Analysis of the bamboo construction process in the architecture of Leiko Motomura and Simón Vélez

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Abstract

The interest in the use of natural materials by construction professionals has been growing as the concern with designing buildings with low environmental impact arises. For this reason bamboo is an excellent choice, as this material has a high resistance parallel to the fibers, is light and has a great capacity to incorporate CO^2. Given the context described above, this article aims to analyze the constructive techniques in bamboo culms in two works of architectural relevance: Max Feffer Cultural Center (Brazil) and Casa Serra Grande (Brazil), by architects Leiko Motomura and Simón Vélez. For this, field visits were made for a better understanding of bamboo connections, analysis of photographs, files, 3D models and bibliographical research regarding the material. The study helps to understand and reflect on the constructive components of bamboo in architectural projects, highlighting the association between the traditional elements of fittings, associated with the technology available today, such as the grout associated with screws, clamps and spacers.

Keywords: Bamboo; Construction techniques; Bamboo architecture.

1. Introduction

Bamboo is a vernacular material, recognized for its structural properties, high flexibility, versatility for presenting applications in different uses, and with native species in different locations around the world. With the advance of science regarding the development and improvement of industrialized materials such as steel and concrete, bamboo ended up being undervalued in civil construction. However, with the advent of sustainability, professionals in the field are now searching for renewable materials once again, as their application has less impact on the environment. According to Xiao *et al.* (2008), its application in civil construction is wide, ranging from small house structures to large bridges.

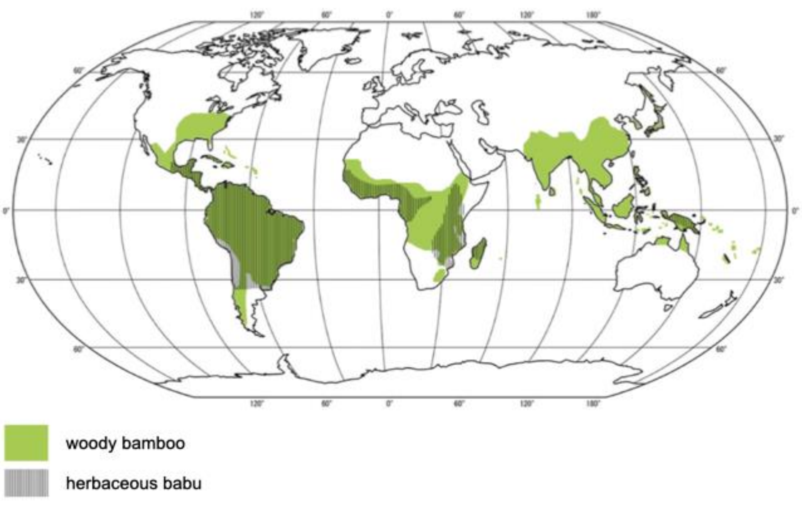
This paper aims to analyze and understand the technique applied to the elements of connections in bamboo culms by investigating two contemporary works by architects who are experts in the use of this material in their architectural projects.

Thus, this research addresses the use of bamboo techniques, both vernacular and contemporary, and their respective valuation of the material in current civil construction. For this reason, the research was carried out in three stages for a better understanding of the construction process: (1) Literature Review - in which the concepts and methods used in the construction with bamboo culms were studied; (2) 3D modeling of case studies - used as a resource for analyzing and detailing the connections used by architects in their works, for a better understanding of the construction system; (3) Comparative analysis of the connections applied in the architecture of Leiko Motomura and Simón Vélez.

2. Bamboo: A natural raw material

Bamboo is present in South America, in countries like Brazil, Ecuador, Peru and Colombia. In Colombia, technical development occurred due to traditional use in civil construction. In order to improve understanding of the properties of the material and its form of use, several regulations were developed, such as NTC 5407:2018 Unions of structures with *Guadua angustifoli Kunth*, which aims to establish the minimum requirements for constructions that use the bamboo species as the main structure. (ICONTEC, 2018). According to DUNKELBERG (1992), bamboo has become better known over the past 30 years, due to its beauty and formal quality in contemporary architectural works, as it is a fast-growing plant. Another fact highlighted by the author are the physical properties such as high tensile and compression strength, and the third factor is that the material is light. Therefore, when compared to other materials, it can generate savings. These factors led the Institute for Lightweight Structures, a University of Stuttgart group led by Frei Otto, to study the material and be part of the IL31 project.

Figure 1 – Map: Geographical distribution of bamboo in the world.



Source: The author based on images from Huang (2019).

Bamboo is a perennial plant that shows rapid growth and regeneration. Some Brazilian bamboo species grow up to "20 centimeters per day". If cut regularly, it continues to sprout for over 30 years without the need to be planted annually. According to Embrapa (2018), with the production management system as planning for regular planting and extraction, high-quality materials applicable to civil construction can be generated.

One of its advantages is the easy handling and the use of simple tools; because of this, bamboo constructions end up becoming accessible. In Colombia this material is used to resist seismic forces, as parts that have been damaged are easily replaced. (XIAO *et al.*, 2008)

Kiran Vaghela (2013) highlights that as it is a plant material, its colors, size and shape of the cross section, and distance from the internodes vary depending on the species. Therefore, the classification and choice of bamboo culms are extremely important for a quality construction, especially when assembling the connections, avoiding potential deformities in the material in the long term. In this sense, the culms must be as straight as possible, with little variation in diameter; also, culms with cracks must be eliminated to reduce attacks by fungi and insects, compromising their resistance.

In the structure, the mechanical strength is also affected by the age of the bamboo, since it must be cut with a maturity of at least three years to be used in structures such as pillars and beams and in civil construction. Before this minimum period, it can cause resistance problems. (KIRAN VAGHELA, 2013)

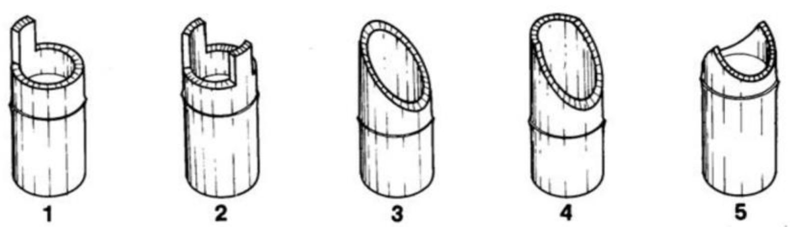
In addition to the numerous benefits mentioned above, bamboo is increasingly attracting attention due to its low environmental impact in sustainable projects, as it is a natural material that can transform carbon dioxide into oxygen and incorporate CO_2 in part of its fibers. In high-slope terrain it can help control erosion from its roots, depending on the species. (KHANNA, 2011)

3. Constructive techniques with bamboo culms

In works with culms, knowing how to use bamboo construction techniques is a very important aspect when it comes to structural assemblies, because, even if culms classified as suitable for construction are used, if the assembly is not done correctly, the complex can come to collapse if its connections are defective (OSTAPIV; LIBRELOTTO, 2019).

New elements are being developed for use in civil construction, for example, in works with culms, different techniques have emerged for assembly with screws, clamps and spacers, different connection components and cutting machines to use them more efficiently in the structure and construction (PADOVAN, 2010). Previously there were only traditional techniques in bamboo, which basically consisted of using pieces fitted together or by means of strings and screws.

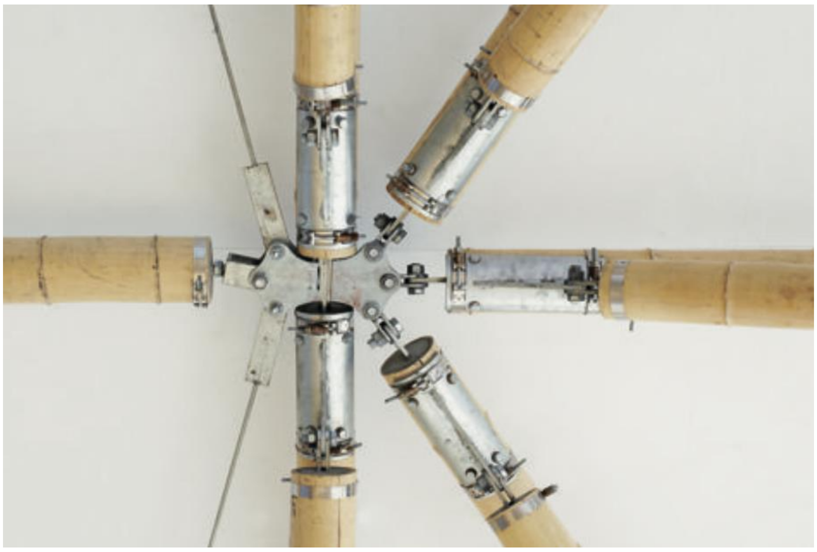
Figure 2 – Main traditional cuts in bamboo culms: 1. One ear 2. Two ears 3. Beveled 4. Flute mouth 5. Fish mouth



Source: Hidalgo-López (2003)

As shown in Figure 2, these are the five main cuts used to make the connections between bamboo culms, however Janssen (2000) highlights that creating bamboo joints is not a very easy task, because the cane used for the structures is hollow, with nodes at varying distances. As it is a natural material, it is not precisely circular, which is why different techniques have been developed to facilitate the assembly of the architectural project and the design of the project. These are called contemporary connections (figure 3), as they allow the use of materials such as steel and mortar incorporated to the bamboo element, in order to reduce deformations that may occur during the process, and increasing its structural performance.

Figure 3 – Example of contemporary connection, using steel to facilitate the connection between the bamboo culms.



Source: Janssen (2000)

Bamboo architecture has gained recognition, such as the works by architects Leiko Hama Motomura and Simón Vélez, in the projects of the Max Feffer Cultural Center and Casa Serra Grande, analyzed below.

4. Case Study

4.1 Max Feffer Cultural Center

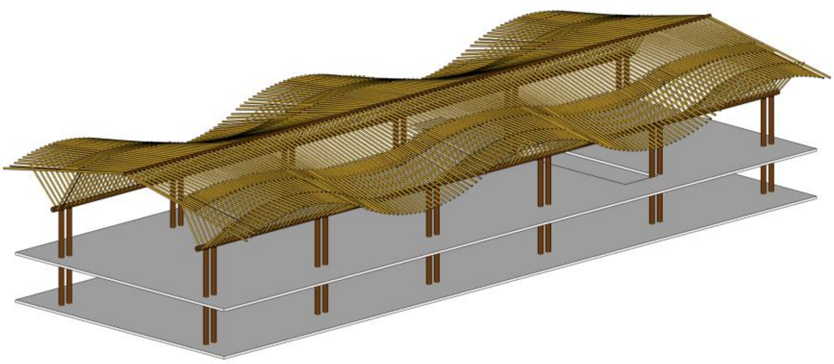
Figure 4 – Max Feffer Cultural Center, by architect Leiko Motomura

Source: The author (2021)

Located in the city of Pardinho, in the state of São Paulo, the Max Feffer Cultural Center was designed and built in 2008 by architect Leiko Hama Motomura, in partnership with the Jatobás Institute, with the aim of promoting interaction between local community residents in an environment where they could develop daily activities. The building was designed to have sustainability concepts, including environmental performance and the durability of the building with the use of low impact materials. In this context, the work is defined by a large open space covered by a curved bamboo roof of the *Guadua chacoensis* species, supported by *Eucaliptus* beams and pillars, granting lightness to the whole. The ground floor and second floor slabs are made of reinforced concrete.

The Center is divided into two floors; the ground floor has rooms for collective activities and the administrative area of the complex, and the upper level has a small library, a stage for presentations and a large covered space for free activities.

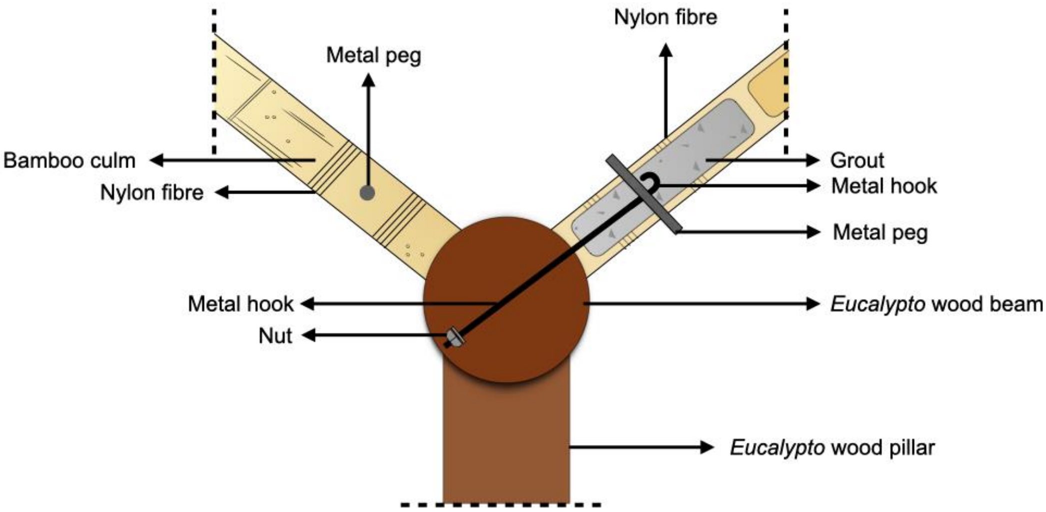
Figure 5 – Perspective of the structure used at the Max Feffer Cultural Center.



Source: The author (2021)

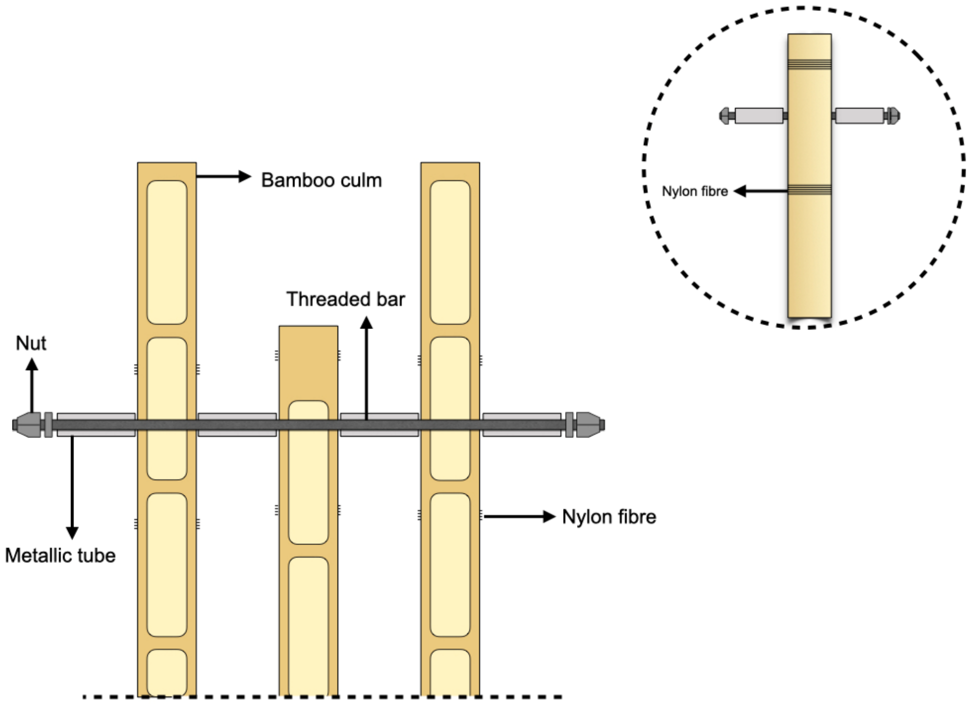
Developed with a mixed structure of concrete, bamboo and wood. The roof is built in bamboo culms supported on two large beams and twenty-four wooden pillars where they unload their efforts. In this project, the architect uses traditional techniques with "fish mouth" connections for joints submitted to significant efforts, as shown in the detail below (figure 6), where we can see the encounter between the bamboo culm and the wooden beam, where the compressive stresses occur.

Figure 6 – Detail of the connection between the wood beam and the bamboo culm.
Source: The author (2021)



To prepare this connection, Leiko used a small metal peg inserted transversely into the culm, where it will support the metal hook which, in turn, will go through the wooden beam, being screwed with a metal nut and capped with a piece of the wood itself. To complete the connection, a little grout is inserted so that there is an increase in the structural performance of the element and the rigidity of the metal parts.

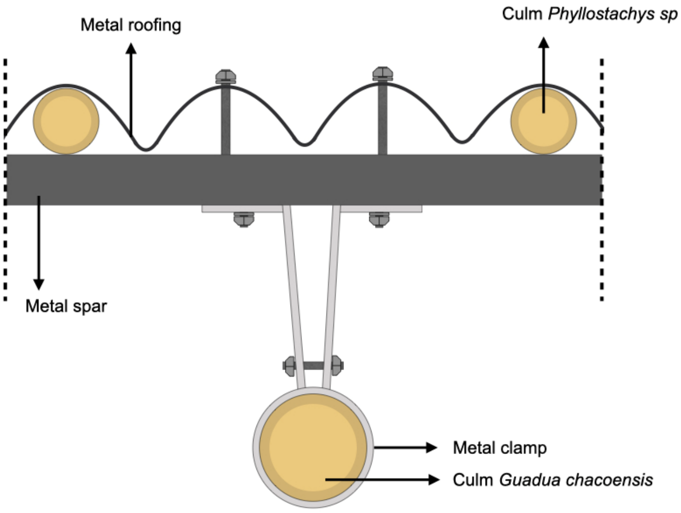
Figure 7 – Detail of the connection between the inclined culms.



Source: The author (2021)

In the elements next to the roof (Figure 7), the solution used differs from traditional techniques where there is a need for greater precision in assembly. The resource used was designed to provide greater flexibility in connections due to the sinuous roof design. Because of this, they were interconnected every three culms, with the versatility to change parts in case there is any damage. The assembly is done using a metal tube, perforating the culm transversally. Inside these tubes, a threaded bar is passed and finished with nuts, making the connection between them. We can notice the use of a nylon thread tied between the metal tubes to compress the material and avoid potential cracks.

Figure 8 – detail that connects the roof to the bamboo structure.
Source: The author (2021)



Finally, the detail that connects the roof to the bamboo structure. We can notice the use of metal clamps joining the culms with the roof spars. This is a more contemporary technique, since it uses metallic pieces and not lashings as in traditional techniques.

In this project we can analyze that architect Leiko Motomura prioritized the use of non-traditional techniques, as they would facilitate the assembly of the set, given that the roof had several different inclinations. One of the projected aspects was the ease of removal of the pieces; in case there is any damage to the bamboo, it can be replaced without the need to disassemble the whole set, thus providing a longer life cycle for the building.

4.2 Serra Grande House

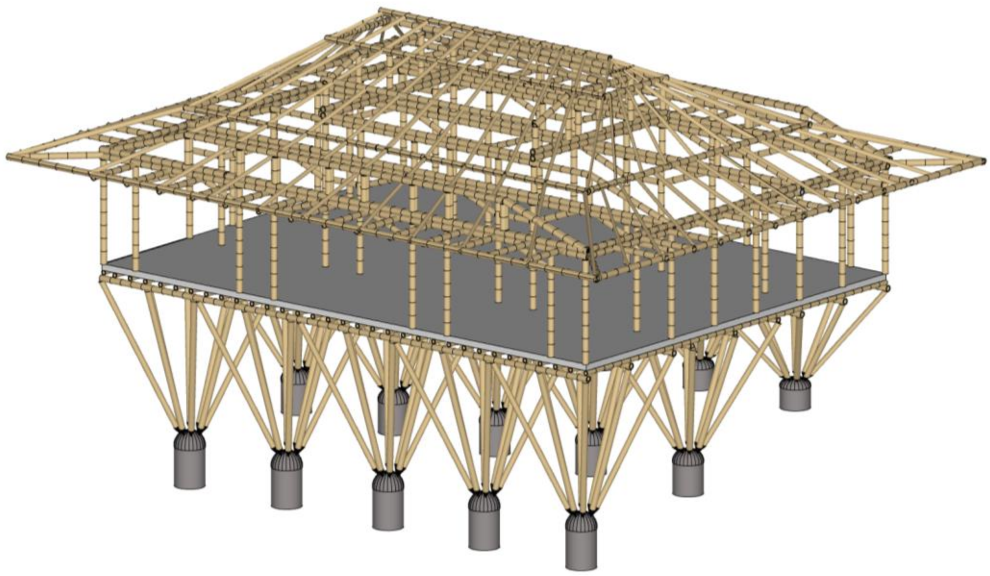
Figure 9 – Serra Grande House, by architect Simón Velez.

Source: Vélez (2021)

Designed by Colombian architect Simón Vélez, the house is located in the south of Bahia, in the city of Uruçuca. It is a single-family house built in bamboo culms of the *Dendocalamus giganteus* species applied to the main structure, such as pillars and beams, and *Phyllostachys pubescens* to the secondary structure, because it has a smaller diameter.

With a total area of 187 m2, Casa Serra Grande is divided into a single floor that is accessed by a ramp, as the terrain is significantly uneven. The internal division of the house integrates an extensive balcony to the bedrooms and living room, while the laundry and bathrooms are in the back.

Figure 10 – Perspective of the structure used in the Serra Grande House.

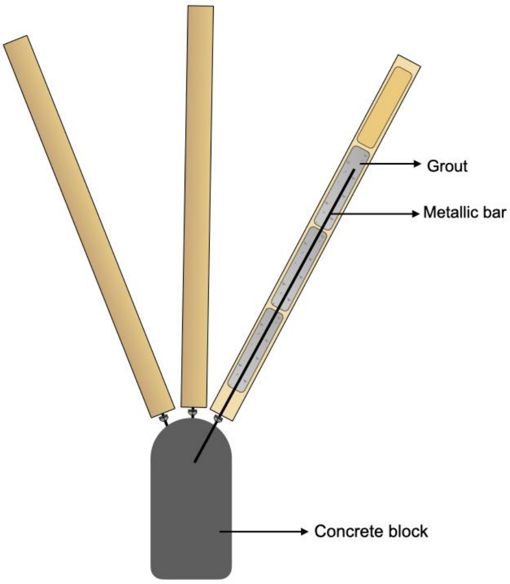


Source: The author (2021)

In the construction process, the foundations are concrete pillars with punctual elements, as the bamboo must not come into direct contact with the soil due to its humidity, which can damage the culms, creating an opening at the edges through which fungi and insects can enter. Built on 15 pillars, each of which has a pyramid-shaped design.

We can see, in figure 11, that Vélez uses his technique in which he enhances the base of the bamboo culm with grout filling in two or three internal chambers of the material, since it already has an iron bar in its internal part. This connection, named after him ("Vélez connection"), helps to withstand the forces of traction and compression.

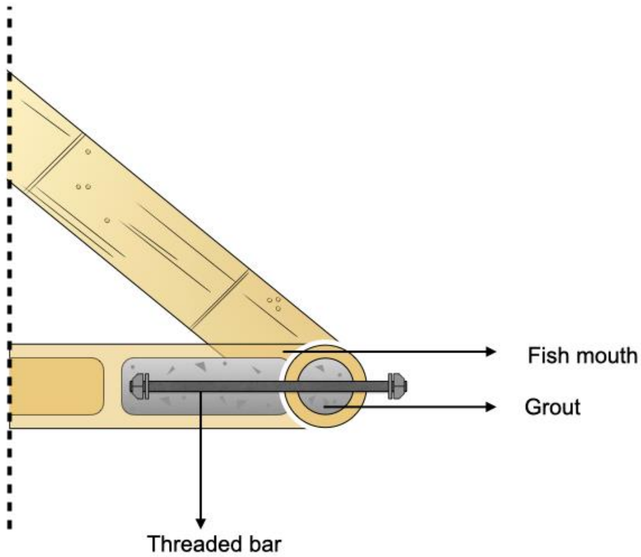
Figure 11 – Detail of the Vélez connection.



Source: The author (2021)

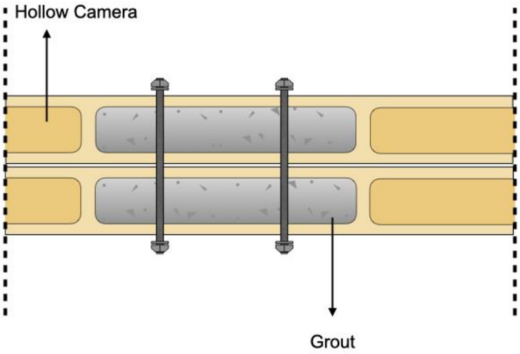
In the central structure of the house and finishing of the roof, we can observe the use of techniques using a bar crossed longitudinally between two culms, being finished with steel nuts. Finally, in the same way used in the beams, the set of connections also has the insertion of grout in the internal culm, as protection so that the culms do not suffer crushing and splitting due to the weight coming from the roof.

Figure 12 – Detail of the roof finish.



Source: The author (2021)

Figure 13 – Detail of the connection between bamboo culms.



Source: The author (2021)

In a craft work, we notice that all the connections where the culms meet were made using traditional connections, such as the fish mouth and the flute mouth. This makes the craftsman's work very precise, since the pieces must connect with precision. Such decisions made by the architect make the project have longer durability, since the pillars were placed away from the ground, and grout was used in the connections, which makes it more resistant and reduces the damage to the pieces, and the long eaves that Vélez uses in his projects help protect the culms from bad weather.

5. Final Considerations

In both works analyzed, we can notice the beauty of the material highlighted by the architects, establishing its value as a primary element. The elements used by Simón Velez and Leiko Motomura were traditional techniques such as the fish mouth and flute mouth connections, associated with contemporary technologies, such as grout, spacers.

In the Max Feffer Cultural Center project, exclusive connections were designed for the building, such as the metallic spacers that link the connections between the culms but do not make the structure rigid, since the roof has approximately 60 different inclinations interconnecting with the wooden beam. Another important aspect in Leiko's work is the care to design in such a way that any piece can be replaced without compromising the structure of the set.

When examining Casa Serra Grande, unlike the Cultural Center, Simón Vélez applies in almost the entire work his construction system with the insertion of grout and metal bars in the hollow center of the bamboo culm to enhance the material's resistance. Therefore, we can recognize that, regardless of the strategies adopted by architects regarding the use of structural connections, they demonstrate that contemporary architecture with good design practices can contribute to the development of the use of the material without neglecting its formal quality.

As analyzed, the bamboo design allows less change in the terrain, due to its easy assembly. It is observed that roofs with large eaves have the function of protecting the building, components such as beam and pillar structure, main and secondary, roof elements. In the Vélez project, the protection of these elements is more noticeable.

6. Acknowledgement

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