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SUSTAINABLE AFRICAN HOUSING THROUGH TRADITIONAL TECHNIQUES AND MATERIALS: A PROPOSAL FOR A LIGHT SEISMIC ROOF

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SUMMARY

We firstly discuss a framework for improving the traditional building techniques currently used for housing in Sub-Saharan Africa countries, illustrating the main building types found in such regions and especially Malawi, as typical example of such states: Yomata, a cylindrical floor-plan with mud and bamboo walls, Mdindo a rectangular wood-bamboo and compacted earthen structure and Zidina, a one or two-storey rectangular layout made of unbaked blocks compacted earthen structure and wood. We then present a proposal for providing greater seismic resistance to such traditional buildings through the application of a light-weight roof. The structural problem considered regards the addition of a light, seismic roof to provide wider spans and more interior space to the above-mentioned building types. The proposal calls for erecting a reticular bamboo beam system with the help of small stainless steel plates. By combining modern engineering technologies (efficient stainless-steel elements to achieve a heightened degree of connection between the bamboo beams) with traditional African techniques and materials (spontaneous no-cost bamboo production and handcrafted building components) it is possible to achieve a high-performance roof with satisfactory levels of safety and durability. The system proposed consists of a classical Polanceau (Fink truss) or Palladian (King-post truss) reticular scheme, in which the traditional natural fibre connections are replaced by steel plates jointed by a screw system. Such jointing improves the seismic performance of traditional housing by increasing the degree of transverse connection of the building tops, without however causing any significant changes in inertial forces. The scheme moreover permits increasing roof spans, and thereby obtaining more comfortable interior spaces. The criteria for the design and assembly of such structures are illustrated in order to demonstrate their feasibility and sustainability from the economic and technical perspectives.

INTRODUCTION

Malawi became independent from Britain in 1964 and has over 85% of the population living in rural areas. Being located in Sub-Saharan Africa, it is assigned medium seismic activity value. Although this is the case, Malawi lies in the Africa great lift valley that covers lake Tanganyika and lake Malawi. As a result, Malawi has experienced intense seismic activity the last intense one was in 1989 that is reported to have caused nine death and left over 50,000 people homeless in rural Salima District [3]. The seismic epicentre was in rural Salima District just off lake Malawi in Central Malawi and had recorded 6.0 magnitude on the Richter scale. The number of casualties could have been worse if the epicentre was in urban area. There is need to raise

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awareness among designers and construction personnel on the need for seismic consideration in their work so that this paper is intended to serve such purpose.
The Country has an agricultural based economy. This has led to loss of forests due to poor agricultural practices and hence loss of cheap timber for construction of buildings. The government established a unit known as Forestry Research Institute of Malawi (FRIM) to promote good forestry practices. In spite of such efforts, the situation on the ground is getting worse. It is unfortunate that FRIM is not promoting growing of bamboo. Bamboo is naturally growing in some parts of the country.
In rural Malawi, the traditional housing technique is still being practised. However, the traditional housing technique has been affected by foreign and new knowledge in building technique. The trend is that the round plan form is being abandoned in favour of a rectangular plan form that is easier to build but is a weaker structural form. The rectangular plan form requires a totally different roof structure to that provided in the round plan form. The rectangular plan form requires longer spanning members that is in conflict with the current forest situation where timber is very scarce. The situation is pathetic such that in some parts of the country people are using sisal stalks.
The viable alternative to timber is bamboo construction. Bamboo can be used to make trusses of 8 metres spans by local craftsmen and even self-made. The 8 metres span is about the largest span in terms of current practices. Mitigation measures in provision of low cost housing such as by Habitat for Humanity, Rural Housing Project and Village Housing Scheme have used spans of 6.5 m, 6.75 m and 4.22 m respectively. The potential for technology transfer and training is high because the country is successfully going through decentralisation in administration and delivery of services.

TRADITIONAL HOUSING BUILDING TECHNIQUES

There are three main building types found in Sub-Saharan Africa, namely, Yomata (daub & wattle), Mdindo (rammed earth) and Zidina (sun-dried mud blocks). The traditional building techniques of each type is detailed below.

2.1 Yomata (Daub & Wattle).

The original house plan was round but today rectangular house plans are also found [5]. The round-shape provided a stronger structural form than the rectangular one. However, the rectangular shape also brought in another dimension to the plan, that of length to width ratio and a totally different type of roof. We shall concentrate on the rectangular type because it is becoming more popular. The traditional materials used in Yomata houses are wooden poles, bamboo, mud, grass thatch and natural fibre in various degrees. The tools used are axe, hoe and buckets.
The construction procedure that takes advantage of communal practices is as follows:

<u>Foundation and wall:</u> The foundation provides continuity with the wall. Timber poles of up to 10 cm diameter are cut to 2.5 m length; holes of 30 cm depth are dug in the ground to receive the poles; poles are then placed in the holes but not firmly back filled; horizontal members of about 2.5 cm are tied to the vertical poles at 30 cm centres to provide continuity matrix of the wall; and the vertical poles are firmly embedded into the ground ensuring that the poles are vertical. The mud is now plastered on both sides of the pole walls matrix.
<u>Roof:</u> As regards the roof, a central pole of about 15 cm diameter is placed at the centre and embedded 30 cm into the ground to receive pitched/sloping members of about 7 cm diameter acting as rafters spanning to outer round perimeter walls. These sloping members receive horizontal members 3 cm diameter acting as purlins placed at 30 cm centres top and bottom and tied by bark strings. The pitch is generally not less than 20 degrees. The grass thichness varies but is in the region of 10 cm thickness plus forming a thatch. The grass is pressed onto the timber skeleton by three rows of fine timber members placed at the eaves level, mid-way and top tied by bark strings.
<u>Khonde or verandah:</u> Poles of about 15 cm diameter that are spaced 60 cm apart support eaves projections. These poles are placed about 70 cm from the wall forming a verandah or khonde. The verandah/khonde is raised 15 cm above ground level to protect wall from surface or rain water.

The roof structure for rectangular plan is similar to mdindo and zidina houses that are detailed below.

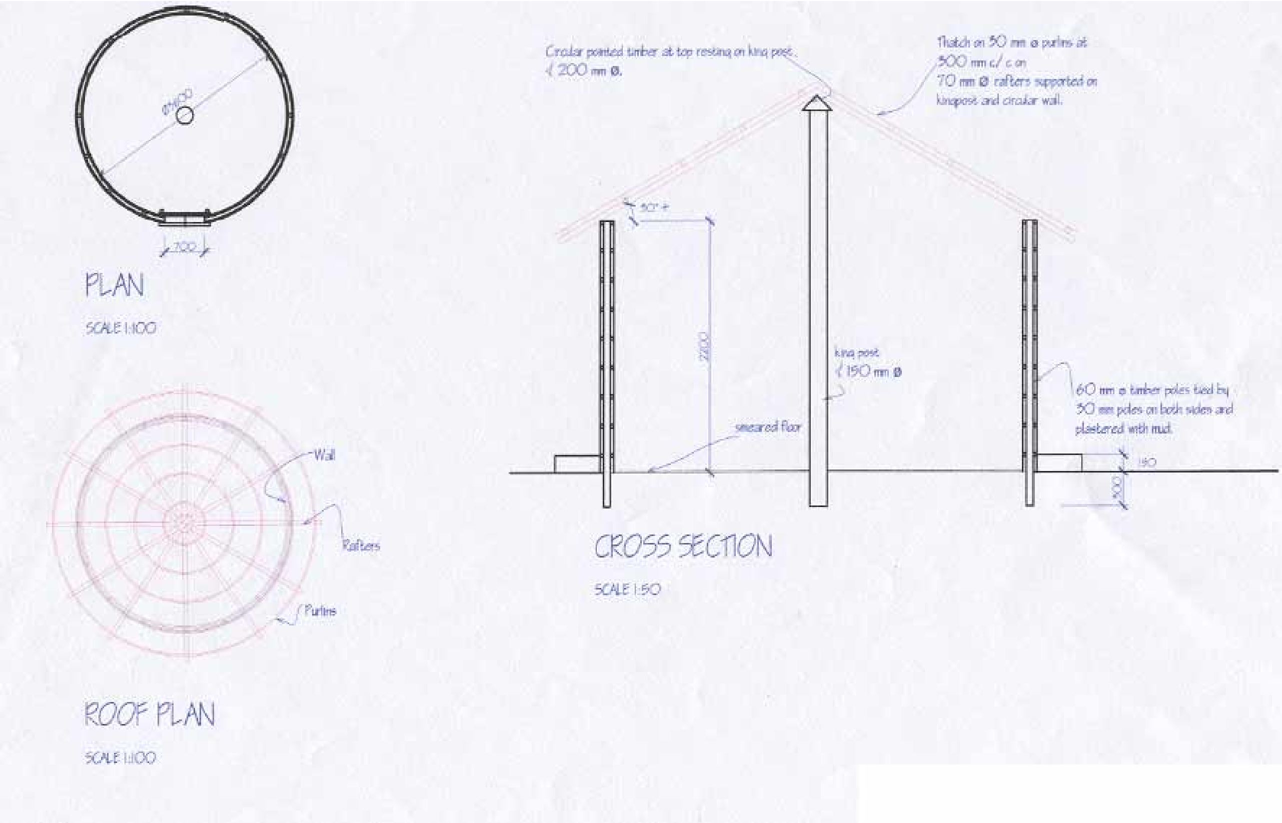

Figure 1 : Yomata House Building Technique

Mdindo (rammed earth)

The house is built by a special master builder who learns the job as an assistant [6]. He learns the job from a master builder as he helps with bringing the soil (as assistant). A pit is dug and water is poured in it overnight. The soil is only expected to be moist i.e. the soil must not retain the water. The tools used are a hoe, two buckets, a mould, a tamping wooden piece, and a scraper for removing soil from the mould.

<u>Foundation</u>: There is no foundation dug into the ground. The lines of the walls are marked on levelled ground and pegs placed where necessary. In oder to prevent the walls from surface or running water, the ground is raised to about 30 cm all round the building thus forming a verandah.
<u>Wall construction</u>: The wall is made of rammed earth. A site of the soil pit is identified with trials to make sure that the soil does not have a lot of clay content. Soil is dug to loosen it insitu and water poured into the pit to soak it over night.The moisture of the soil is critical so that remixing is done from time to time. The soil is then moved to the mould which is already placed in the proper place at the construction site. The soil is rammed in layers in the mould. It is necessary to ensure that a proper compacting effort has been achieved before removing the mould. The walls are about 26 cm thick.
<u>Roofing</u>: The roof structure is made up of grass thatch placed on timber poles made into a grid/mesh to retain the grass. The poles are supported on a timber pole beam which is itself supported on two king posts which are supported by timber pole beams spanning across the longitudinal walls. The two beams are placed at 1/4 points from the ends. Once the grass thatch has been placed, small sized timber poles are split and placed above grass and tied to poles below grass so that grass does not move out of place. This is done at 1/3 points all round.
<u>Openings</u>: The openings are provided sparingly. Timber lintels are used although they are not used efficiently so that sagging is very common.

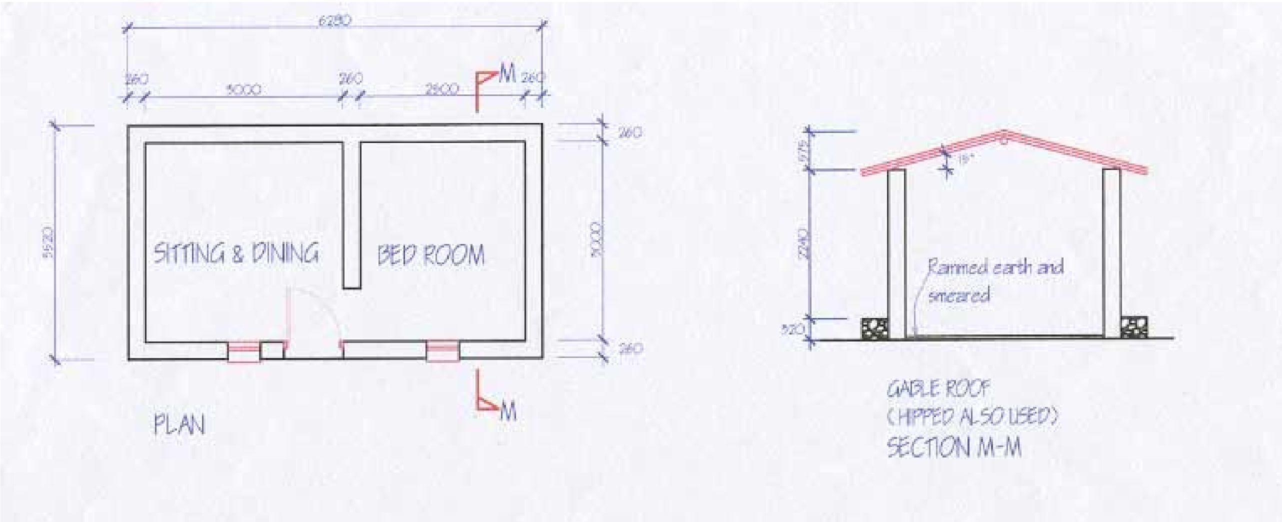

Figure 2 : Mdindo house building technique

Zidina (Sun-dried mud blocks)

The house is constructed by locally trained builders [7]. General knowledge is key during construction.

Foundation: The ground is leveled. A stone wall in mud mortar 40 cm thick is built along the wall perimeter from ground level to a height of 40 cm.
Wall construction: The sun-dried clay/mud blocks form the masonry units with mud mortar as the bonding medium. The procedure is similar to any masonry wall construction. The mortar thickness is 1 cm to 1.5 cm. At the roofing level of the wall, a wall plate is introduced which is generally of timber poles. The wall thichness depends on the size of blocks used beginning from about 20 cm thickness.
Roofing: Grass thatch or iron sheets are supported by timber purlins (generally poles) which run over the gable walls. Truss roof construction is also used.

PROPOSED IMPROVEMENTS:- LIGHT SEISMIC ROOF

Sections one and two have reinforced the need to find a substitute to timber roof but should be a light seismic roof structure due to seismic nature of the area. A bamboo roof structure becomes a primary candidate.
A number of researchers [1] have attempted to address this necessity but no sustainable solution has been found and the search has to go on.
The solution presented here considers a King-post truss (Palladian) and a Fink truss (Polanceau). The spans considered are 8 m, 6.5 m and 4.22 m because of the reasons given in section one. The critical features and parameters to be investigated are roof loading, truss spacing and joint connections. Both schemes are typical for historical roofs used in traditional European buildings.

Roof loading: The roof loading to be used has to take care of the worst self-weight due roof covering materials. Grass thatch has a density of 243 kg/m^3 (average for Malawi grass) giving a unit weight of 2.4 kN/m^3. The thickness of grass thatch for pitch not less than 35° is 300 mm [2] giving a load of 0.72 kN/m^2 whereas for pitch not less than 45° it is 150 mm giving a load of 0.36 kN/m^2. Fibre cement roofing tiles weight 3 kg each and ten tiles are required to cover 1 m^2 hence giving 0.29 kN/m^2 loading. These two roof covering materials shall act as reference point. The maintenance load has been taken as 0.5 kN/m^2 which is generally considered adequate. The self-weight of bamboo and connectors has been calculated as 0.2 kN/m^2. It is therefore safe to take service (unfactored) roof loading as 1 kN/m^2.

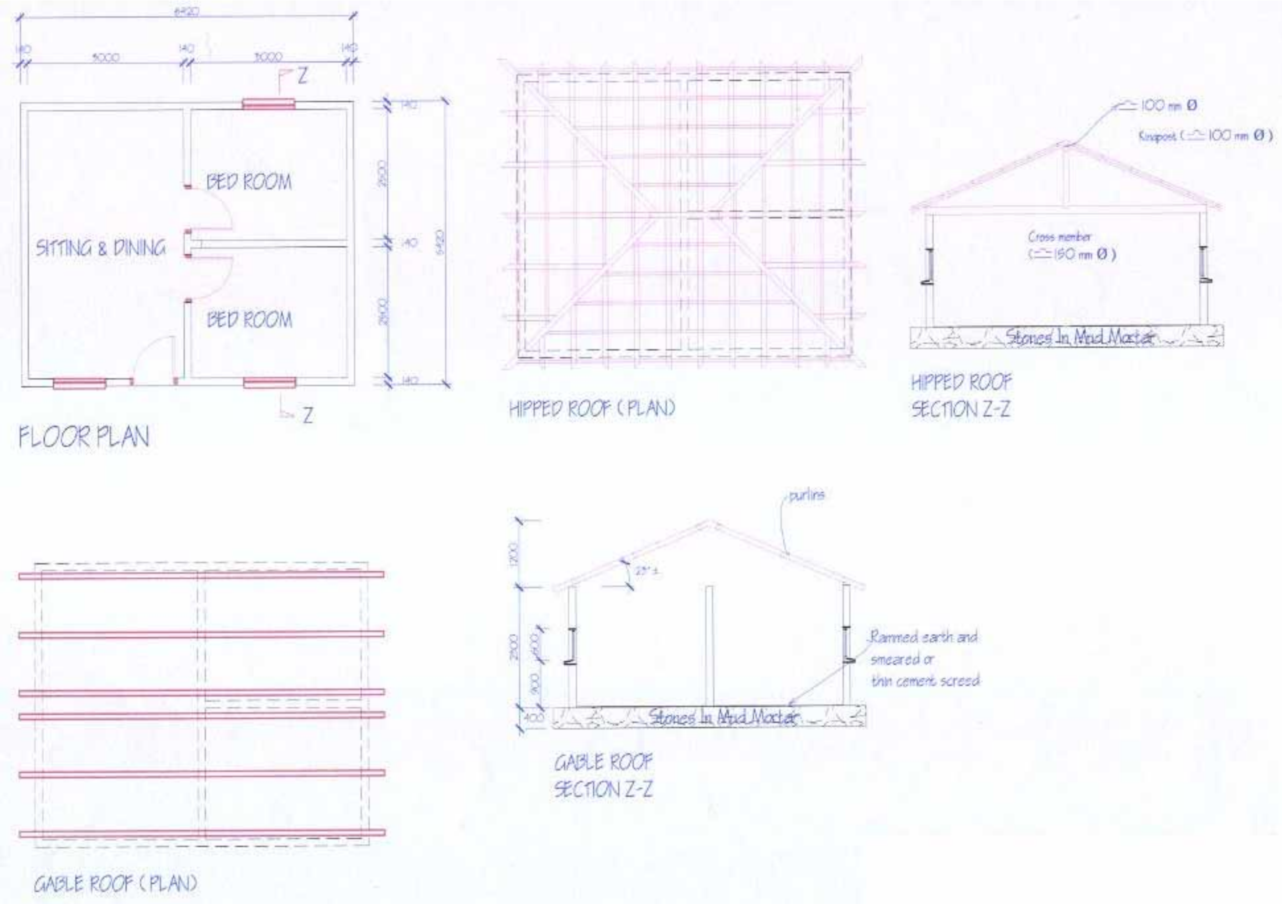

Figure 3 : Zidina House Building Technique

<u>Truss spacing:</u> The truss spacing were considered at 2.0 m, 1.2 m, and 0.76 m to take account of various roof covering materials specifications [2]. The spacing of the fabricated model depended on theoretical calculations and cost.
<u>Connections:</u> The techniques investigated in joining members are two as follows: the first one being of stainless steel gusset plates and screw nails and the second one is similar to the first one except that the bamboo hole is reinforced inside with a circular timber member rubbed with glue to bond to internal bamboo diameter to control bamboo end splitting [4].
<u>Coupling of Bamboo:</u> The technique of using more than one bamboo per member was also explored to increase material usage and hopefully test versatility of bamboo to the limit. Timber and steel have also been used in doubles per truss member such as double angles.
<u>Aim of the technique:</u> The aim in this investigation is to propose a technique that permits the following possibilities:

(a) Use of materials freely found on site;
(b) Improve the material assemblage so that people can make a 'self service' assembly activity.

THEORETICAL CALCULATIONS

The analysis of the truss utilised SAP 2000 to determine capacity of the various trusses and spacing.

The following results were obtained:

Table 1. Fink Truss Theoretical Displacements for 8 m Span

Span (m)	Spacing (m)	Total Truss Load (kN)	Direction of displacement	Joint Displacement (mm)					
				2	3	4	5	6	7
8	2	12.6	X	10	7	5	14	9	5
			Y (-)	44	49	44	0	48	48
8	1.2	7.56	X	6	4	3	9	5	3
			Y (-)	27	29	27	0	29	29
8	1.2	9.45 applied in 0.63 units at 0.525 m spacing	X	6	5	3	9	6	4
			Y (-)	29	32	29	0	31	31
8	0.76	4.8	X	4	3	2	5	3	2
			Y (-)	17	19	17	0	18	18
8	0.76	6 applied in 0.4 units at 0.525 m spacing	X	4	3	2	6	4	2
			Y (-)	18	20	18	0	20	20

Table 2. Fink Truss Theoretical Displacements for 6.5 m Span

Span (m)	Spacing (m)	Total Truss Load (kN)	Direction of displacement	Joint Displacement (mm)					
				2	3	4	5	6	7
6.5	2	10.41	X	6	5	3	10	6	4
			Y (-)	29	32	29	0	32	32
6.5	1.2	6.15	X	4	3	2	6	4	2
			Y (-)	18	19	18	0	19	19
6.5	1.2	7.65 applied in 0.51 units at 0.0.43 m spacing	X	4	3	2	6	4	2
			Y (-)	19	20	19	0	20	20
6.5	0.76	3.9	X	2	2	1	4	2	1
			Y (-)	11	12	11	0	12	12
6.5	0.76	4.8 applied in 0.32 units at 0.43 m spacing	X	3	2	1	4	2	1
			Y (-)	12	12	12	0	13	13

Table 3. Fink Truss Theoretical Displacements for 4.22 m Span

Span (m)	Spacing (m)	Total Truss Load (kN)	Direction of displacement	Joint Displacement (mm)					
				2	3	4	5	6	7
	2	6.66	X	3	2	1	4	3	2
			Y (-)	13	14	13	0	14	14
	2	7.77 applied in 1.11 units at .0.56 m spacing	X	3	2	1	4	3	2
			Y (-)	13	14	13	0	14	14

TEST MODEL SPECIFICATIONS

A pilot test has been arranged in [4]. Aim of the joint conception is the achievement of a resistance comparable with the traction strength of the bamboo cane. Two different versions of the joint were tested, both featuring a pinewood cylinder inside the ending part of the bamboo rod; in the first case the connection between the pine cylinder and the bamboo is provided by a vinyl glue layer (fig.5), in the second one a set of steel screw nails, applied through the bamboo and the wood reinforcement, is added to increase the joint strength (fig.6). In both cases the connection between the steel plates and the wooden parts is assured by three bolts.

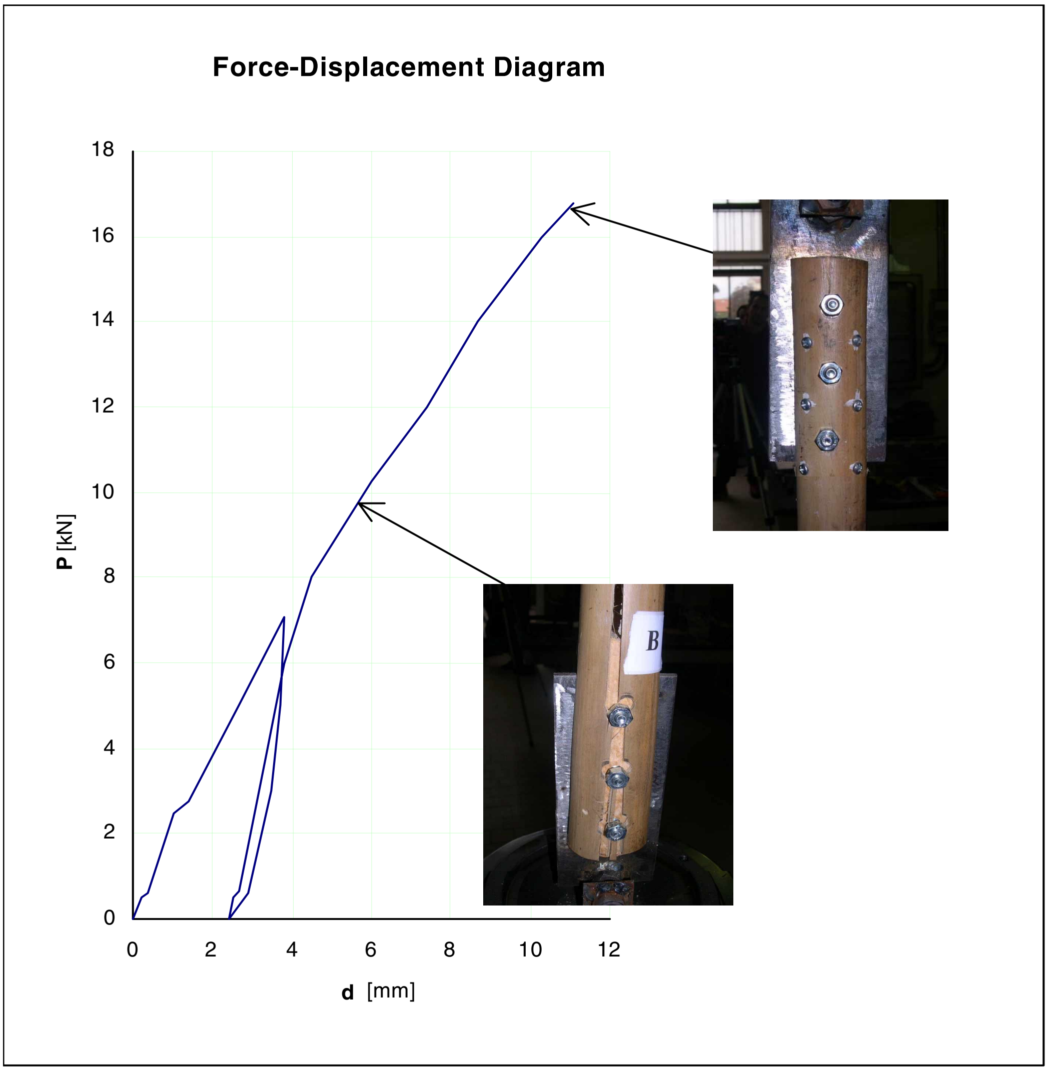

Figure 4: force-displacement curve and images of the joints

An ultimate state traction test was arranged to point out the joint resistance and the force-displacement relationship of the specimen. The extremities of the steel plates were welded to a steel bar, then linked to the jaws of an INSTRON test machine (model 1186, maximal compression/traction force 200kN) (Fig. 6); this was endowed with an electronic extensometer (1/100mm tolerance) and with a graphical output device to plot the force-displacement curve, which is reported in Fig.7. The trial was carried out in controlled displacement conditions, and the deformation rate was set to 10mm/min.
The experience gained in the study of the described specimen has revealed several aspects, which likely turn out to be very important in order to design an effective linear or plane-angled bamboo joint, both from a static and an executive point of view.

a) Although the first inelastic phenomena involved the reinforced joint B, probably due to imperfections located in the bamboo culm, the final collapse occurred in the simple joint A: the role played by the screw nails therefore provided a crucial contribution to the strength of the connection.
b) The glue action is important only in the initial stages, while the bamboo interior layers are subjected to limited tangential stresses.
c) The bolts underwent plastic deformations during the test, without showing any crack or reducing the joint load bearing capacity.

The use of the screw nails seems than preferable, in relation to the strength of the connection between the external part of the rod and the cylinder, rather than the "glue-only connection": anyway the glue performs suitably during the elastic stage, strongly reducing those rigid movements between the wood core and the bamboo rod, and probably this action can be improved by a preliminary scratching of the internal joint surface with common glass paper. Moreover, the use of screw nails and bolts to joint steel plates requires low cost technologies in terms of materials and technical skilfulness of the operators.

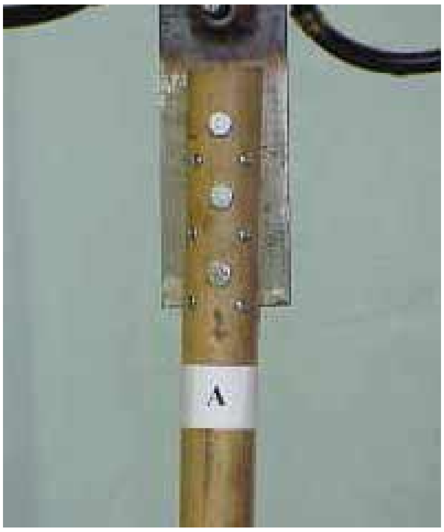

Figure 5. Screw nails reinforcement (extr. A)

Figure 6. Glue-only connection (extr. B)

CONCLUSIONS

The development of low-cost techniques involving bamboo structures could represent an interesting help to improve comfort in housing constructions located in developing countries, like the southern part of Africa. The crucial aspect releated to the structural performances of bamboo joints could find relevant improvements by way of stainless steel joints, in order to increase the span of lightweigth seismic roof, using building techniques easy to disseminate in rural areas.

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