the form of a lattice (skeleton) and articulated to each other to absorb these stresses.
2. Uni-resistant forms are suitable for supporting only compressive or tensile stresses, using construction systems of segments composed of flexible elements, (Cardellach, 1970, p. 12-16).

Structural configurations initially pointed out to the metal tendon its appropriate place in the masonry and due to economic circumstances facilitated the development of the tendon system, the masonry takes a back seat as a protector of the lattice system by fixing the tensioned tendon and transmitting its strength to the concrete, as shown in Figure 1.

Figure 1

Iron reinforcements in stone, St. Geneviève de Paris church



Note. Source: http://www.wikiwand.com/es/Jacques-Germain_Soufflot

This strategic placement of the tendinous system is a way to solve the structural problem, this ramification reaches the aspect of a network in the very core of the structure and in union with it, it manages to give forms to the structure, (Cardellach, 1970, p. 52-75). Cardellach concludes that

> Such is the fineness and elegance achieved by the tendinous system in the resolution of a problem of structural resistance, obtaining an original and economical structure, resistant and elastic, which synthesizes the advantages of construction that are proper to reinforced concrete..., here dies the mechanical rationalization of the Roman structures as a necessary consequence of the general characteristic of concrete, (1970, p. 83).

According to Cardellach, within the uniresistant systems of load transmission, he classifies the principle of stacking or overlapping of materials, as the principle of all constructive processes, which is defined as "a rudimentary arrangement inspired by those offered by natural piles and without apparent law of the material deposited by fortuitous accidents", (1970, p. 94). Structurally, it defines three classes of tendons:

1. Tendons by ligament, used to join critical points in masonry in order to avoid partial slippage and maintain the monolithism of the structure.
2. Apparent tendons, used to bind together the entire contact surface of the elements, in order to improve the mechanical resistance of all its elements.
3. Bonded tendons, used to be placed internally in the structure in order to form a single monolithic structure.

Torroja in 1957, expresses that reinforced concrete is an organically constituted stone, within whose mass the tendon complex of the reinforcement is optimally distributed, it is dosed to provide the concrete with the tensile strength it needs at each point, the joint work between the mass of concrete and the steel bars is confined to adhesion, ensuring the transmission of stresses from the reinforcement to the concrete and vice versa, (Torroja, 2010, p. 67-68). Concrete is a different material from reinforcing steel, since it is very weak when working in tension compared to its good performance in compression. For this reason, in structures, reinforcing rods are placed in the regions where tensile stresses occur, resulting in the cross section of the structure behaving as a section composed of two materials, concrete and reinforcing steel (White, 1980, p. 52-54).

Tendon Wall System in Colombia.

The following are the results of the research carried out at regional level, where the constituent materials, composition and structure of the tendon wall are explained in detail, when applying this non-traditional construction system in Colombia.

A) Thomas in the 90's, presents the Tendinoso System as "a research that integrates design, technology and culture, which responds to the felt need to live in a material house" (2002, p. 25), it is a non-conventional constructive alternative that starts from the traditional peasant architectural knowledge and techniques, optimizing this knowledge and responding to the need of these communities to build their own housing in more resistant, safe and durable building materials over time, (2015, p. 170).

The typology of this construction system consists of the on-site fabrication of flat modular panels, reinforced on the inside with a barbed wire mesh that serves as integrated tendons, joined by means of staples to vertical and horizontal elements forming a rigid structural frame composed of sawn or round wood, guadua, metal angle iron or reinforced concrete. The core of the partition walls is a biodegradable natural fiber lattice called costal, whose base is cabuya, mezcal or fique, which is interwoven with the barbed wire lattice, in order to serve as a support for the application of the mortar mixture, by successive layers to provide union between its elements and give rigidity to the framework, constituting a monolithic structural element that will behave as a confined wall, giving a final finish to the panel with average thicknesses of 4 to 5 centimeters (Torres, 2013, p. 1), (Figure 2). 1), (Figure 2).

Figure 2

Components of the tendon wall system

Note. Source:Mora (2022, p. 47)

The tendon wall system consists of the integration of two basic elements, the linear elements (horizontal and vertical) that act as a frame and structural support, and the flat elements of the modular panel or partition, composed of the barbed wire mesh or tendons intertwined with the fiber core to which the adhesive mortar will be adhered. Thomas argues that "the research bet consisted in stimulating an integral approach to environmental design, which recreates the positive aspects of the existing technoculture" (2002, p. 28), where there is a political boundary that comes from the conquest and subsequent colonization. (2002, p. 28), where there is a political boundary that comes from the conquest and subsequent colonization, since the architecture was imposed with durable materials such as brick, which he calls colonial technoculture, over the local biodegradable technoculture of wood (malocas and bahareque) which was excluded being of indigenous type, which he calls the great oblivion of technological education. From this ideological perspective, the tendinous system is materialized, developing construction techniques and using traditional wooden structures of the region, so that the inhabitants were their self-builders through the ancestral customs of the mingas and convites (indigenous tradition of community work), other important factors is that the resulting constructions are comfortable for its inhabitants (Figure 3).

Figure 3
Construction of the tendon wall system

Note. Source: http://www.zuarq.co/

Thomas defines it as "appropriate technology" when designing an environmentally friendly construction system that responds to the socio-cultural determinants of the place, from the aesthetic, structural and economic point of view (2002, p. 31).

B) Guerrero y Casas, analyzes the seismic aspect, emphasizing that the Pacific region is located in an area of high seismicity, the behavior of the different structures and their vulnerability to these events and the safety that buildings can guarantee against earthquakes, adding that the earthquake in Armenia in 1999 showed the high seismic vulnerability of buildings of less than one and two stories that were built without meeting the requirements of seismic-resistant design (2002, p. 51). This system can be classified as confined load-bearing walls and its basic structural system consists of a wood, guadua or steel frame, which when integrating the tendon wall panel to this structure works as a load-bearing wall, this construction system has been successfully used in one and two-story houses (Guerrero and Casas, 2002, p. 52-53).

C) Velázquez analyzes the tendon wall system: due to its versatility, speed of construction and economy, it was a pilot project of the Colombian Coffee Growers Federation (Federecafé) using this construction system in the Department of Valle del Cauca (Colombia) and specifically in the municipalities of the coffee axis (Caicedonia, Sevilla, Restrepo, Trujillo, La Victoria, Bolívar) among others, where there are large plantations of bamboo or bamboo, (Velázquez , 2010, p. 8-10).

Franco (2019), analyzed different traditional construction techniques in Colombia, mainly those based on the use of bamboo in the construction of one or two-story buildings, also studied the possible bioclimatic criteria to be taken into account to ensure optimal adaptation to the local climate, resulting in achieving user comfort without the need for high energy consumption. This system gradually became widespread in other regions mainly due to its ease of construction, since it does not require skilled labor and can be carried out by community self-construction methods (Figure 4).

Figure 4
Construction of the tendon wall system

This construction system is not endorsed by the Colombian Seismic Resistant Construction Regulation, (NSR-10), Title G, however it had its first fire test during the Armenia earthquake in 1999 (seismic magnitude on the Richter Scale of 6.1) where it showed an optimal behavior due to its inherent ductility that prevents the collapse of the walls, some of the houses built by this system and that were affected by the earthquake did not present major damages nor did their walls collapse, unlike the bad behavior of the traditional brick construction systems, (Velázquez, 2010, p. 8-10). Due to its ease of construction, speed of execution and low cost, this construction system has made it possible to respond to the needs of many people with low economic levels. These characteristics have made the tendon walls popular in these areas, reproducing and adapting the construction methods with new materials and various geometric configurations (Velázquez, 2010, p. 15-16). From the structural point of view, the tendon wall is heterogeneous, it is a composite material, anisotropic and its components present a non-linear mechanical behavior, its structural characteristics are the following:

- Confining structure, these elements work with a double structural function by transmitting the vertical loads to the foundation, horizontally confining the panel frame, as well as being the physical support for all the other elements of the system.
- Although it does not have a specifically structural function, its main function is to give consistency to the wall in the face of loads perpendicular to its plane of placement, it also gives adherence to the tendon wall as a whole.
- Barbed wire, its behavior is that of a tensioning cable that absorbs tensile loads in the horizontal direction of the wall, it also allows the grip and support of the natural fique lattice.
- Fique natural fiber lattice is the surface that allows the placement and cohesion of the mortar in the face of loads perpendicular to the plane of the wall (Velázquez, 2010, p. 21-22).

In addition, Velázquez differentiates the structural systems of the tendon wall with its various constituent materials:

- Structure with metallic profiles, the sections of these metallic profiles A-36 is small (1 1/2" to 2" x 1/8"), its anchorage to the foundation is totally embedded (the angle or profile is embedded) or its fixation can be made by the anchorage system with embedded bolts, the union between the elements of the framework is made by means of electric welding, this means that it can assume movements of the structure or framework without compromising the stability of the wall, to these profiles the galvanized hooks must be welded to fix the barbed wire tendons, as the sections of the profiles are small it does not reduce the architectural area of the houses.
- Wooden structure, the sections of this framework in sawn or round wood can be 4" x 4" x 6 meters, its anchorage to the foundation is totally embedded (the column is embedded), the union between the elements of the framework is made by means of bolts, it is required that the wood has undergone a process of immunization.
- Guadua structure, the sections of this framework can be from 10 to 15 centimeters in diameter, its anchorage to the foundation is totally embedded (the column is embedded), the union between the elements of the framework is made by means of bolts, it is required that the guadua has undergone a process of immunization.

The geometry of the panels of the tendon wall is rectangular in shape, the columns of the confining structure can be sized from 0.75 meters to a maximum of 1.2 meters, with an average height of 2.4 meters at most, the placement of the barbed wires can be between 20 and 30 centimeters, intercalating their distance between the parallels, (Velázquez, 2010, p. 24-26). The functionality of the tendon wall system is analyzed from a constructive point of view, as a whole of the house itself, highlighting the following functionalities:

- Enclosure, its basic function is to separate the different rooms of the house, it constitutes a solid matrix as a whole that is capable of resisting impacts perpendicular to its plane of action and is relatively light in comparison with conventional brick masonry construction systems.
- Resistance, the tendon wall is not self-supporting and its vertical structure must be embedded in the foundation, the resistance of the whole tendon wall system is subject to the confinement given in the structuring of the construction system, being suitable for one and two-story constructions.
- Insulation, it does not have any kind of acoustic or thermal insulation.
- Durability, the tendon wall requires adequate maintenance when there are cracks, flaking of the mortar, cracks in the construction joints, with timely patching a good durability can be guaranteed.
- Watertightness, the tendon wall by its nature is not watertight due to the porosity of the glue mortar, to avoid this phenomenon the wall must be waterproofed on its exterior face to avoid filtrations.
- Construction time, one of the most important advantages of the tendon wall system is its fast construction process.
- Versatility, this construction system is applicable to social interest housing (VIS), in country houses of high strata, due to its adaptability to all kinds of projects with different climates and topographies of the terrain.
- Aesthetically, constructions with tendon walls have a lot of freedom from the architectural point of view, (Velázquez, 2010, p. 42-44).

D) Bedoya emphasizes the aesthetic aspect of the structure, it is very necessary for the acceptance or rejection of a construction technique or construction material, (2011, p. 82). List the characteristics, properties and functions of the materials involved in the construction of a tendon wall, which are the following elements:

- Barbed wire, base material that acts as reinforcement in the tendon framework, its structural function is to absorb the tensile stresses in the wall panel.
- This material is the core of the panel and is composed of sacks or bags of fique, it acts as a mesh that covers the entire length of the panel. Its main function is to give adherence to the tendon system with the mortar that is loaded in successive layers until the desired thickness of the wall is obtained.
- This material is in charge of giving solidity to the panel of the tendon wall and at the same time giving it its final finish, the activities of the placement of this mortar is similar to the plaster, the first activity is the loading of the panel by means of a mixture of mortar rich in cement and water that is thrown on the natural fiber lattice in order to obtain adherence, then after the drying of this layer, the successive layers are placed that will give the necessary thickness to the tendon wall.
- The confinement structure is composed of vertical elements (columns) and the materials used can be wood, guadua, angle iron, reinforced concrete, etc. (Bedoya, 2011, p. 82-83).

E) Builes analyzes the constructive aspect of the tendon wall, where the foundation is constituted by an overlying beam, on it is built a perimeter masonry wall of brick starting with the purpose of giving insulation to the structural system and to the tendon wall itself, on this wall are built the panels that make up the resistant structure and are formed by the columns and beams that provide confinement to the system, the columns are embedded in a sill both at the top and bottom in order to provide rigidity to the system (Builes, 2011, p. 44-45). 44-45).

F) Casas defines it as a non-conventional construction system, which must provide safety, stability and durability over time, (2011, p. 27). Defines the aspects of this system to be evaluated:

- Environmental aspect, this is composed of two orders:

1. Formal order, it is the urban or rural environment where the system will be implemented.
2. Functional order, which is composed of geography, climate and construction regulations.

- Technological aspect, this includes the level of use of the construction system.
- Socio-economic aspect, relates the economic situation of the region, (Casas, 2011, p. 28-36).

G) In his research Giraldo - Raigoza and Sanchez, emphasizes the construction of: Housing in the rural area with the application of bioarchitecture of tendon wall, based on the characteristics of the social environment, areas of influence with latent need for a model of improvement at the level of housing and need, it is considered urgently to meet the deficit presented. Environmental awareness, is another factor to be addressed in rurality from the incursion of the new rural housing model raised, (2016, p. 16). The guadua angustifolia is the most important raw material in the construction of a kind of tendon wall, it is a renewable and sustainable resource as it fixes carbon dioxide (CO_2), complying with the constructive sustainability.

H) Mora conducts an experimental research in the laboratory, manufacturing various types of tendon walls subjected to lateral loads, the dimensions of these tendon walls have a height of 2.20 meters, a width of 1.20 meters and a thickness varying between 5 and 7 centimeters, listing the following prototypes, (Mora, 2022, p. 47-49):

- Thomas type tendon wall, which consists of a guadua portico, an internal matrix made of fique sacking, barbed wire and covered on both sides with mortar mortar with cement and sand.
- Chacon type tendon wallconsisting of a guadua portal, an internal matrix of metal mesh with a vein, an internal grid reinforced with 3/8" corrugated steel and coated on both sides with cement and sand mortar.
- Morachá type tendon wall, which consists of a guadua portico, an internal matrix of guadua mat, reinforced with 3/8" corrugated steel and coated on both sides with cement and sand mortar.

From the bending test with lateral loads performed on the tendon wall specimens in the laboratory, the following results of the maximum ultimate load were obtained (Mora, 2022, p. 91) the following results are obtained for the maximum ultimate ultimate load, (Mora, 2022, p. 91):

- Thomas type tendon wall, X = 6.12 kN.
- Chacon type tendon wall, X = 7.00 kN.
- Morachá type tendon wall, X = 6.55 kN.

	CARGA MÁXIMA DE ROTURA		
	THOMAS	CHACÓN	MORACHÁ
Ensayo 1	6,75	8,2	6,9
Ensayo 2	5,99	6,15	6,64
Ensayo 3	5,4	7,55	6,47
Ensayo 4 _	6,33	6,08	6,2
X =	**6,12**	**7,00**	**6,55**
S =	**0,5705**	**1,0506**	**0,2941**
CV =	**9,33**	**15,02**	**4,49**

When performing a statistical analysis of the lateral flexural test values of the tendon walls, the highest arithmetic mean corresponds to the Chacón test, the Thomas value is lower by 12.6% and the Morachá value by 6.4%, with respect to the highest value. The coefficient of variation (CV) value of the Chacón trial has a high variation (15.02%), followed by the Thomas trial (9.33%) and the lowest coefficient for the Morachá trial. It is concluded that the various types of tension walls perform well under horizontal or lateral bending loads.

I) Garcia and Velasquez in their experimental laboratory research, propose a new alternative for tendon walls, by replacing the fique sack and barbed wire with a netting of PET (polyurethane terephthalate) bottles and banana rachis (stem), recycled waste materials, generating a new form of reuse of these products to be used in the manufacture of tendon walls for construction (2021, pp. 15-17). When the respective laboratory tests were carried out, it was concluded that the rachis fibers did not adhere well to the mortar; additionally, according to the compression and flexural tests, the PET meshes do not generate or provide resistance to the tendon wall. As a conclusion of the research carried out, the implementation of this kind of materials in the fabrication of tendon walls is not feasible, (García and Velásquez, 2021, p. 97).

Discussion and Conclusions

Tendon systems are considered constructive forms that have their origin in the zoological architecture of vertebrates, such as the combination of skeleton, muscles and tendons (Cardellach, 1970). In relation to this research, this constructive system proves to be useful in load-bearing and division elements, mainly in the direct relationship between the materials that make it up and the purpose for which it will be designed. This is supported by Cardellach (1970), who states that the sole origin of these structural and constructive forms is at a higher level of mechanical sensitivity and natural inspiration. Cardellach concludes that the engineer, with this innovative spirit, must discover new forms of resistant frames for the current construction.

The tendon wall system has been applied in Colombia since the 1990s and, because it is environmentally friendly, it has provided an answer to the need for low-income housing, since it does not require skilled labor. The confinement transmitted by the tendon wall system is highly resistant to gravity loads and very stable to seismic events as demonstrated in the Armenia (Colombia) earthquake of 1998 (Zuluaga, 2012, p. 14-15). From the technological point of view, the adoption of non-conventional alternative construction systems brings with it the innovation or improvement of these systems, either through the use of traditional regional materials, the implementation of new construction, organization and production methods to reduce construction costs, or the use of recycled materials in some cases, all these aspects listed are possibilities that at a given moment can become real and effective options for the use of existing resources, and in this way help the less favored classes to improve their living standards with the construction of decent housing, such as those built in the neighborhood La Independencia, Municipality of Restrepo, Valle del Cauca, Colombia, Figure 5.

Figure 5
Group of houses built with the tendon wall system

The advantages of this tendon wall system are as follows:

- Ancestral peasant building traditions can be applied and improved.

- Labor and material resources from the same region are used.
- Mortar-coated panels can be given a rustic finish, or they can be stuccoed and painted afterwards.
- The panel system allows the internal placement of all kinds of pipes for electrical, hydraulic and gas installations.
- The panels, due to their thickness, serve as thermal and acoustic insulation in the house.
- The tendinous system is very economical so that houses can be built at low cost, and houses can be built in both rural and urban areas of a locality.
- The behavior of this tendon wall system in the face of the seismic actions presented in the region was very positive with a value on the Richter scale of 6.5and the Armenia earthquake in 1998 with a Richter scale value of 6.4, both rated as strong. The houses built with the tendon wall system did not suffer structural damage.
- The tendon wall system does not overturn in earthquakes, as was the case with wattle-and-daub and simple brick walls. This seismic response factor is very important when it comes to safeguarding the lives of the occupants.
- It is an environmentally friendly construction system.
- This construction system is part of the framework proposed by the Regional Action Plan for Sustainable Development of Agenda 21 of the United Nations, regarding the recovery of traditional systems and materials, by using non-conventional and alternative systems.

The few disadvantages of this tendon wall system are:

- Direct humidity can occur in the walls located in the external parts of the house, as a result of rainwater, which can be prevented by performing periodic maintenance with impermeable plastic paint coatings.
- When building in wood or guadua, these must be well immunized to prevent attacks by xylophagous insects, in order to guarantee their durability over time and good structural behavior.
- Another very important factor to take into account are the construction errors that may occur in its execution, as a result of inexperience in self-construction.

The following aspects are left as a topic for research and technical discussion:

- Such is the importance achieved by the tendon system in solving a structural resistance problem that an original, economical, resistant and elastic structure is obtained.
- Thomas materializes the tendinous system, developing construction techniques and using traditional wooden structures of the region, implementing the self-construction system.
- This tendon wall construction system responds to the housing needs of the underprivileged classes and can be implemented in any geographical location.
- This new construction system technology is intended to comply with environmental requirements, taking into account, from this perspective, the application of new clean technologies in the field of construction.
- It is a basic tool that must guarantee a decent quality of life, responding to the unsatisfied primary needs of low-income families.
- The community self-construction system can be implemented, since it does not require prefabricated elements.
- As it is a very flexible construction system, the architectural spaces of the house can be easily adapted and modularized.

- The system is adaptable to any geographical area and topography, as well as being environmentally friendly.
- Because of its versatility in construction, it is possible to use various materials in the structure of the house, whether wood or guadua from the region.

The following conclusions are drawn from this research process:

1. The viability of the construction system to respond to the housing deficit problem in both urban and rural areas was demonstrated.
2. The tendon system results in a quality construction with local materials.
3. From its philosophical principle, it contributed the integrating concept of appropriate technologies.
4. From the professional and academic point of view, when working with the community, an apprehension of ancestral constructive knowledge is made.
5. Academically, the concept of exclusionary architecture is overcome by the evolutionarily creative function of inclusive architecture.
6. Philosophically, the social acceptance of this technology is significant, as the community qualifies it as appropriate to be implemented by them.
7. The construction projects of tendon walls in rural or urban developments must satisfy the physical and basic social needs of the communities, in accordance with sustainable construction and maintaining a balance between the existing ecosystems.

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