HUYS ADVIES

THIN BAMBOO CULMS FOR TRUSSES

Use of Two and Three Culms in Composite Beams

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Title: Thin Bamboo Culms for Trusses – Use of Two and Three Culms in Composite Beams

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Abstract: Harvesting, curing, preservation and building construction using thin bamboo stems or culms of 40 mm diameter. Making composite beams for trusses with connectors and dowels. Stress reinforcement with galvanised wire for lightweight roof constructions covered with thatch or reed. Illustrative sketches and photos.

Key Words: Bamboo trusses, thin culms, roofs, composite beams

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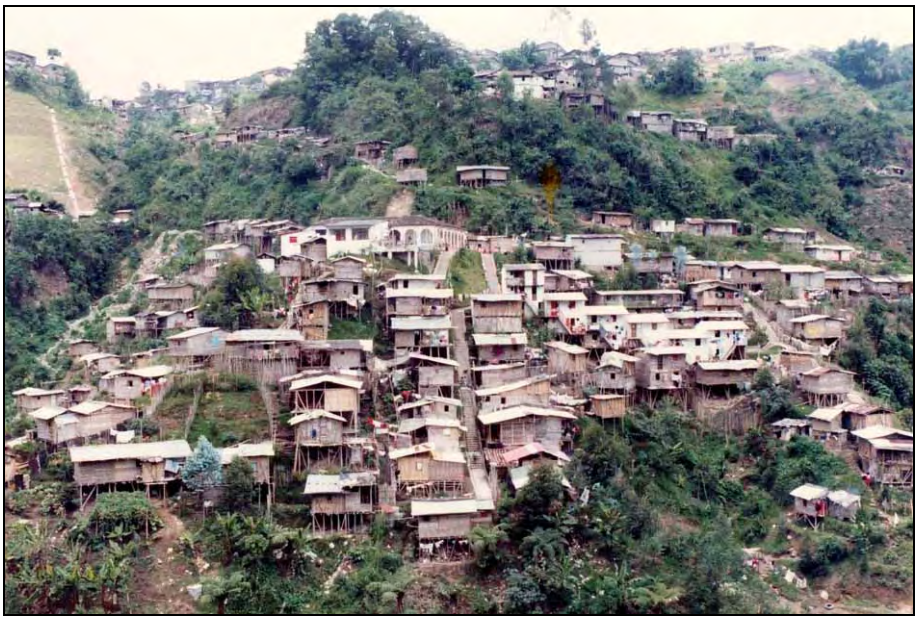


Lightweight bamboo houses on slope.

Photo Front Page
Bundles of thin green bamboo culms with diameters from 30 mm to 45 mm for sale.

Introduction

Bamboo is an excellent lightweight and strong construction material for buildings and furniture. It is also widely used for baskets, kitchen utensils, matting and other household artefacts. Sustainable bamboo plantation management can generate substantial employment requiring only simple tools, machines and artisan-level work.

However, the harvesting of bamboo is often done unplanned, allowing insufficient re-growth and causing deterioration of the local ecosystem. This results in total disappearance of the bamboo and eventually causing soil erosion and finally desertification. The loss of bamboo forests and plantations has a negative effect on the local ecosystems and climate.

An underlying problem is that bamboo forests are often on public land and villagers use total cutting and scavenging techniques in exploiting these fields. The stems (culms) are harvested immature, bundled and sold for construction material without any curing or preservation.

Too early and improperly harvested, non-cured and non-preserved thin bamboo has a short lifespan (less than five years) and should NOT be used for structural purposes. Culms with a diameter <40 mm should not be used for permanent constructions or composition beams.

With improved forestry management, sustainable bamboo production can be achieved and a constant supply of bamboo products generated. This can supply both the building and artisans markets and generate permanent employment. Importing new bamboo species suitable for the local climate of the region can greatly enhance the quality of the products. Bamboo plantations can be used as final treatment for water purification installations when intermittently and moderately flooded. Good management in combination with such filtration areas can greatly increase the annual bamboo production.

Depending on the altitude above sea level and other climate conditions, thin stem bamboo may be easier to grow than the thicker (>7 cm Ø) bamboo. In such a case, it is possible to use the thin bamboo culms for various construction elements, including lightweight roof trusses and woven wall panels. This paper presents some criteria and options for these light trusses.

The disadvantage of such constructions is that it is labour intensive and the exposed surface becomes very large. Because the thinner bamboo is more vulnerable to termites, insects and fungus, good preservation after curing is essential and good annual control, as well as periodic cleaning of the construction in the roof, is required.

Two storey houses of bamboo construction with lime-cement plastered walls on sloped terrain. In this design low-angle fibre cement roofing has been used.

1. Thin Bamboo Culms

When constructing buildings with bamboo, it is recommended to use the large, fully grown thick bamboo culms (stems). These grow wild in many countries, but with a selective harvesting system, optimum benefit can be obtained from the productivity of such forests.

Bamboo types do not grow in all soil and climate conditions. The thinner bamboo does not always grow in defined clumps and are often spread over wide areas.

Thick bamboo clumps and scattered thin bamboo types growing at an altitude of about 1500 m above sea level.

Thinner bamboo have diameters ranging from Ø 1-6 cm, depending on the variety, and are often harvested at <Ø 3 cm. For construction purposes, it is recommended to harvest only culms of Ø 4 cm and larger. The bamboo needs to be straight, cured and preserved before being used for structural elements. Thin bamboo that is not cured and preserved will rapidly deteriorate by climate and insects; thus losing its structural strength.

The use of the thicker, well cured bamboo types is preferred because their lightweight and excellent strength properties allow large spans, reducing the amount of construction work.

Left: Thick cured bamboo (Ø 7 cm) in hotel lounge.

Right: Trusses of small diameter bamboo (Ø 4 cm) causing much more work and larger exposed surface.

Spanning large areas with thick bamboo (>Ø 7 cm) avoids the making of combination beams and triangular truss constructions with several joints, and allows better maintenance control. Bamboo constructions should not be covered up.

However, when the larger diameters are unavailable, it is still possible to construct 4-5 m spans with thinner bamboo. The technical designs can also be used with the thicker bamboo to make spans over 6-8 m.

2. Bamboo Trusses

The best and most durable species of bamboo are to be selected. The *Bambu Gadua Angustifolia* of South America is one of the strongest, tallest and most insect resistant. Excellent quality of bamboo species can also be obtained from countries such as China and Indonesia. It needs to be assessed whether good quality bamboo can be transplanted and grown in forestry projects in the country of use. Climate conditions should be similar; near the equator the most favourable altitude is around 1000 m above seal level. Clumping bamboo types are preferred as these do not spread very fast with horizontal root systems or uproot buildings.

Bamboo can be used as a lightweight, strong and durable construction material when ALL of the following conditions have been met:

(a) Mature (fully grown) bamboo with straight stems need to be harvested. The forests need to be pruned during the bamboo shooting season to allow the best shoots to produce new culms. Most bamboo species can be harvested after three years. Bamboo can also be grown in filtration and purification beds of sewage installations, but they should be only flooded intermittently since permanent flooding is harmful to their root system and growth.

(b) The bamboo needs to be harvested in the dry season, preferably at new moon (first quarter), and the leaves left on for a few days (until they turn yellow) to allow them to extract the moisture from the stems. The plant sap and starch are the food sources for insects. A few stems on each clump should be left for continued growth of the clump.

(c) The culms need to be cut from the clumps between 04:00 hrs and 06:00 hrs. If the weather is overcast, this time period can be extended until 09:00 hrs. The point is that with sunlight at daybreak, the fluids in the bamboo start rising up from the root system, caused by photosynthesis in the leaves.

(d) The bamboo needs to be cured and treated against insects and beetles (Powderpost beetle) with a borax + boric acid solution. The simplest curing method is to punch out the nodes and soak the culms in clean river water for one month so the starch can leach out. When treating vertically, the last node should be left untouched.[1]

(e) After treatment, the bamboo should be fully air dried. This means that it needs to be stored horizontally and ventilated under a roof for an extended period depending on local climate conditions. Drying in a greenhouse construction will speed up the process. Given the harvesting, curing, treatment and drying period, adequate time planning is required for obtaining durable building material. For the making of furniture and gluing the bamboo into floor boards, it needs to be air-kiln dried down to 8-10% moisture.

(f) The bamboo construction should be elevated from the ground, soil or any permanent moisture areas. The construction should remain dry and ventilated under all climate conditions. The foundation and the lowest column or wall section of the building should therefore be from cement blocks, reinforced concrete or baked brick. Up-splashing water from rain should not reach the bamboo elements.

(g) The bamboo construction should be dimensioned in such a way that the beams (trusses) are not strongly bent during their static load period, otherwise the construction will permanently deform. Occasional live loads will bend the constructions, but when the load disappears, the construction will reshape.

[1] Good instructions can be found on website: www.bamboocentral.org
Picture article: www.bambooman.com.au/bambootreatment/ebf.php#Harvesting%20Bamboo
Information on lime/heat treatment: www.chalet-bamboo.com/treatment.html
Large construction bamboo: www.guaduabamboo.com/bamboo-preservation.html
Further information on termite testing/treatment: www.bamboocentral.org/index1.htm

3. Making the Truss Design

The design of the bamboo trusses depends on the quality and strength of the treated culms or posts. It also depends very much on the roofing material and the related roof inclination, whether metal sheeting, thatch or other materials.

The following sketches are related to the use of treated bamboo posts that have diameters (Ø) between 4 cm and 4.5 cm and are assembled to double or triple beams to obtain greater strength and stiffness. The lightweight roofing material is from reed, thatch, folded or woven coco palm leaves, zinc aluminium roofing sheets, etc.

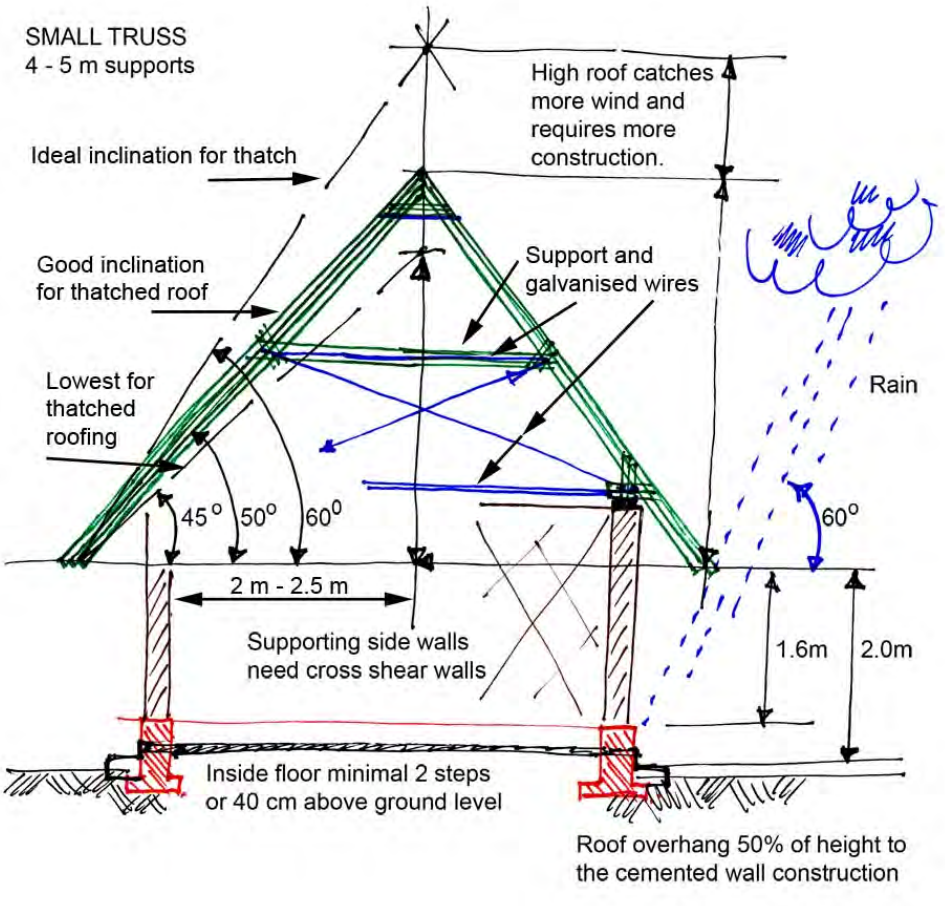
Roof Inclination

The roof inclination for natural or artificial thatch is between the 45° and 60°. The sketch below gives an inclination of 50° by which the length between the support and the roof ridge is about as long as the span between the walls (4-5 m).

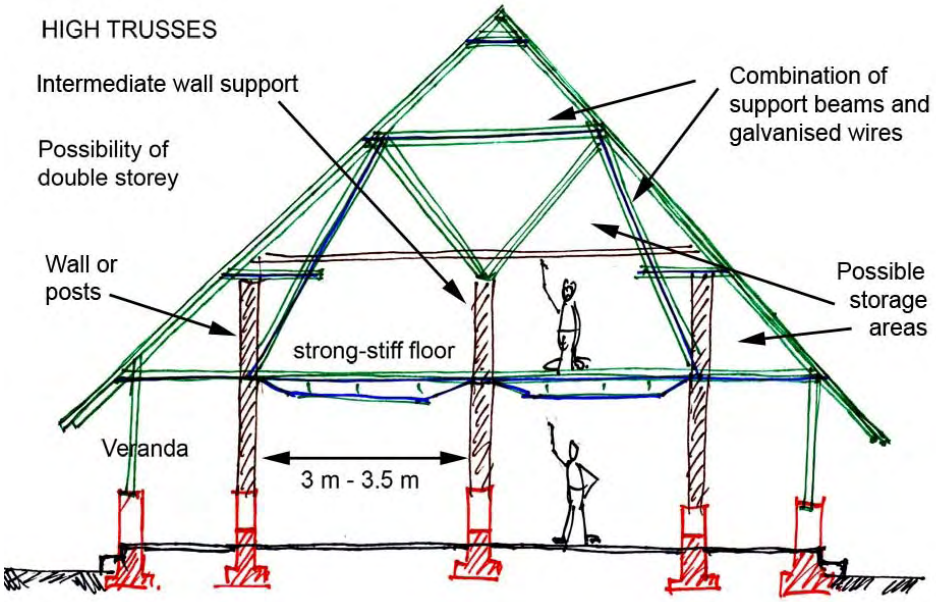
A roof inclination lower than 45° is not recommended because it may cause water infiltration, which will reduce the lifetime of the thatch. When the thatch leaks, it will negatively affect the underlying bamboo structure.

When the exterior walls of the building are made from stabilized soil construction or plastered bamboo, these should remain dry under all climate conditions. The roof overhang should be minimum 60° from the water-resistant foundation or wall material.

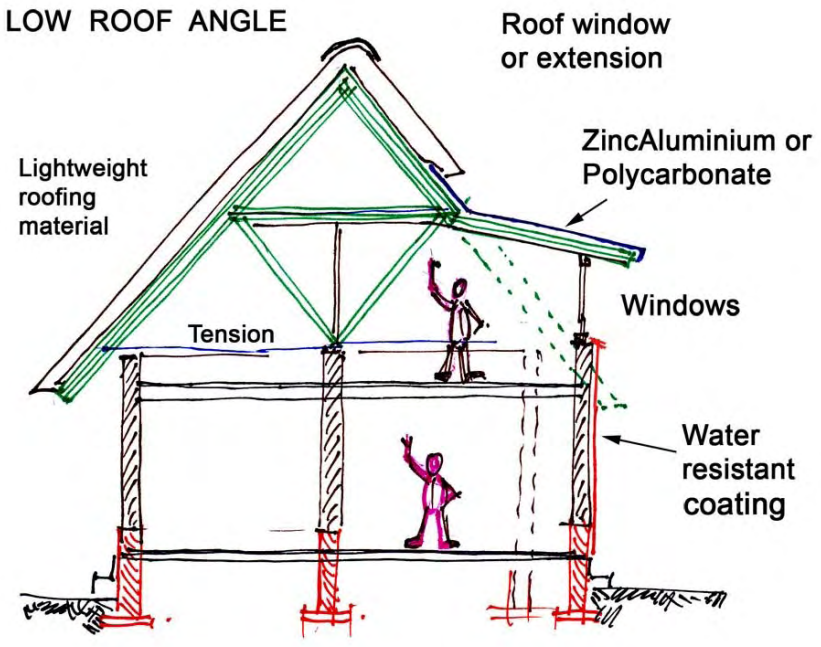
The plinth of the building needs to be fully water resistant with membranes between the foundation and the upper wall construction. The inside floor should be minimum 40 cm above the field around the building. In areas where flooding can occur, all sections below the maximum flood level should be made from cemented building materials or fully water-resistant timber columns.



When the roof inclination is steep, a second floor can be made under the roof. If windows or ventilation openings are required on the second floor and these protrude through the roof line, those sections of thatched roof should have an inclination of minimal 45° as well.



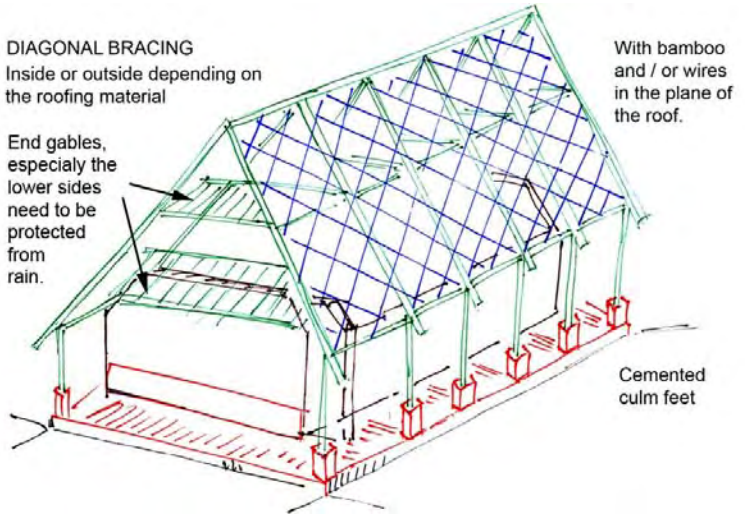
When the inclination above protruding roof windows is lower than 45°, other roofing material should be used instead, such as metal sheets, zinc aluminium or transparent polycarbonate.



The components for producing large roof trusses should be manufactured and pre-assembled on the building site using jigs for similar components. The sections should be easy to handle and lift to the roof where they are connected together. Temporary supports and diagonal bracing will be required in the plane of the roof. The stress wires are connected to the junctions when assembling the components. Trying to manufacture the entire truss on the ground and then lift it on the support structure is not advised.

Permanent bracing can be realised in the plane of the roof either on the inside or outside depending on the final roofing material.

When long woven leaves/tiles of the coco palm tree are used and double-diagonal bracing is placed at distances of about 30 cm, the leaves can be attached directly to the bracing.



Ventilation and Wind

Tent-shaped roofs can have the benefit of good cross ventilation in climates with a distinctive wind direction, such as from the sea. Such high-pitched roofs, however, need additional protection of the lower walls at the open ends from sun and rain. The construction of smaller roof sections in between the window or ventilation openings is required or weather-fast building materials need to be used.

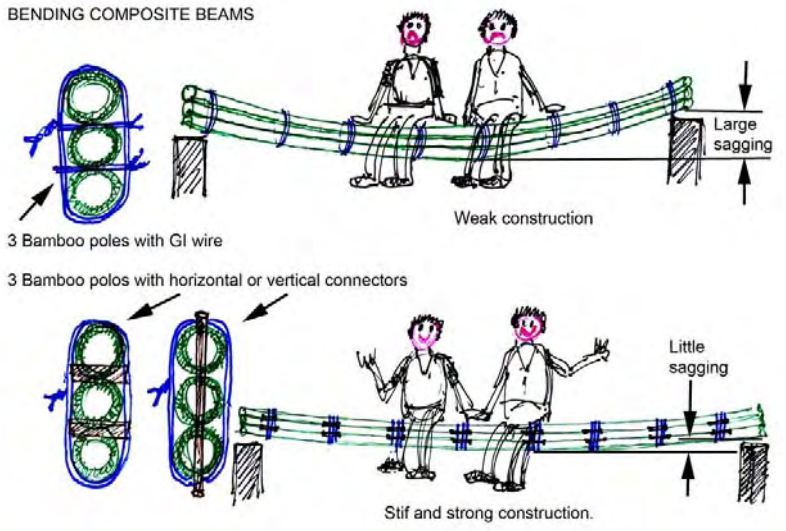
The above two pictures show a high pitched saddle (tent) roof in which the top part is extended outwards for sun and rain protection. In areas where it may be expected that strong winds such as hurricanes or tornadoes can develop, this construction needs to be additionally reinforced.[2]

The above houses have woven coco palm leaf roofing with a dense spacing of 6-8 leaves per 20 cm. The leaves are attached with rubber bands manufactured from used car tyres. These bands are very strong and totally weather and sun resistant.

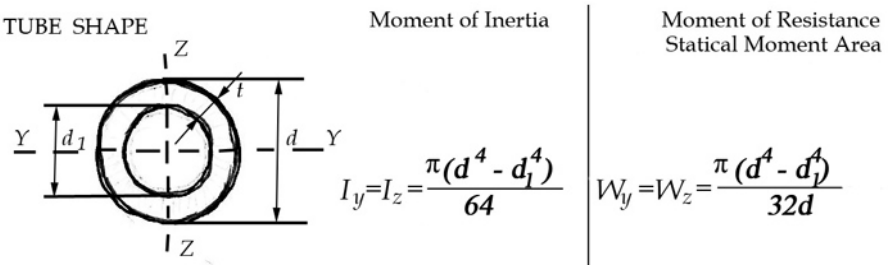
[2] Due to global warming, the occurrence of hurricane force winds is increasing and becoming more frequent in the tropical areas. It is highly likely that the frequency and the force of these winds will increase in the coming decennia. House designs should be based on these strong winds.

4. Composite Beams in Trusses

Fitting two or three thin bamboo culms together with connectors makes the composite beam stronger than the two or three single posts together. By fitting three culms together, several length pieces can be used to make beams that are longer than the original pieces. In making these composite beams, sections of equal thickness should be used. The photos and sketches are of composite beams made of Ø 4 cm culms.



Formula for calculation of inertia and moment resistance of tube-shaped bamboo culms.



	***d* Outside Diameter**	***d*$_1$ Inside Diameter**	***t* Wall Thickness**	***Section Wall A***	***I*$_Y$=*I*$_Z$**	***W*$_Y$=*W*$_Z$**
1	4.0 cm	3.2 cm	0.4 cm	4.5 cm^2	7.4 cm^4	3.7 cm^3
2	4.5 cm	3.6 cm	0.45 cm	5.7 cm^2	11.9 cm^4	5.3 cm^3
3	5.0 cm	4.0 cm	0.5 cm	7.1 cm^2	18.1 cm^4	7.2 cm^3
4	5.5 cm	4.4 cm	0.55 cm	8.6 cm^2	26.5 cm^4	9.6 cm^3
5	6.0 cm	4.8 cm	0.6 cm	10.2 cm^2	37.6 cm^4	12.5 cm^3
6	6.5 cm	5.2 cm	0.65 cm	12.0 cm^2	51.7 cm^4	15.9 cm^3
7	7.0 cm	5.6 cm	0.7 cm	13.9 cm^2	69.6 cm^4	19.9 cm^3
8	7.5 cm	6.0 cm	0.75 cm	15.9 cm^2	91.7 cm^4	24.5 cm^3
9	8.0 cm	6.4 cm	0.8 cm	18.1 cm^2	118.7 cm^4	29.7 cm^3
10	8.5 cm	6.8 cm	0.85 cm	20.4 cm^2	151.3 cm^4	35.6 cm^3
11	9.0 cm	7.2 cm	0.9 cm	22.9 cm^2	190.1 cm^4	42.3 cm^3

When the outside diameter of the bamboo culms increases, the wall thickness will also increase slightly. For many bamboo types, the thickness of the strongest part of the wall section is about 10% of the diameter. At the lower side of the stems, this section is thicker.

Because different types of bamboo have different growth patterns, the above table is a rough approximation. The calculation shows that the strength increases substantially with the diameter in combination with the thickness of the wall. A Ø 8 cm culm is eight times as strong as a Ø 4 cm culm. Stems with Ø <4 cm are not recommended because the amount of construction work will greatly increase. Bamboo is a very strong material, but it will easily bend under a load perpendicular to the stem.

When two stems are linked together, the stiffness and moment resistance will substantially increase. The diameters of two stems are seldom exactly the same while in each culm the diameter can vary between bottom and top.

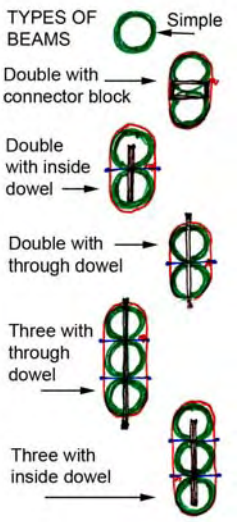
Varying Strength for Combinations

Bamboo is a natural material and the dimension of each stem (culm) will vary slightly over its length. Making exact calculations of strength will be difficult and a reduction of the calculated value needs to be taken into account, especially when several members are connected together.

For the calculation, only the outside zone of the culm is taken into account. The strongest fibres of the bamboo are located in the outside 10% of the diameter of the culm. This is the stress or compression zone that will take the load. The stem fibres towards the inside of the culm are softer and more porous; thus having no contributing factor to the strength. The thickest portion of the culm wall is near the base; this section should be for making the dowels.

The more members linked together into a single beam, the higher the reduction should be. The reduction in the calculations below is obtained by not counting the strength of the intermediate culm(s). The reduction is different from the safety margin. The safety margin in the construction should be based on safety standards being applied in house and other building construction and depends on its use. The safety margin can be obtained by adjusting the compression and stress resistances of the material with the calculation of the maximum expected moment.

Several resistance moments have been calculated for Ø 4 cm single culm and composite beams to compare the different structural designs. This illustrates the substantial strength increase for double and triple composite beams that can be used in trusses. In floor constructions, the amount of bending or flexing of the beams under a load is in most cases more determining than the strength; stiffer beam constructions will be required.



Six types of beams are compared:
D = outside diameter, d = inside diameter of the culm

- Single hollow round culm. $W_Y = \Pi(D^4-d^4) / 32D$
- Double culm beam with connector block.
- Double culm beam with 1.6 Ø dowel inside.
- Double culm beam with through-dowel.
- Triple culm beam with through-dowel.
- Triple culm beam with inside 2.6 Ø dowel.

For the calculation of the triple hollow culms, the entire middle culm is not counted.

Values for Ø 4 cm Culms	A	B	C	D	Total W_Y	Strength
Single hollow round culm.					3.7 cm^3	= 1
Double culm beam with connector blocks.	3.2 0.0	3.8 0.0	5.6 -	2.9	15.5 cm^3	x 4.2
Double culm beam with **inside** Ø 1 cm and 1.6 Ø long dowels.	3.2 0.4	3.8 0.8	5.6 -	2.9	16.7 cm^3	x 4.5
Double culm beam with Ø 1 cm through-dowels.	3.2 0.4	3.8 0.8	5.6 -	-	13.8 cm^3	x 3.7
Triple culm beam with Ø 1 cm through-dowels.	5.2 2.3	5.6 3.2	13.0 -	-	29.3 cm^3	x 7.9
Triple culm beam with **inside** Ø 1 cm and 2.6 Ø long dowels.	5.2 2.3	5.6 3.2	13.0 -	7.9	37.2 cm^3	x 10

From the last column of the table, the significant increase in strength can be observed for combination beams. The double beam with either connector blocks or inside dowel is at least four times stronger than the single culm. The double culm beam with the connector blocks or inside dowel is 15-20% stronger than the double culm beam with the through-dowels. For this reason, such through-dowels for the double culm beam are not recommended.

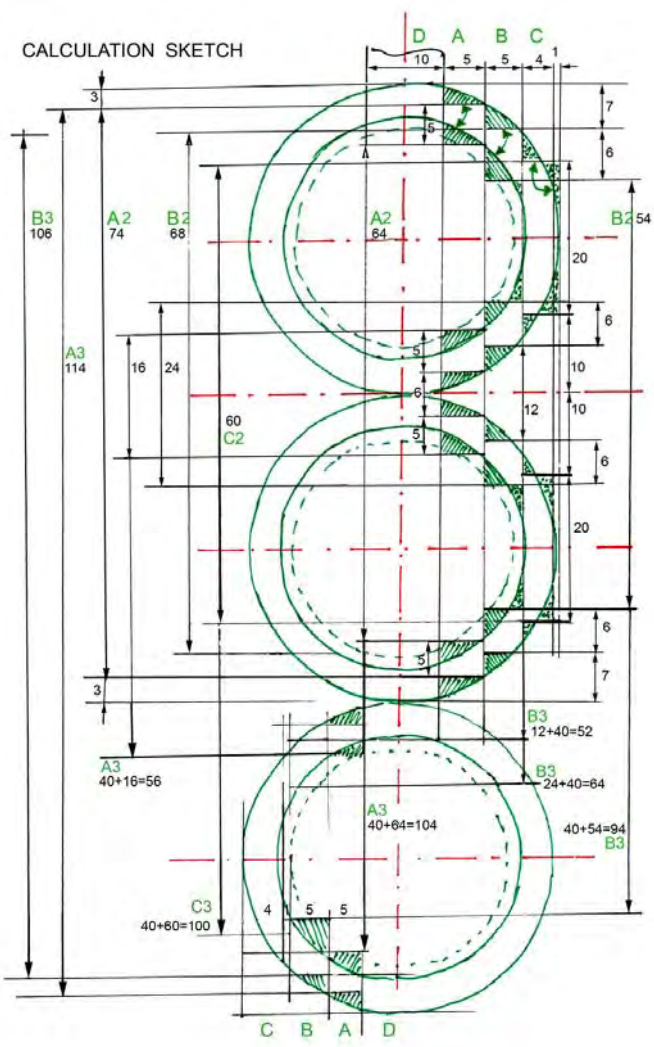
The triple culm beam with through-dowels is about 8 times as strong as the single culm.
The triple culm beam with inside dowels is about 10 times as strong as the single culm or 25% stronger than the through-dowel beam. Because the middle culm has Ø 1 cm holes in the top and

bottom, its structural strength is only W_Y=1.3 cm^3 or one third of the single culm beam. For this reason, the in-between culm for the triple culm beam is not counted but serves as an additional margin (strength reduction) for these composite beams.

It is clear from the table that the inside dowels create a stronger construction than the through-dowels, but the manufacturing requires precise handling. On the other hand, the finishing is smoother than the through-dowel connection.

Calculation

For the calculation of the block or dowel constructions, the rounded shape of the culm is vertically divided into rectangular sections of 10 mm wide (or 2 x 5 mm wide). The sections A, B, C and D are added together to obtain the total W_Y (see sketch).



Because of the compensation triangles, the values below are approximations.

The W_Y formula for rectangular hollow shapes is used.

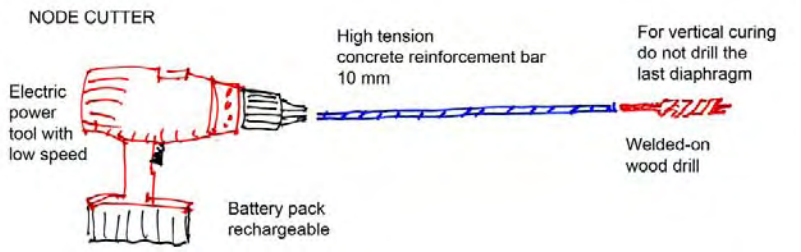
For two times the A, B or C rectangular section:
$W_Y = \{2 * (A * A_{2outside}^3 - A * A_{2inside}^3)\} / (6 * A_{2outside})$

s = section width = 1 cm (left + right)
H = external height of section
h = internal height of open space.

$W_Y = (sH^3 - sh^3) / (6H)$ cm^3 Because s = 1, the formula becomes: $W_Y = (H^3 - h^3) / (6H)$ cm^3

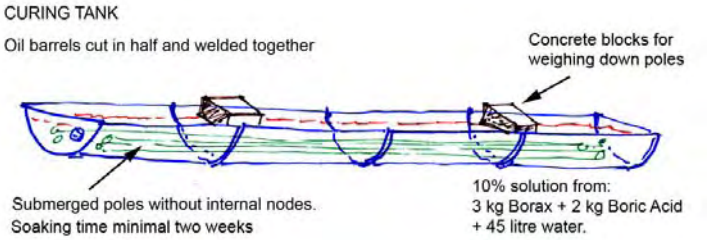
Curing Tank

It is essential that the bamboo being used for constructions are harvested, cured and treated correctly. Once inside part of the construction, it is very difficult to replace rotten members or sections that are affected by termites, fungus or other deteriorating elements.



The picture right is a cold deformed concrete reinforcement bar with a point. The thin bamboo post is forcibly pushed over the bar. After opening the nodes inside the entire culms, these are laid in a tank with a borax and boric acid solution of 10% and left for at least one week.

A long soaking tank can be made from half oil barrels welded together.



To avoid that the stems are floating, the bundle is weighted down with a few cement blocks. To minimise the effect of air bubbles inside the stems, they should be given half a turn everyday.

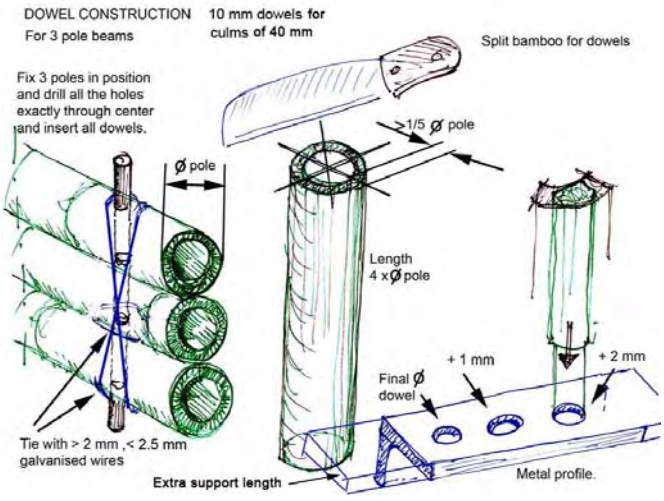
With vertical preservation treatment as is depicted in:
www.bambooman.com.au/bambootreatment/ebf.php#Harvesting%20Bamboo
the last node is not perforated. The culms are placed vertically in a barrel and filled from the top with the 10% borax-boric acid solution; refilling when the level in the culms is lowered by absorption.

Dowel and Block Constructions

There are various methods of making the connectors between two or three stems. The block connector and pin or dowel connector are illustrated.

After the connectors are precisely placed, the connections are tied together with galvanised wire (>2 mm, <2.5 mm) over the two or three culms. The wires are wound minimum two times around the dowels and minimum three times around the block connection. Wire thinner than 2 mm is not advised. The 3 mm galvanised wire is too stiff to be used for winding; it is used for the vertical anchoring of the wall plate and the main tension wires in the trusses. In the market, 2.2 mm and 2.3 mm galvanised wires are often available having good winding properties.

For making a stiff beam from three times Ø 4 cm culms, the dowels are Ø 10 mm and minimum 4 x culm diameter long. They are fitted precisely through the three posts at intervals of ≈ 30 cm. After that, the connection is diagonally tied with galvanised wires.



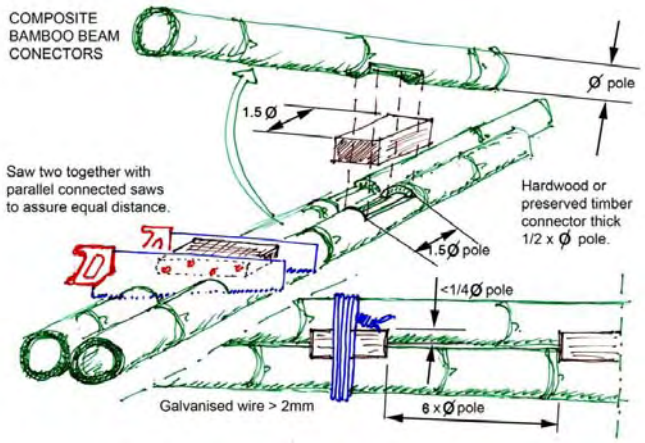
The dowels are obtained by splitting a thick section of culm and pre-shaping these. Then the lengths are hammered through a metal profile with reducing hole sizes until a smooth dowel is obtained with the required diameter.

Connector Blocks

Two culms together can be connected with blocks when sawn together, assuring that the blocks fit precisely.

In this case, the tool consists of a double saw bolted together. In this way, the double cut in both culms has the same width. The sawing depth (¼ Ø pole) can be regulated by the position of the block between the two saws. The connection between the culms with the block is wired tight with a minimum of three wires >2 mm.

For all connections: the cut ends of the twisted wires are folded in between two bamboo culms to avoid injury when handling.



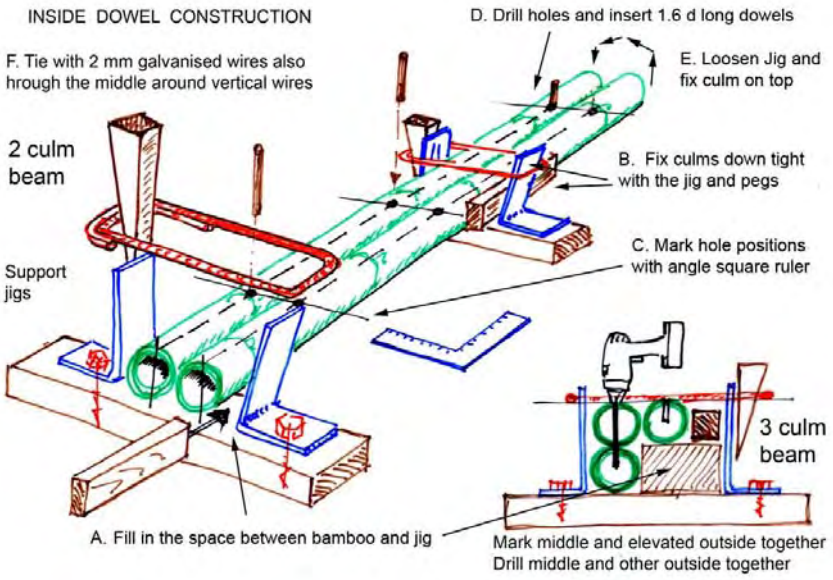
Assembly of Inside Dowels

For the assembly of the composite beams with inside dowels, the holes for the dowels need to be drilled precisely in line with each other. Fixing the culms in a jig and using a measuring square is essential. The drill should be adjusted to the precise drilling depth in order to avoid drilling through the most outside culm wall. The drill must be kept precisely vertical. Using wood drills which have a centre point, or first making a small hole at the exact position, will avoid that the drill slides sideways at the starting point.

The long spiral drill on the left will maintain its position when sunk into the hollow of the bamboo.

The wood drill on the right with a narrow shaft can easily shift in position when the blade enters the hollow inside the culm and the shaft is not supported by the sides of the hole in the bamboo.

The sketch provides a suggestion for a jig that holds the culms in a fixed position for measuring, drilling and assembly. When making a three culm beam, the middle and upper culms can be marked together so the holes will be corresponding exactly. The middle and lower culms must be drilled together, making sure the drill does not enter the most outside wall of the lower bamboo.

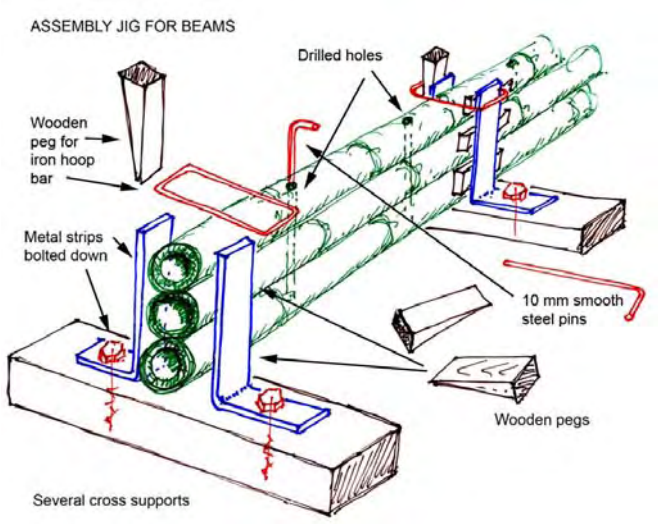


Systematic Work with Jigs

It is recommended to make the building designs with as much as possible similar components, such as roof trusses, wall panels, doors and windows. Series manufacturing is more time efficient and therefore lowers considerably the production costs.

The making of good quality jigs is easily recovered from the faster production. Good jigs will avoid making mistakes and allows precision work.

When drilling the holes in the three culms, these must be well fixed in place to avoid shifting during the drilling activity. A few jigs can be made that holds the three long culms in place while drilling.



A smooth metal pin should be placed in the newly drilled hole to avoid any shifting of the culms by accident with the drilled holes. When the dowels are placed, the connections need to be wired up crosswise and in between the culms to fix them tight.

As a guideline, the following dimensions can be used for the double culm-beam:

	Ø of the Two Culms = Width Connector Blocks	*Cutting Depth into Culm for Connector Block ¼ Ø*	*Thickness of Block Connector ½ Ø*	*Length of Connector Blocks = 1.5 Ø to 1 Ø*	*Distance Centre to Centre of Connector Blocks*
1	4.0 cm	1.0 cm	2.0 cm	6.0 cm	36 cm
2	4.5 cm	1.15 cm	2.3 cm	6.0 cm	39 cm
3	5.0 cm	1.25 cm	2.5 cm	6.0 cm	42 cm
4	5.5 cm	1.35 cm	2.7 cm	6.0 cm	45 cm
5	6.0 cm	1.50 cm	3.0 cm	6.0 cm	48 cm

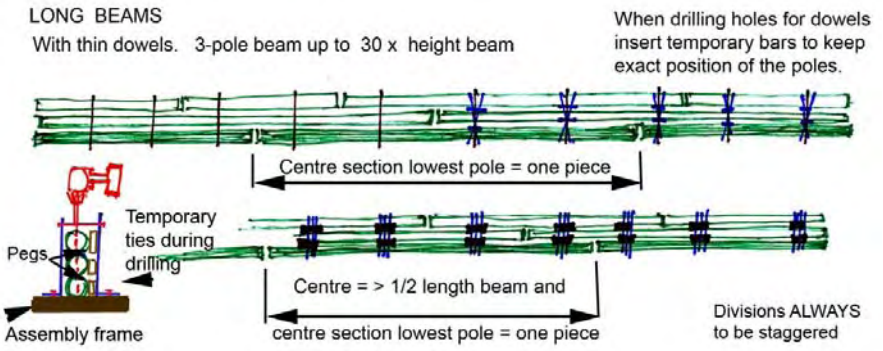
As a guideline, the following dimensions can be used for the three culm-beam:

	Average Ø of the Three Culms of Beam	*Ø for the Dowels/Holes ≈ Total Wall Thickness*	*Length of the Dowels = 4 Ø*	*Distance Centre to Centre of Dowels = 7 Ø*
1	4.0 cm	1.0 cm	16 cm	28 cm
2	4.5 cm	1.1 cm	18 cm	31.5 cm
3	5.0 cm	1.2 cm	20 cm	35 cm
4	5.5 cm	1.3 cm	22 cm	38.5 cm
5	6.0 cm	1.4 cm	24 cm	42 cm

The maximum external moment that can be applied depends on the material resistance, the thickness of the culm wall and the maximum bending tolerated under full load. Test beams should be made of the available bamboo material.

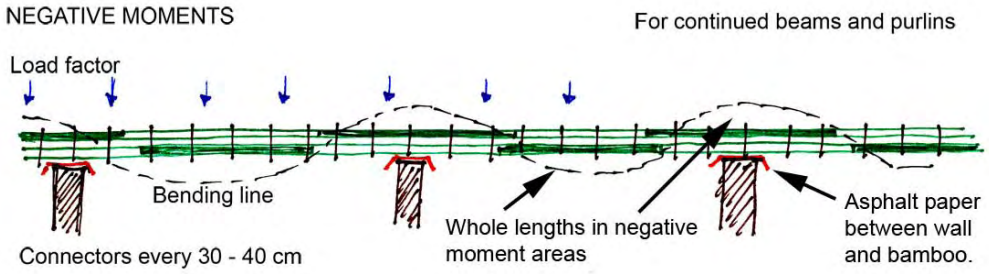
5. Maximum Moment Area

When the composite beams are part of the construction and used as components for trusses, the location of the maximum moment area of these beams should be known. The best culms should be used in these zones, while no lengthwise connection of culms should be placed in these maximum moment areas. Shorter sections can be used in the middle and pressure zone of the beams.



It is important that the people making the construction or the trusses on site are well aware of the differences between the upper and lower side of each beam and where maximum positive and negative moments will occur.

Long sides of trusses and long purlins over several truses will have alternating locations of the maximum moment areas. In this case, the outside culms of the trusses and purlins should have the longer sections at these maximum moment areas. It will be important to mark the correct side of the beams precisely, indicating the inside or outside of the beams.



In areas where large forces are expected, or where junctions between different truss components are to be made, the number of culms in the beam can be increased to four.

<< < < < *Inside*

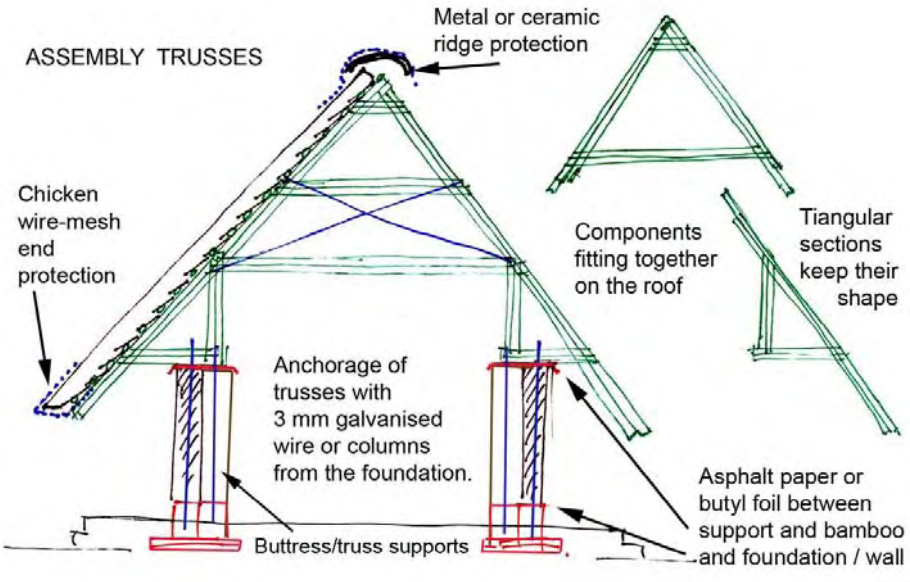
Outside > > > >

In the pictures above, the support of the truss is connected with the wall plate and a horizontal tie-bar or wall plate. The 3-culm truss beam continues outside the wall to create the roof overhang and the veranda. At this support point, both positive and negative moments are possible and an additional culm section has been added near the support area. The horizontal lower tie-bar can be substituted with a few 3 mm galvanised wires; this is more cost efficient.

6. Assembly of Components in the Roof

The thin bamboo composite beams are stiff in one direction, but weak in the other direction. Prefabricating long elements or whole trusses is not advised. They will be difficult to handle and can break when loaded perpendicular to their plane of stiffness.

Depending on the strength of the elements, easy to lift and handle sections should be assembled together in the roof by inserting the dowels and applying thin galvanised bolts/nuts.

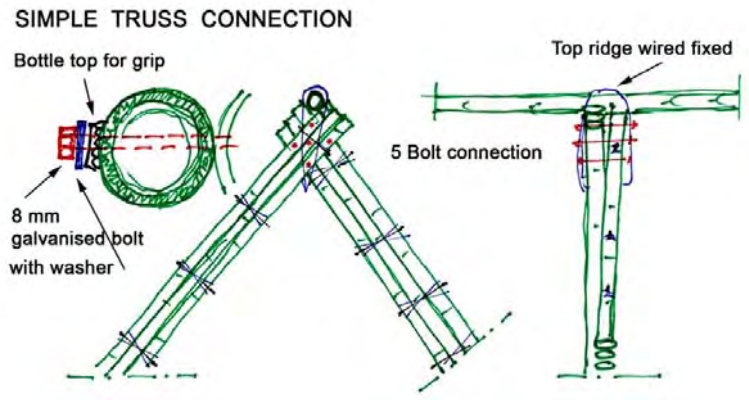


Many truss designs are possible, but all should have a triangular section providing support with a few 3 mm galvanised tension wires.
In this design, buttresses are supporting the trusses and provide some stability of the walls.
Shelves can be placed or storage areas made in between the buttresses or pennants.

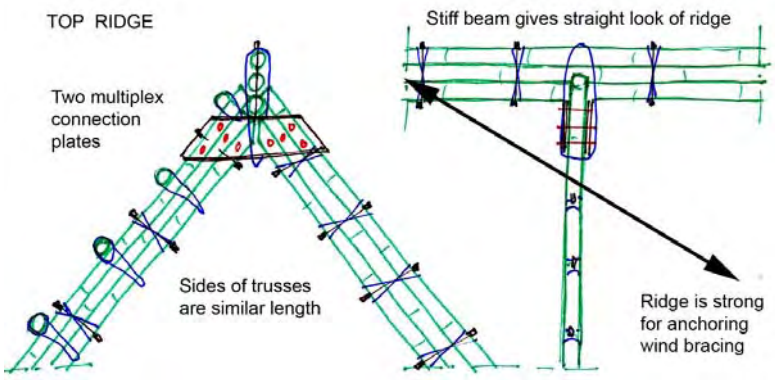
During the assembly in the roof, bracing in the perpendicular direction of the truss is required. This bracing can be temporary depending on the roof covering design and material.

The stiffness of the top ridge is important for having a straight rooftop. A double culm is recommended here when the purlins are single culms. The top ridge of thatched roofs can have an extra load because of cemented ridge tiles.

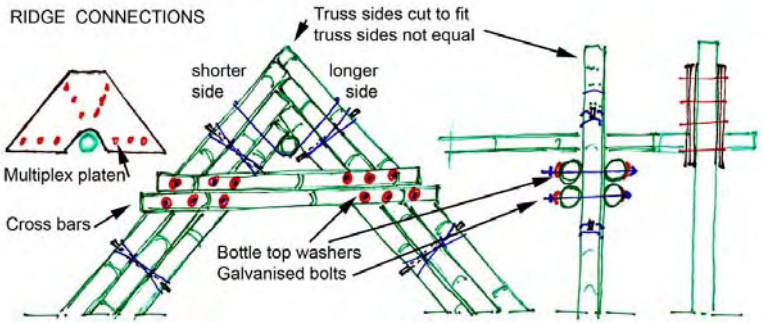
The simplest connection is to bolt the truss sides directly together with five galvanised bolts. The ridge is wired fixed. To secure the bolts on the rounded bamboo, washers made from bottle tops should be used directly on the bamboo to improve grip and then covered with the bolt washers.



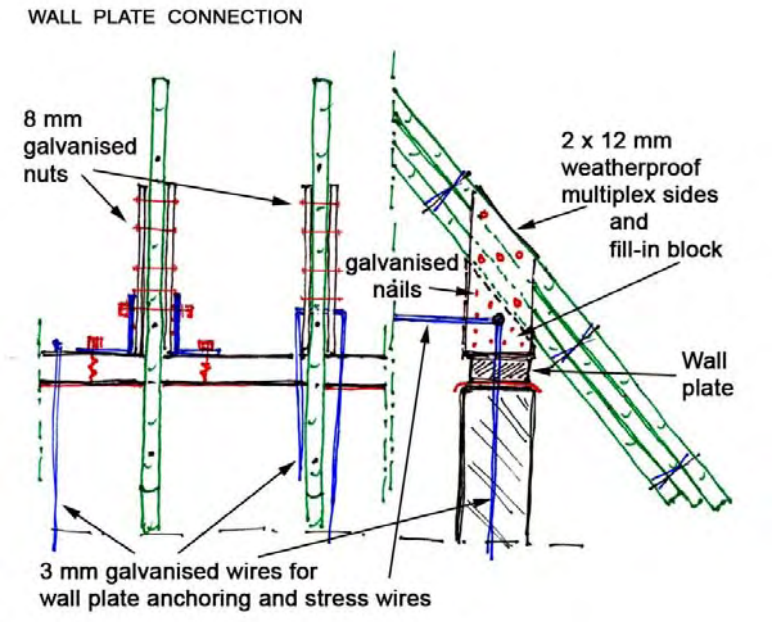
In this second design below, the connection between the two truss sides is made with 2 x 12 mm weatherproof multiplex plates bolted together with 8 mm galvanised bolts and nuts.



When the two truss sides are linked together at the top, the length of each side can be a culm thickness different (sketch below). This requires good marking of the components during the prefabrication on the ground. Bottle tops are used as first washers on the round bamboo poles for better grip.



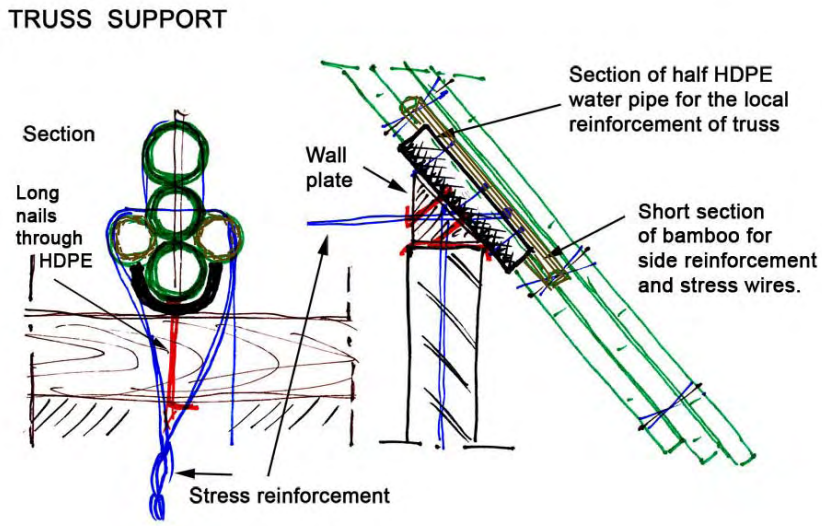
The load from the roof trusses needs to be transferred down to the supporting walls or columns and at the same point the horizontal stress wires need to be fixed. Several solutions are possible.



The sketch shows the use of double multiplex 12 mm sides which is filled up with a block. The sides are glued and nailed to the central block, and a hole is drilled into this support for the anchorage of the block to the wall plate and the stress reinforcement. The truss is fixed with 5-6 galvanised 8 mm bolts. When the wall plate anchors are not in the same location as the trusses, the block can be fixed with angle irons and bolts to the wall plate.

When there is no supporting wall, but a timber column, the same construction can be applied. In this case, the block is replaced by the tailored top side of the column.

The three culm truss should not be fixed directly onto the wall plate because the thin bamboo can get easily damaged due to the sideway point loads in combination with the stress wires.



When sections of thick HDPE water pipes cut-in-half are first fixed to the wall plate, placing the trusses will be easy. Tying two short sections of bamboo to the lower and middle culms will further strengthen the anchoring area of the truss. The horizontal stress wire will go around these additional sections and through the middle culm of the truss leg. The vertical wall reinforcement can also be brought upwards and anchored through the same middle culm of the truss leg.

All bamboo constructions should remain open and visible for inspection. No double or hollow wall constructions should be present for animals to hide or build nests. All the open ends of all bamboo culms need to be sealed to avoid insects from entering. This can be done in various ways, but the filling should not fall out during the lifetime of the construction.

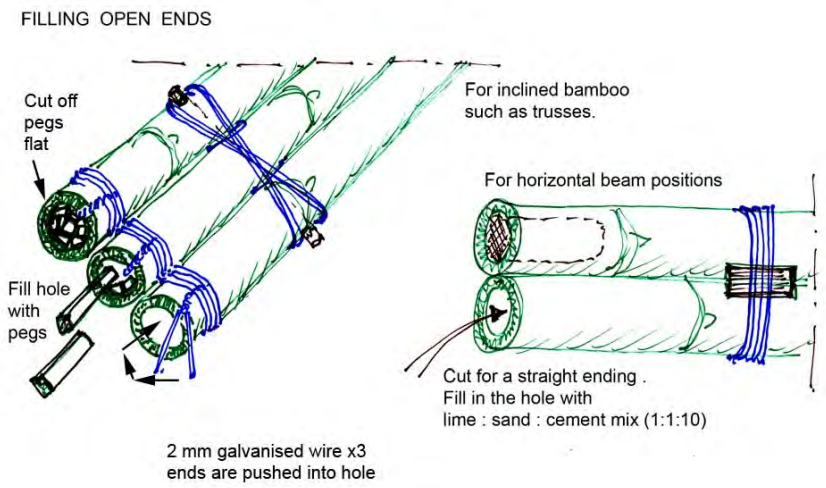
Stuffing horizontal ends of floor beams with a sand : cement : lime mixture (10:1:1) is effective.

When the bamboo is still drying a little after the construction, the filling will become tightly fixed.

For inclined trusses, these plugs may fall out in due time and therefore some anchorage may be required.

When the ends are plugged with small pieces of bamboo, those ends need to be reinforced first to avoid splitting open. Hammering the pieces in place can close all small openings. The protruding ends need to be sawn off straight.

The long end of the twisted wire around the end of the bamboo can be stuck into the opening when filling this opening with short bamboo sections. This wire will also hold the cement and lime mortar plug in place.



Annual Inspection

The roof construction should remain accessible for inspection and maintenance. Ceilings and horizontal truss components should be strong enough to hold the weight of a maintenance person. The openings above the ceilings and in between the truss triangles should allow easy passage of a person.

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