PURLIN-DOWEL CONNECTION FOR BAMBOO CONSTRUCTIONS AS SUSTAINABLE PROPOSAL FOR THE AMAZON HOUSING

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Summary

The housing project is located in the Amazon region of Peru, in the region of Cusco, in a Native Community in the Manu National Park. The proposal offers an eco-friendly house designing made of bamboo for the Amazon communities.
The first part, propose a " Appropriate construction system" based on the architectural features and structural components of the natives matsiguengas techniques, natural materials, conception of their vision of housing; with the addition of bamboo as the main structural element and predominant material, allowing own construction, with a practical system for easy assimilation and learning. The use of bamboo is posed in different ways: cane, slats and mats. The principal criteria of the proposal are: "Alternative production of ecological and healthy bamboo housing for the Amazon" and "creativity with identity, design that responds to the habitat of Amazonian peoples.
The second part is devoted to presenting the experimental investigation, the purlin-dowel connection as complement at the frame structure system.
The two parts presented through a case study, allow to valid the prototype house "Matshigenga house" which has the particularity of a structure with purlin-dowel (moored) connections. The proposal brings recommendations for future research in the field of the structure, the details of connections and the bearing capacity of the housing elements.

Fig.1 Proposal Matsiguenga housing: Front View

Theme: Architecture, Engineering and Social Housing

1 Problems to be addressed

Peru is one of the 17 megadiverse countries of the world and its Eastern Tropical Andes-Amazon region is globally recognized conservation priority. However, deforestation in the Andes-Amazon is increasing as rural populations rely on natural resources for their livelihoods. New opportunities to develop sustainable productive alternatives of wood are urgently needed.

Peru has abundant bamboo resources with 67 species distributed in approximately 71,000 km2 area, especially in the southwest Amazon where up to 30,000 km2 of tropical rainforest are dominated by native Guadua genus bamboos. However, local foresters and farmers lack knowledge of how to sustainably manage bamboo forest. The natives know about bamboo, they used it in ceremonial acts, arrows, for making musical instruments, in some elements of their temporary housing, but they don't know the potential of bamboo in construction and the possibility of industrial products. Current uses remain artisanal and rudimentary. All of these have resulted in a low benefit from bamboo resources in the Amazon of Peru.

On the other hand, the Amazon Indigenous groups, continue suffering the impact of colonization, construction of roads, of large and small extractor of natural resources, of the pressure of people who think that in order to be recognized as citizens, they should adopt western culture models. They don't live in good conditions, they have they have health problems associated with the housing.

2 Intervention Universe in potential areas

1. Zone 1: North Coast, Tumbes, Piura, Lambayeque and La Libertad Regions. Marketing area of the resource as raw material, where bamboos enter from Ecuador legally and illegally. In recent years the planted areas of Guadua angustifolia have increased. Presence of bamboo in some colonial, touristic and institutional buildings
2. Zone 2: Northwest Center, Cajamarca, Amazonas and San Martin Regions. Starting from the last region, the bamboo (Guadua sp native species), is transported to zone 1, where it is mixed with the imported one, with destination is Lima. Presence of bamboo in some rudimentary local buildings.
3. Zone 3: Central Forest, Cerro de Pasco, Huánuco and Junín Regions. Zone populated by various indigenous communities, mainly of the "Ashaninka" ethnicity, who have used bamboo for centuries for their temporary buildings and handicrafts.
4. Zone 4: Central Coast, Lima and Ica Regions. Lima is the main market for bamboo from zone 1 and 2. Presence of bamboo in colonial buildings, in some beach buildings mostly as a decorative use, some after earthquake examples in Pisco (Ica).
5. Zones 3 and 4 are strategic for marketing and plantation establishment for the suitability of climatic factors, soil and the proximity to the capital, it is a potential axis.
6. Zone 5: Southeast Forest, Andean Amazon, Cusco and Madre de Dios Regions. Zone covered by extensive areas and varieties of species of the genus Guadua. It is the region which concentrates most of the area of bamboo's native population, which are minimally exploited. This zone is populated by different indigenous communities, such as the "Matsiguenga and Wachiperi" who have used bamboo for centuries. This studio is located in this fifth zone (Tab.1)

Table 1 Natural and local material uses

Zone		Regions	Proposal
Zone 1	North Coast	Tumbes, Piura, Lambayeque and La Libertad Regions.	
Zone 2	Northwest Center	Cajamarca, Amazonas and San Martin Regions.	
Zone 3	Central Forest	Cerro de Pasco, Huanuco and Junin Regions.	
Zone 4	Central Coast	Lima and Ica Regions.	
Zone 5	Southeast Forest	Andean Amazon, Cusco and Madre de Dios Regions.	Bamboo housing proposal for the Amazon

3 Place and people

The housing project is located in the Amazon region of Peru, in the region of Cusco, in the Native Community of Santa Rosa de Huacarias in Manu National Park. The Community is populated by two ethnicities: Matsiguenga and Wachiperi. The Matsiguenga, are one of the most representative indigenous communities in the Amazon, in extension and territorial occupation.

4 The proposal

The proposal offers an eco-friendly house designing made of bamboo that meets the physical, environmental, socioeconomic and cultural characteristics of the site. It endows of spatial conditions, functional, thermal comfort, durability, flexibility, adaptability and Earthquake resistant.
It proposes a "Appropriate construction system" with around 95 m^2 based on the architectural features and structural components of Matsiguenga's techniques, natural materials, conception of their vision of housing; with the addition of bamboo as the main structural element and predominant material, allowing own construction with a practical system for easy assimilation and learning. The use of bamboo is posed in different ways: cane, slats and mats.

4.1 Proposal Criteria

4.1.1 Alternative and production of ecological and healthy bamboo housing for the Amazon.

- Attends and protects vulnerable Amazonian native communities.
- Promotes the rational use of local resources, bamboo, adding value as a building material, reducing the use of wood.

Fig.2 Proposal housing: Structural System

- Promotes ecological building with bamboo in the Amazon, protecting natural protected areas, with minimal impact to the environment.
- Promotes research on native species of bamboo for use in construction in order to be introduced in the Peruvians standards.
- Encourages the use of bamboo to be part of the habitat and constructive culture of the habitants.
- Management of existing forests and establishment of new plantations.
- Promote the Life-cycle assessment – LCA of bamboo

4.1.2 .Creativity with identity, design that responds to the habitat of Amazonian peoples.

- Rates and affirms the cultural identity of Amazonian native communities.
- Responds to understanding the habitat of Matsiguengas and community residents and housing as a place of refuge, as a place for the protection of both aspects of nature (rain, insects, wild animals), and spiritual (related with their culture).
- The proposed stilt house is composed of the core house with garden and outside toilet service and an upgraded kitchen.
- The core house consists of 3 spaces (social two- and one private) with multifunctional character.
- Answers to Matsiguengas architectural codes, such as oval plan, their integration with nature, plastic, dynamic, with curved ceilings. The spaces at all times follow the transparency and generate this integration with nature, responding to climate conditions and cultural patterns.

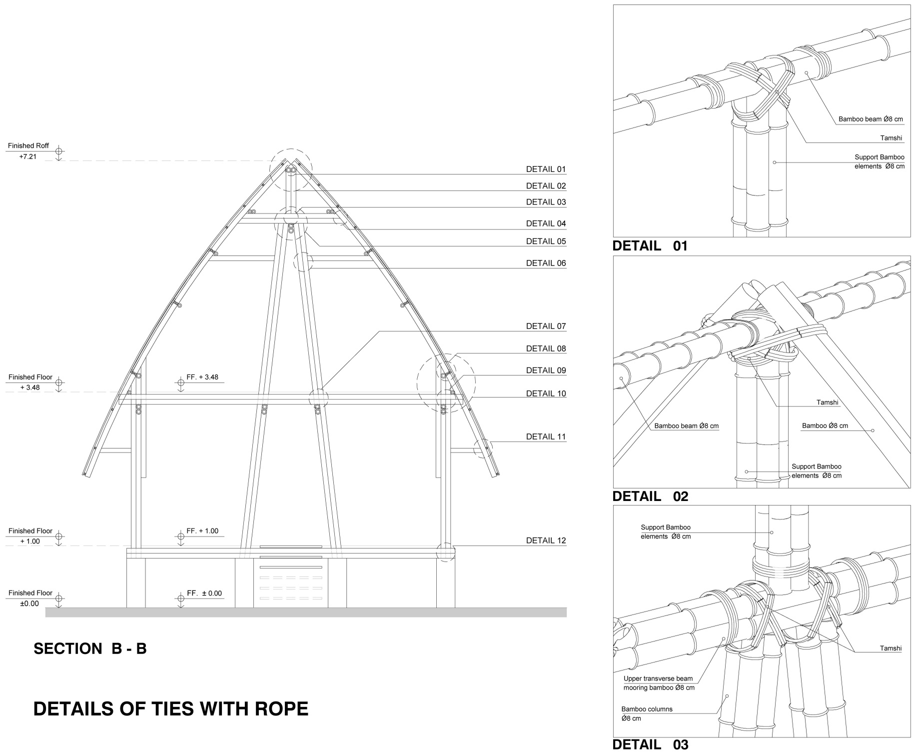


Fig.3 Proposal housing: Section and purling-dowel detail with “tamshi”

- Binds the Matsiguenga architecture with architectural plasticity flexibility, guided by bamboo to get their own identity.
- It adopts ancestral construction techniques such as tie-ups with tamshi rope and move them to the joints of the bamboo elements, designing each of the connections, which make it more authentic.
- Answers to environmental conditioning:
  For lighting: the first type through a vertical enclosure, generating vertical "filters" of light in moments when the sun falls directly, generates shadows and bright lines uniform on the floor, typical of Matsiguenga's house. And a second type, is a window in the cover, with two leaves "pivot" which control the desired light and air.
  For ventilation: air circulation is where you enter the lighting.
  High ceilings tilt angle of 57 °, slightly curved, frilly, covered with “crizneja” (woven palm) for protection against the rain.

4.2 Materials proposed

Local and natural materials, mainly bamboo. Endemic species of the genus *Guadua* bamboo: *Guadua angustifolia*, *Guadua sarcocarpa* and/or another endemic specie.

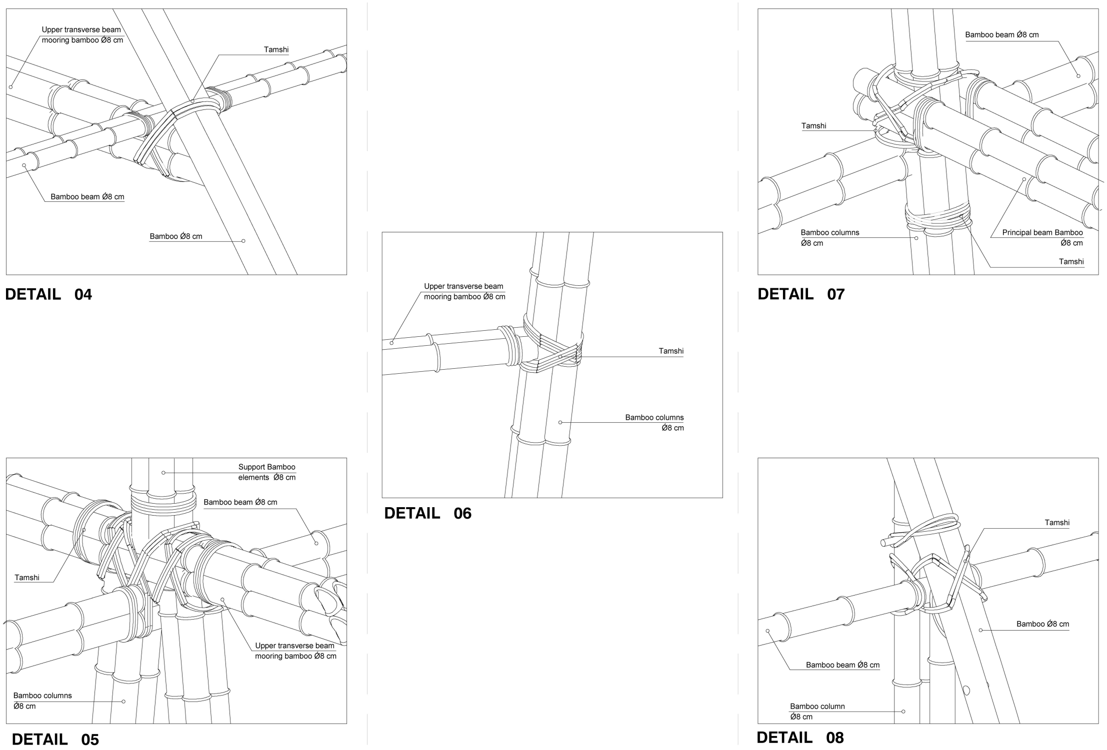


Fig.4 Purling-dowel detail proposal with "tamshi"

4.3 Structural conception

The two floors structure was designed based on two systems: frame system, braced frames in the other direction, and a light coverage. The structural walls are composed of a skeleton of stud bases and bamboo bracings; an upper and a lower bamboo ribbong; and reed coverage. The frames are made up of vertical and diagonal elements receiving the ridge, which fulfil the bracing function. The structure is supported by a system of piles and concrete that transmit the loads to the ground.
The floor and the mezzanine are supported by twin bamboo beams. On the floor, these beams rest on the piles. On the mezzanine, these beams are supported by tie-beams which in turn rest on bamboos forming columns (frame system).
The cover is formed by trusses whose elements are made of bamboo and are contained in a plane, supported by bamboo straps which in turn receive the cover closure material, "crizneja".
The structural modeling was performed in the elastic range, considering the elements as homogeneous and linear. The SAP2000 v16 software was used to implement the structural modeling. The walls were analyzed using a structural model of cantilever walls built into the base. Trusses and belts were analyzed representing the elements as lines and unions were analyzed as articulated joints, unless any of the elements retained its continuity.
The loads applied to the structural model including dead load, cover live load, wind load and earthquake load according to loads Standard E020 and the seismic resistant analysis Standard E030. Deflections verification was carried out including immediate and deferred deflections caused by combined sustained loads considering the moisture content to be equal or lower to 19% and the temperature will be equal or lower to 37°C. The permissible deflections used were selected considering the coverage is slanted.
The stress verification was based on the application of the principles of structural mechanics considering the dimensions shown on the structural drawings. In the elements subjected to flexion the axial stresses parallel to the fibre, shear parallel to the fibre and crushing stresses perpendicular to the fibre were considered. For elements subjected to axial force, tension and compression stresses were considered. In the elements subjected to flexion and axial load, the interaction of the forces produced by the flexion-compression or flexion-tensile stress was considered.
The design of the bamboo elements was made by the method of the admissible stress. The values of allowable stresses specified in Standard E100 were used.

Because of the need to achieve a solution that suits the constructive cultures of the area, items are interconnected so that the tensile and compressive stresses are transmitted principally perpendicular to the fiber and the clamping of the elements is achieved with the use of moorings with vegetable fibers. In this sense, the connections used are a proposal of the architecture specialty based on an investigation into the constructive culture in the area. The empirical nature of these solutions requires corresponding experimental validation.
In the pile-column connection the incorporation of steel rods and threads are proposed due to the need to properly connect the bamboo with the pile. It was not feasible to drive the bamboos directly into the ground due to durability problems that this entails.

5.Experimental investigation

Validation of the purlin-dowel joints

The critical feature of the bamboo anisotropy stresses the structural design, especially at the purlins and dowels joints; the joint favours a better yield by supplying a safety factor, as proven in other fibre purling reinforced Timber Joints studies. This work attempts to research the bamboo cane joints mechanic functioning without metallic pieces such as pins (bolt coupling) but dowels joints reinforced with purling reinforcement. We presented the reinforcement of bamboo with fibre, as reference to export the method.

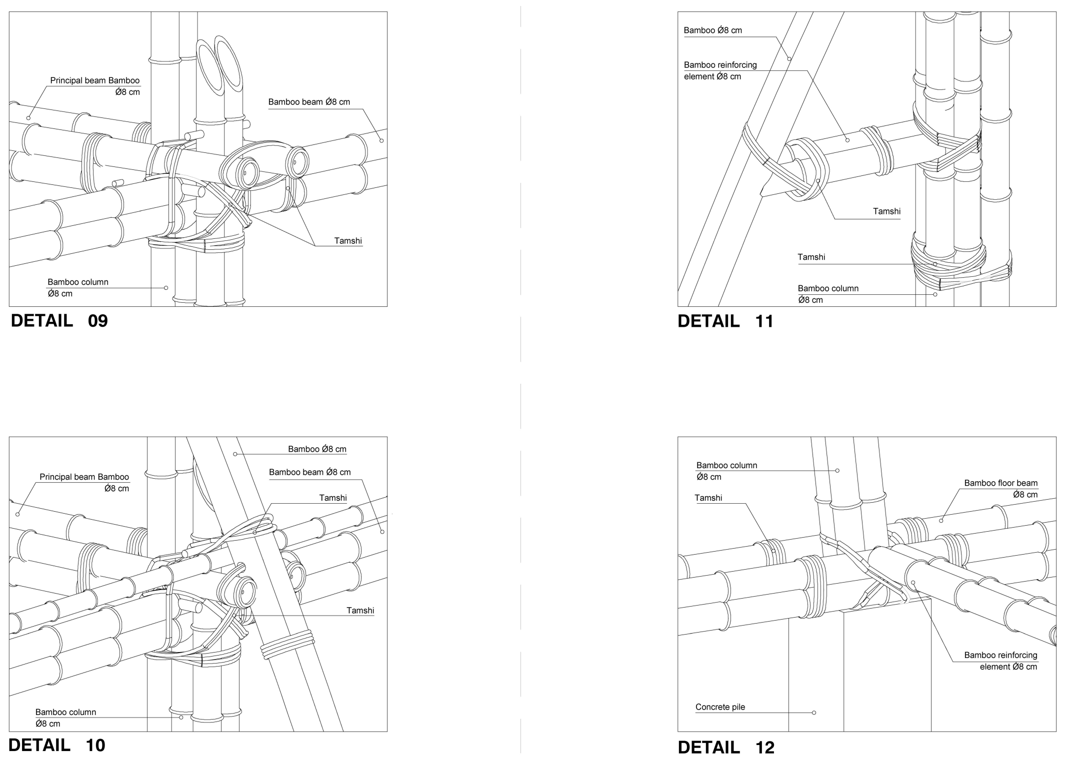


Fig.5 Purling-dowel detail proposal with “tamshi”

5.1 Reinforcement test

The main objective of the experimental investigations described in this section is to improve joint behavior in the canes, initially using bamboo reinforced with fibreglass and subsequently testing other textile reinforcements.

5.2 Specimen testing of first series

Twelve specimens were prepared for testing in both parallel to the fibre and perpendicular to the fibre compression tests. Six bamboo cane test specimens without the diaphragms -area specified by the internodes- in order to take into account the most unfavorable part, were used for the parallel to the fibre compression test, each specimen having two perforations, one on each side (Fig. 6)-left.

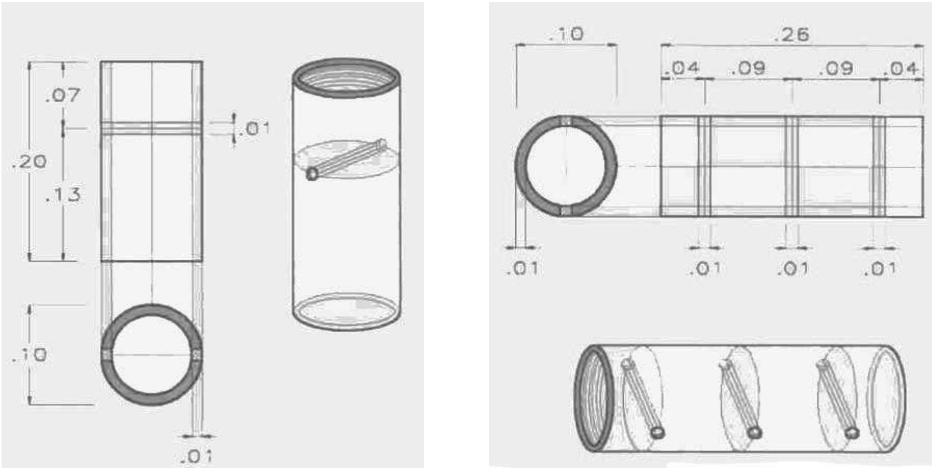


Fig. 6 Specimen for behaviour of opening in bamboo parallel to the grain test (left).
Specimen for behaviour of opening in bamboo perpendicular to the grain test (right)

For the compression perpendicular to the grain test, six specimens of the same form, without diaphragms, were prepared with six perforations, three on each side, (Fig. 6)-right, measuring 26 cm long, 10 cm in diameter, and 10 mm section of the cane wall. All specimens testing presented is reported in Table 2.

Table 2 Specimen testing for bamboo reinforcement

Test in compresion	Specimen Reinforcement		Pieces		
	Whitout (unit)	Whith (unit)	Long (mm)	Diameter/Thickness (mm)	Perforations/Ø (unit)/(mm)
Parallel to the fiber	3	3	20	100/10	2/12.5
Perpendicular to the fiber	3	3	26	100/10	6/12.5

Condition: 22°C 65%H

5.3 Bamboo of specimen

The bamboo used for the tests originated from Latin America, where temperatures of +22°C and 65% humidity conditions prevail. For the reinforced specimens, the outer parts were previously sanded for better adherence. The non-reinforced specimens were worked on directly, and drilled according to the requested orientation.

5.4 Method

A 12-mm Ø metal bar was placed through the cane, and 2 or 3 (as applicable) steel sheets that would transfer the load to the bamboo cane. (Fig. 7)
The test was made simpler by bringing the holes closer to each other, in order to prevent flexure. The load strength was measured through a load cell set up in the machine, and deformation was measured by displacement transducers.

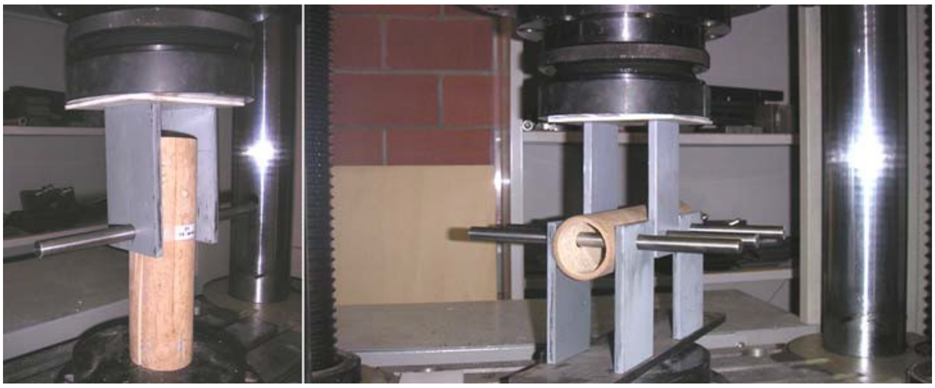


Fig. 7 Position of specimen for parallel compression to the grain (left)
Position of specimen for perpendicular compression to the grain (right).

6. Results of bamboo reinforcement with fiberglass

An increase of almost 30% over the value given between reinforced and non-reinforced may be seen in the parallel-to-the-fibre compression (Fig. 8 , Fig. 9) for load vs. displacement without reinforcement and with reinforcement, respectively).

The elasticity module did not show further increase, but the fibreglass efficiently prevented seaming, and showed a significant ductility (Fig. 10).

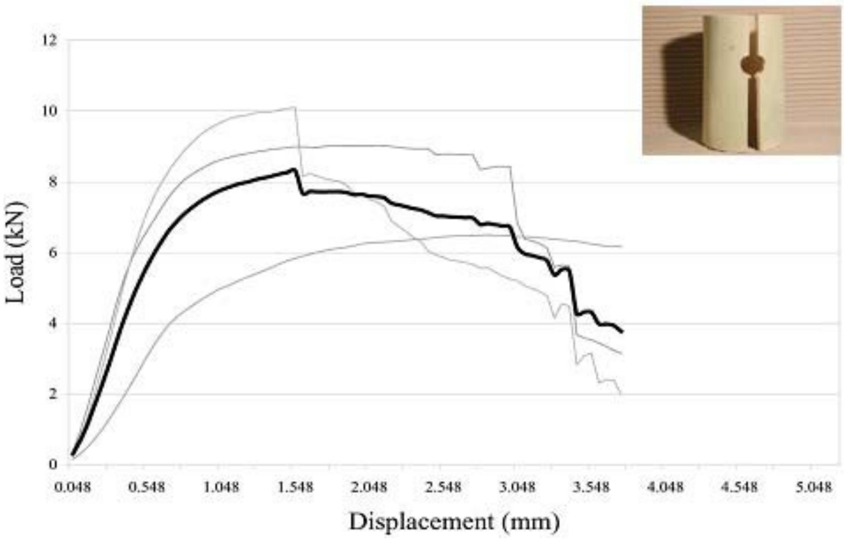


Fig. 8 Load-displacement curve in compression parallel to the grain for unreinforced bamboo

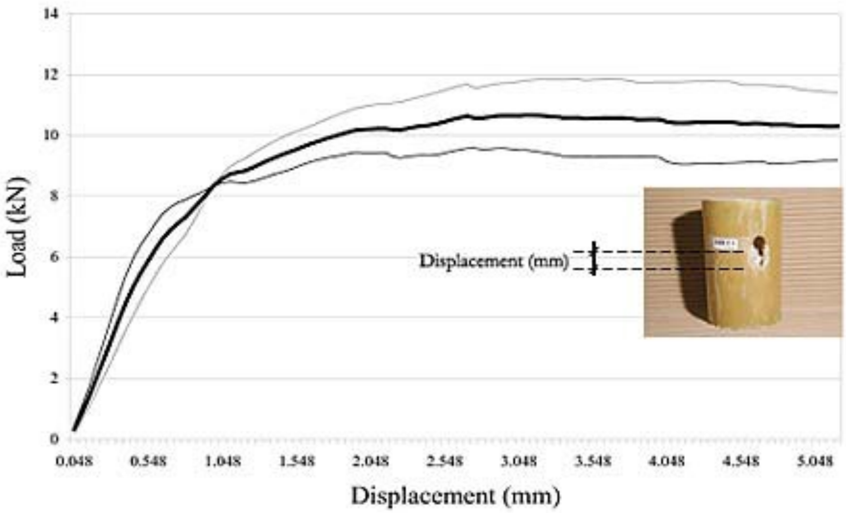


Fig. 9 Load-displacement curve in compression parallel to the grain for reinforced bamboo

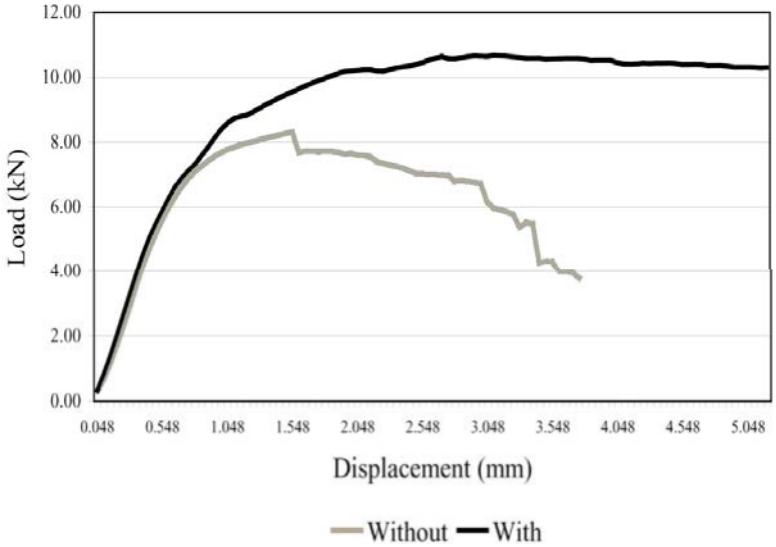


Fig. 10 Load–displacement, comparison curve in compression parallel to the grain

As to the perpendicular-to-the-fibre compression case (Fig.11, Fig. 12), it can be seen that without reinforcement, it has a low load level, but shows a 260% increase with reinforcement. It was also noted that the parts were seamed, and the fibreglass plays a role in transmitting shear stress. The elasticity module had not greatly varied. (Fig. 13).

The fibreglass-reinforced bamboo cane confirms the need to continue attempts to improve the limitations of the cane (Fig. 14), as it does not have fibres running perpendicular to the cane length.

This may also apply to the fixing of seamed sections.

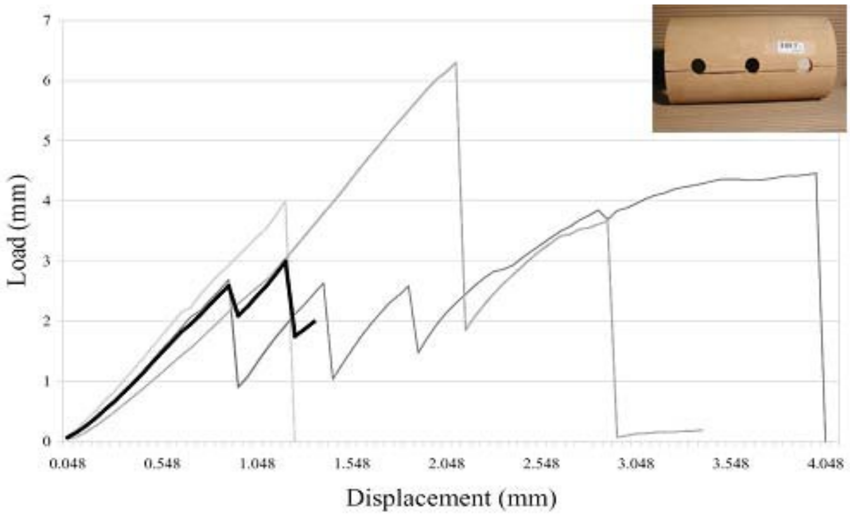


Fig. 11 Load-displacement curve in compression perpendicular to the grain for reinforced bamboo

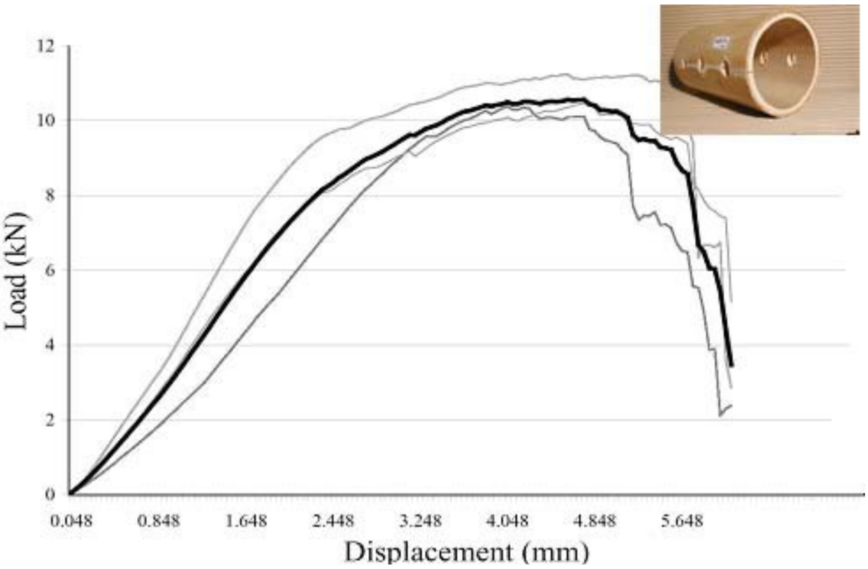


Fig. 12 Load-displacement curve in compression perpendicular to the grain for reinforced bamboo

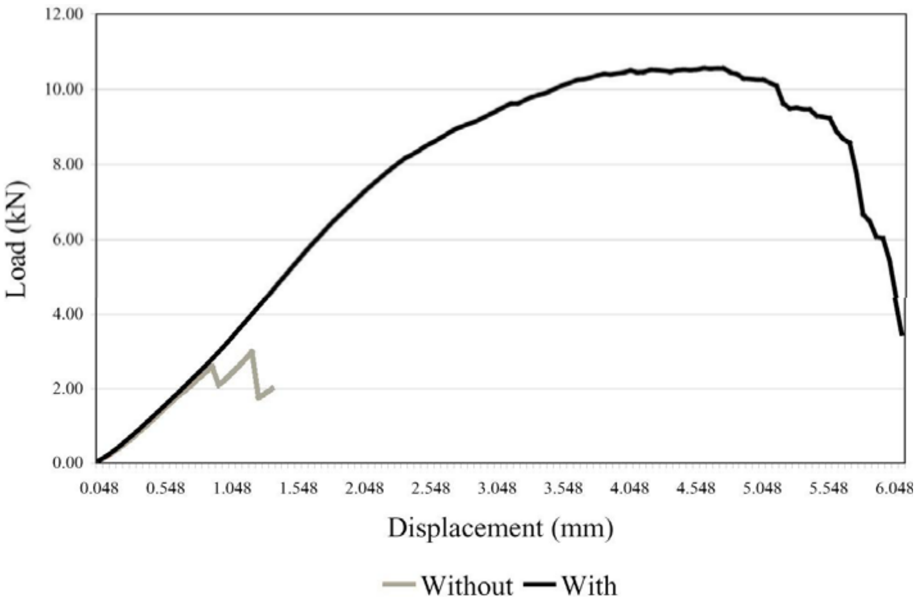


Fig. 13 Displacement comparison curve in compression perpendicular to the grain

7 Discussion of bamboo reinforcement with fibre

i. In the parallel compression to the grain test, a non-fragile fissure is identified (Fig. 8). In the parallel compression to the grain test, a fragile fissure is identified. (Fig. 11)
ii. A fragile bamboo fissure was prevented by fibreglass reinforcing
iii. In the compression perpendicular to the grain test, the reinforcing assimilates the effort in parallel, all at the same time.
iv. In the compression parallel to the grain test, the reinforcing assimilates the effort in a one by one chain.
v. The photodegradation caused by the fibreglass exposure over a long time period is a problem that remains to be solved, due to the ultraviolet radiation; therefore, the use of an opaque reinforcement is recommended.

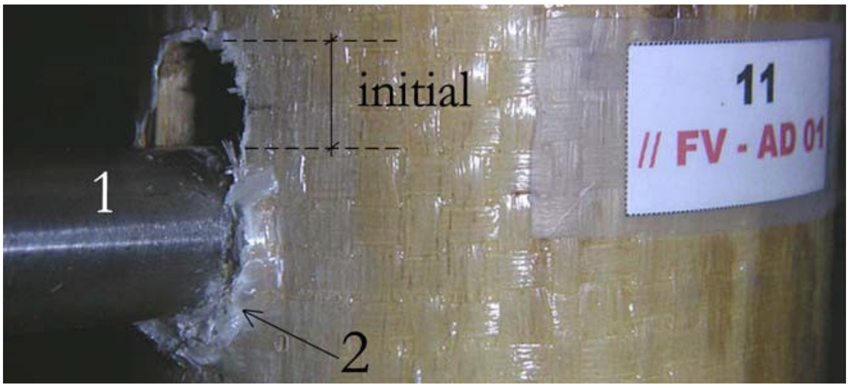


Fig. 14 Specimen photo

8. Discussion of bamboo reinforcement with fibres

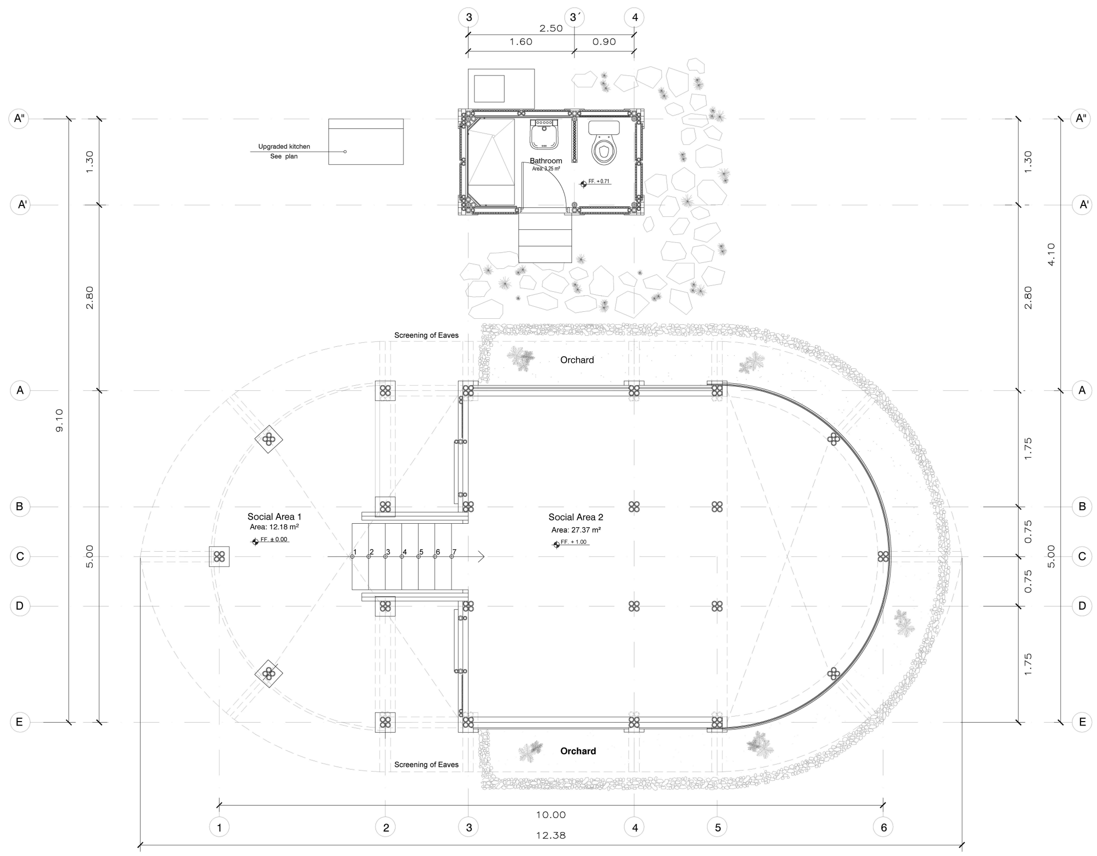
i. The use of fibre as reinforcement was effective in avoiding longitudinal strain.
ii. The reinforcement generates ductile behaviour of the bamboo cane, thus allowing anticipation of how to avoid strains that may give way to figuration when we must propose connections in bamboo structures.
iii. There are no significant variations in quality between glass fibre and jute as reinforcement. Therefore, it can be said that jute behaves well as reinforcement. In the case of specimens reinforced with cotton there was a 50% decrease in capacity although it cannot be affirmed that the deficiency was due to the textile, since it was not possible to do all the tests using the SINKOL 79 glue.
iv. The usefulness of jute as opposed to glass fibre allows a significant contribution to be made to ecological and economic sustainability because the natural element offers an equal support and rigidity_ quality when compared with an artificial material

9. Acknowledgement

We thank SENCICO, from Ministry of Construction and Sanitation, who facing the need to continue conducting studies for Peru, aimed at rural and social interest housing, as well as the use of local and natural materials in construction, commission the preparation and study of the project.
We recognize the development of the architectural project and the design of connections to Cerrón SAC Architects, the structural study to Eng. Juan Carlos Atoche, the study of other specialties to Eng. José Soto and the Association for the Conservation of the Amazon Basin - ACCA for providing information of the study area and connection facilities to the native community of Santa Rosa de Huacarias.

10. Annex

Fig. 15 Elements of the structure and the enclosure



GENERAL PLANT

Fig.16 General plant

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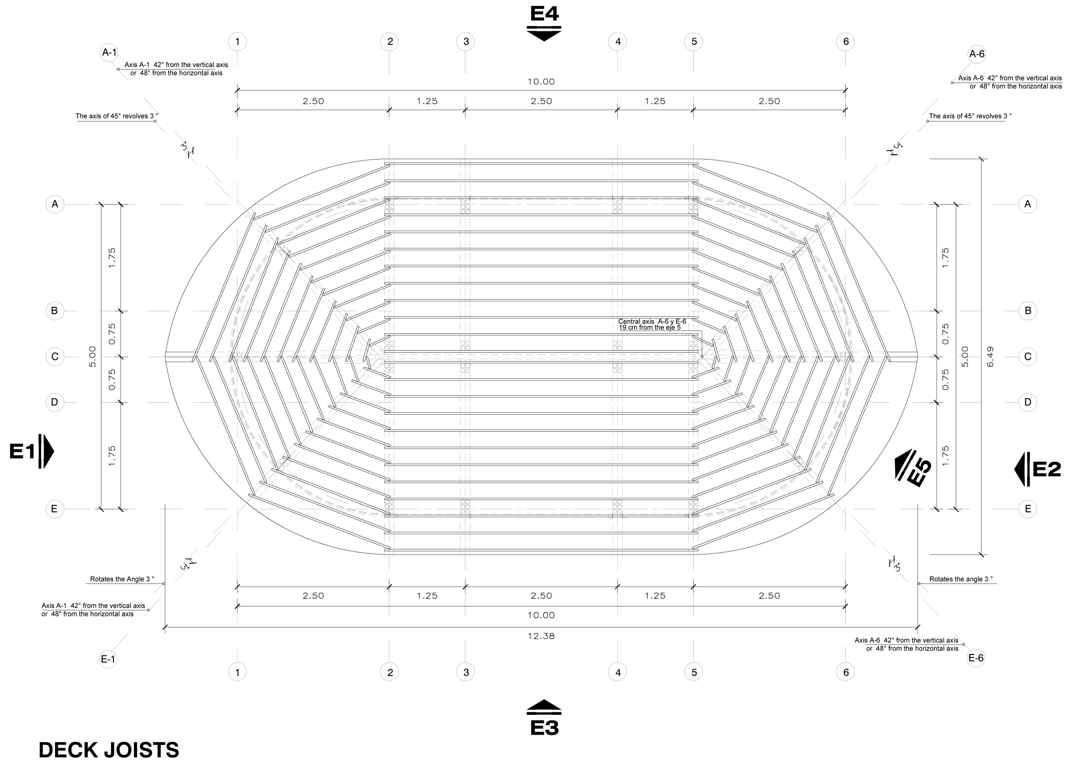

Fig. 17 Beams Ceiling

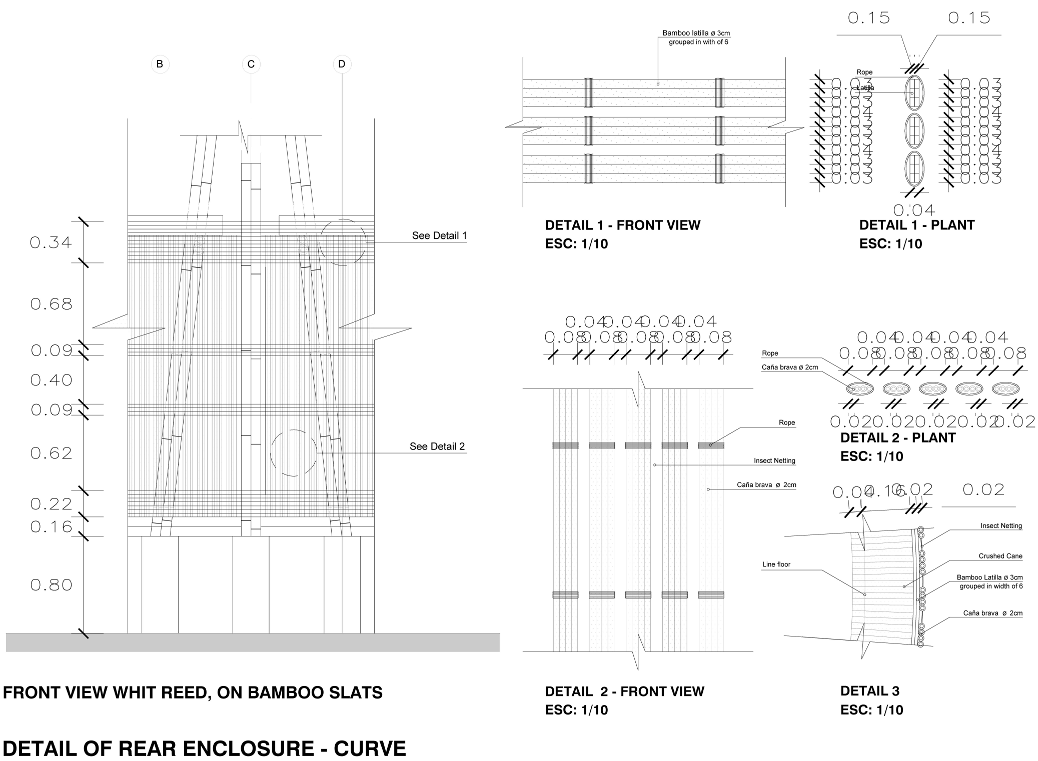

Fig. 18 Detail of back coating – curve

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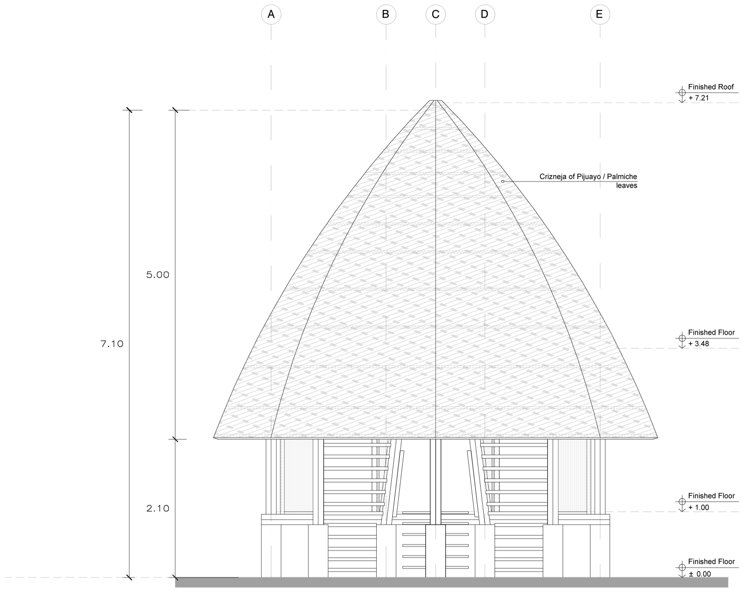
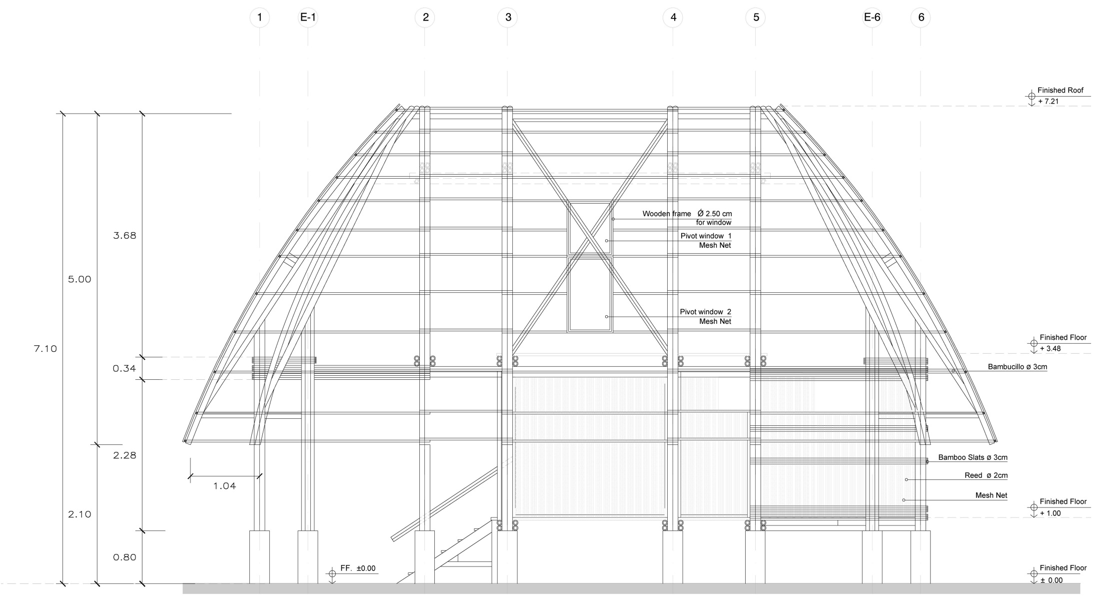


ELEVATION 1 - FRONTAL

Fig. 19 Elevation 1



ELEVATION 3 Y 4 - UNCOVERED

Fig. 19 Elevation without covert

Tab 3 Characteristic of materials

Common name	Description of the material		Use
	height (m)	diameter(m)	
Wood Aguano Masha	30.00	1.20	Floor Slats of 10 cm wide, for the first and second floor, on bamboo beams.
Wood Aguano Masha - carpentry	30.00	1.20	Windows, door frame
Caña brava	12.00	0.030	Lining of the walls
Crizneja	1.00	0.010	Roof Coating
Guadua native - "paca"or *Guadua angustifolia*			
	15.00	0.080	Structural elements
			Bamboo slats for structural moorings curves, in housing
			Mat for the walls of the bath
	15.00	0.060	Vertical ladder - bath enclosure□
	15.00	0.050	Stair Steps
	15.00	0.040	Enclosure elements
	12.00	0.030	Straps for cover
Tamishi	12.00	0.007	Moorings

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