

Building with bamboo

- the basics



building trust
international



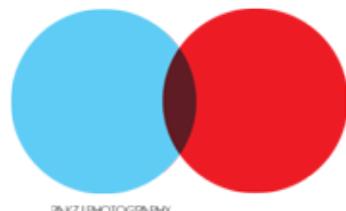
Komitu Architects

Most pictures in the guide are from the construction of the Kouk Khleang Youth Center by Komitu Architects.

* Front/Back cover Kouk Kouk Khleang Youth Center by Komitu Architects

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Drawings by Elina Tenho.



More info on bamboo:

www.inbar.int

www.guaduabamboo.com

www.chiangmailifeconstruction.com

www.bambooroo.net

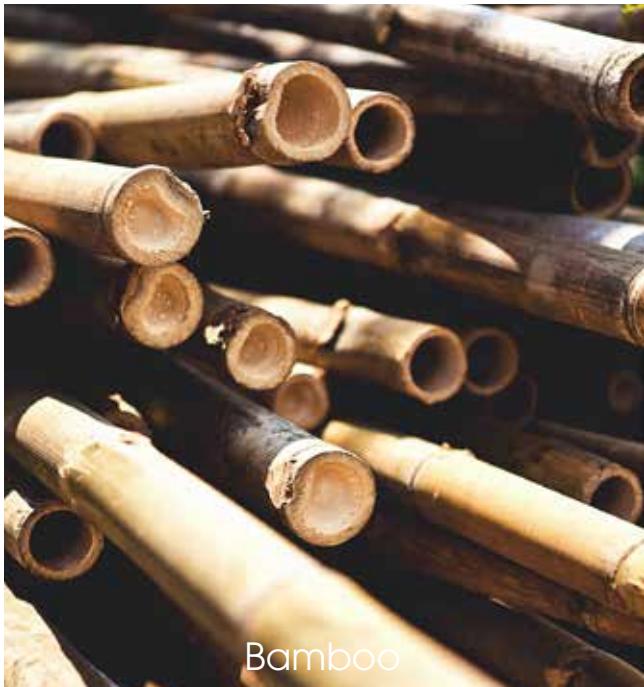
www.naturalbuilding.com

www.komituarchitects.org

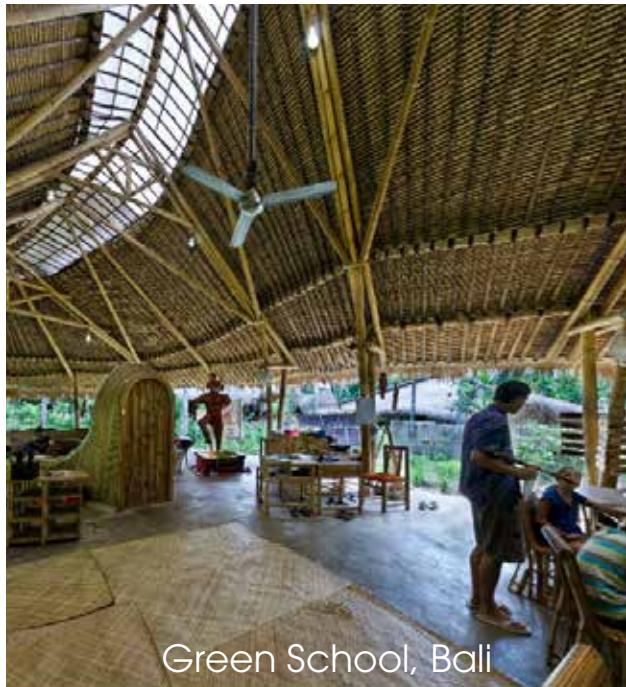
A close-up photograph of a stack of light-colored bamboo poles. The poles are arranged horizontally, showing their natural节 (nodes) and some small brown spots or insect damage. The lighting highlights the texture and color of the bamboo.

Building with bamboo:

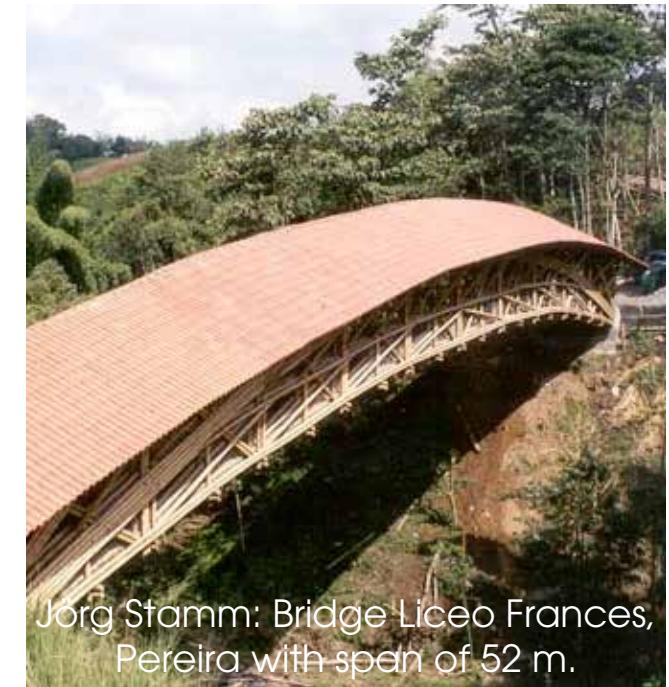
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Bamboo



Green School, Bali



Jörg Stamm: Bridge Liceo Frances, Pereira with span of 52 m.

Bamboo as a building material is:

- Strong
- Ductile
- Rapidly renewable
- Inexpensive
- Locally sourced
- Beautiful

Quick facts

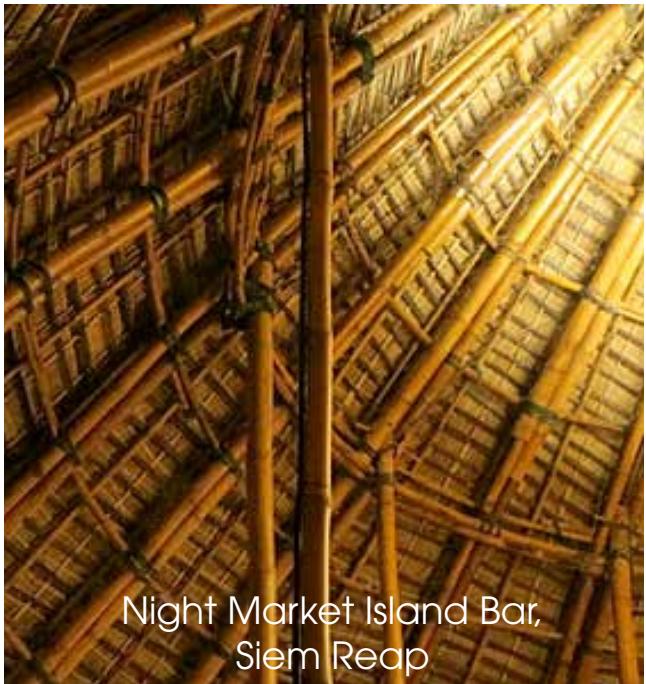
In India there is a saying that "after birth one cannot survive without bamboo". The early human use of bamboo tools and technology may have preceded the usage of the Stone Age tools, but unlike stone, bamboo is perishable and no record of the use has been preserved.

Bamboo is an extremely sustainable building material. Bamboo plants renew themselves very fast, from 30cm to 100 cm/day. As bamboo reaches maturity very fast, it should be harvested for

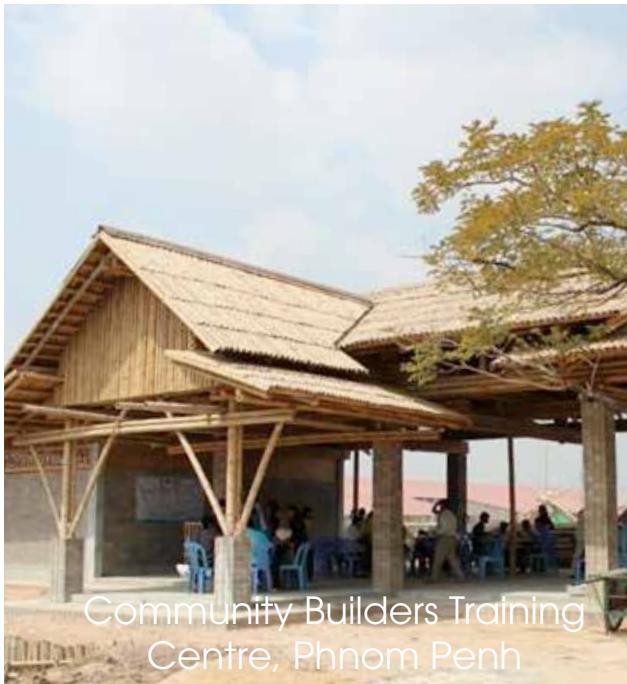
building purposes in the age of 3-8 years. The plant doesn't die when harvested and starts growing again immediately after harvesting.

The yield of bamboo (weight/acreage/year) is 25 times higher than timber. The tensile strength of bamboo is relatively high and can reach 370MPa.

Approximately 50 or 100 bamboo species are preferred for use and are undergoing some degree of domestication. However, there are estimated to be nearly 2000 species.



Night Market Island Bar,
Siem Reap



Community Builders Training
Centre, Phnom Penh



CBET Chi-Phat, Koh Kong,
Wildlife Alliance

Bamboo in Construction:

Energy balances:

Concrete	240 MJ/m ³
Steel	1500 MJ/m ³
Wood	80 MJ/m ³
Bamboo	30 MJ/m ³

(The amount of energy required to produce a unit of a building material with a certain level of land-bearing capacity.)

Bamboo is vulnerable to the attacks of environmental agents, insects and moulds. The right treatment and

construction methods are vital to the use of bamboo in construction. Bamboo structures should be lifted up from the ground and protected by large eaves. Bamboo should also be treated with a preservative, i.e.. borax.

Because of its round, tubular form, jointing two or more bamboo members requires a different approach to that of solid timber. Despite its high tensile strength, bamboo is vulnerable to crushing and splitting. Also variations in diameter, wall thickness and straightness must be considered when designing connections.

When sourced locally, bamboo forms a low-cost building material. Unfortunately, it also has the reputation of being "the poor man's timber" and in contemporary building it has widely been replaced by industrial materials such as steel and concrete. However, there are new technologies invented every day concerning bamboo and its possibilities are growing. Hence, it is important to promote high quality bamboo buildings and enable making bamboo "the wise man's material".



Bamboo species

Of the thousands of bamboo species in the world, about 50 species exhibit favourable properties for construction related purposes, like flooring, panelling, laminated lumber, etc. These woody bamboos (BAMBUSEAE) have the most economical value.

The Chinese bamboo *Phyllostachys edulis* (Moso) is the most commonly utilized species for industrial bamboo manufacturing in the world. China is the largest producer, and almost all products in the West are made from this species.

Few other commonly used species:

Dendrocalamus giganteus is good for construction, paper production and young shoots are good for vegetable products.

Dendrocalamus asper is used as a building material for heavy construction, and shoots are consumed as a vegetable.

Dendrocalamus latiflorus has sweet edible shoots and is often used in light construction.

Bambusa vulgaris is widely planted and used for a variety of purposes, primarily for use in light construction, fences, scaffolding, furniture, musical instruments and handicrafts

Dendrocalamus strictus is used as a raw material in paper mills and has edible shoots.

Bambusa polymorpha's culms are used for house construction, woven matting, baskets, furniture, handicrafts, and as a raw material for paper pulp and board making. It is also suitable for landscaping.

Bambusa blumeana's culms are used in construction, parquets, basketry, furniture, concrete reinforcements, kitchen utensils, handicrafts, chopsticks,

hats and toys. It has great potential for the rehabilitation of marginal lands and can be used to border agricultural areas as living fences, as a windbreak, or to prevent erosion along streams.

Bambusa bambos' culms are used for house construction, scaffolding, rafters, thatching and roofing, handicrafts and art objects. The raw material of this bamboo is an important source for paper pulp and panel products. Shoots and seeds are edible and leaves are used as fodder and medicine.

Bambusa balcooa is often used as a food source, in scaffolding, for paper pulp or wood chips.

Guadua Angustifolia Kunth is used for purposes as furniture & crafts work, raw construction material, panels (plywood, laminates, floors), bio-energy industry, musical instruments, houses, etc.

Cambodian focus: **Dendrocalamus Asper** “Chinese bamboo”

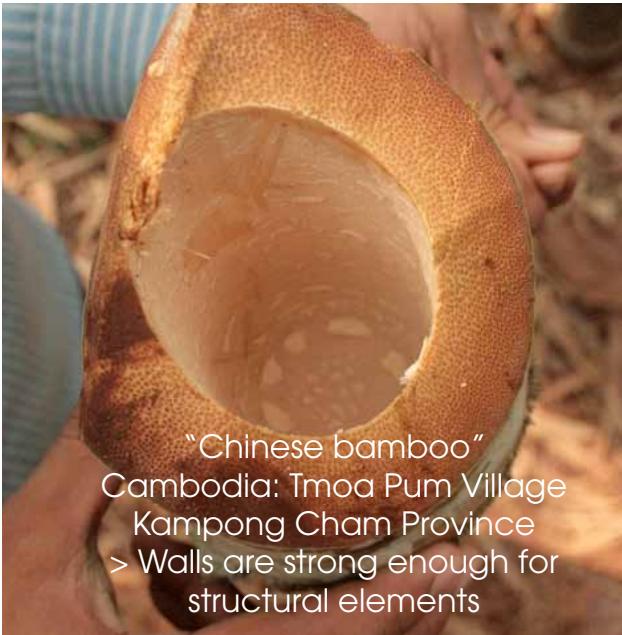
Height	20 - 30 m
Diameter	8 - 20 cm
Growth Habit	Clumping
Climate	Tropical - Subtropical
Hardiness	-4 °C
Origin	Malaysia



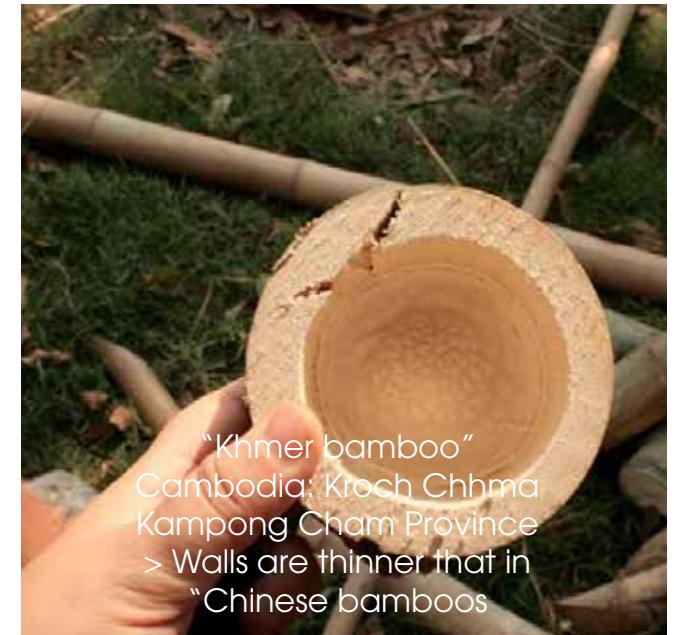
"Chinese bamboo"

Dendrocalamus asper, which in Cambodia is called "Chinese bamboo" is used as a building material and structural timber for heavy construction such as houses and bridges.

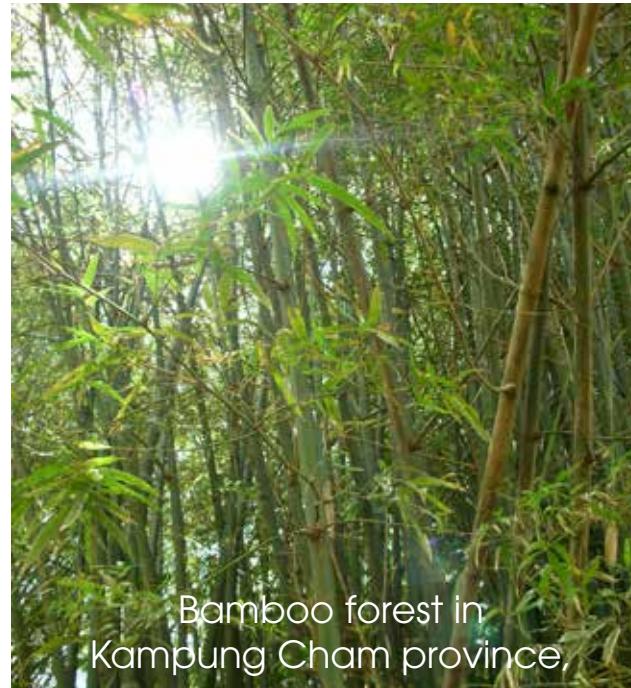
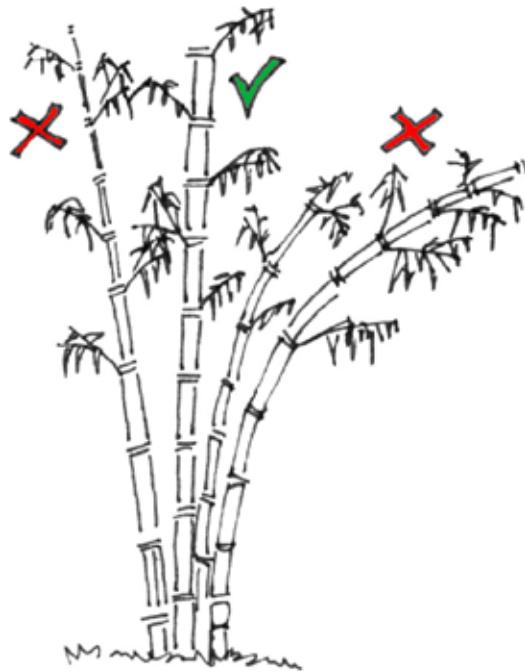
D. A. is a strong species to work with, but the vascular tissue tends to shrink at a higher percentage on drying than that of some of the other "building grade" bamboos. Due to this, direct sunlight exposure for structural elements should be limited as much as possible in the final implementation, as this will reduce opportunities for shrinkage/cracking and short term "wear" on the building.



"Chinese bamboo"
Cambodia: Tmoa Pum Village
Kampong Cham Province
> Walls are strong enough for structural elements



"Khmer bamboo"
Cambodia: Kroch Chhma
Kampong Cham Province
> Walls are thinner than in "Chinese bamboos"



Harvesting

Besides choosing the correct species of bamboo, the bamboos should be harvested at the correct maturity and be given proper care.

Fiber density, diameter, wall thickness and even sugar/starch content can vary in a species given even minor differences in temperature or soil nutrient.

The individual quality of the bamboos will affect the final building design as well.

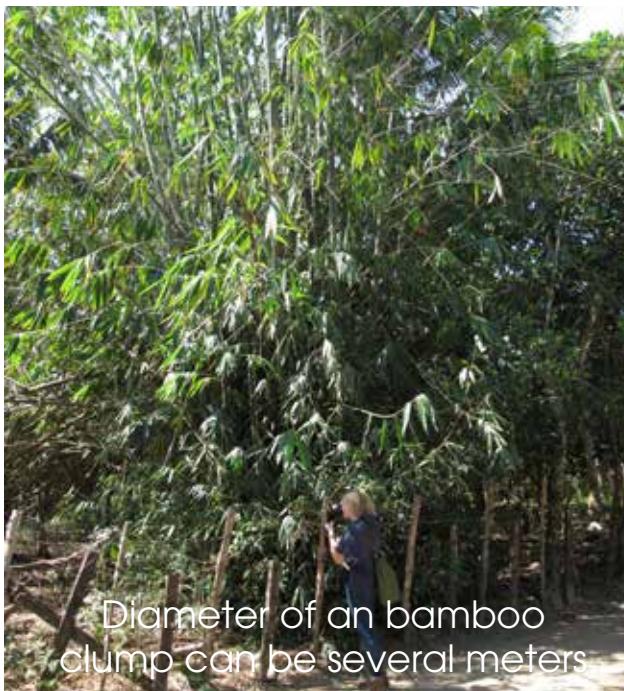
The bamboos you harvest should be...

- Straight
- Mature (3 - 8 years old)
- As evenly thick as possible from top to bottom.

Age

The maturity of the bamboo can be recognized from the skin: young bamboo (0-2 years) have a smooth, shiny skin and culm sheaths, whereas old bamboo has fungi and mosses growing on the surface.

The age of a bamboo culm should be at least 3 years old but not more than 8 years. Once bamboo is older than 8 years, it starts to dry and gradually loses its mechanical properties.



Best time to harvest

The recommended time to harvest bamboo is at the end of rainy season - beginning of the dry season, as that is when the sugar and moisture content in the bamboo plant is at its lowest.

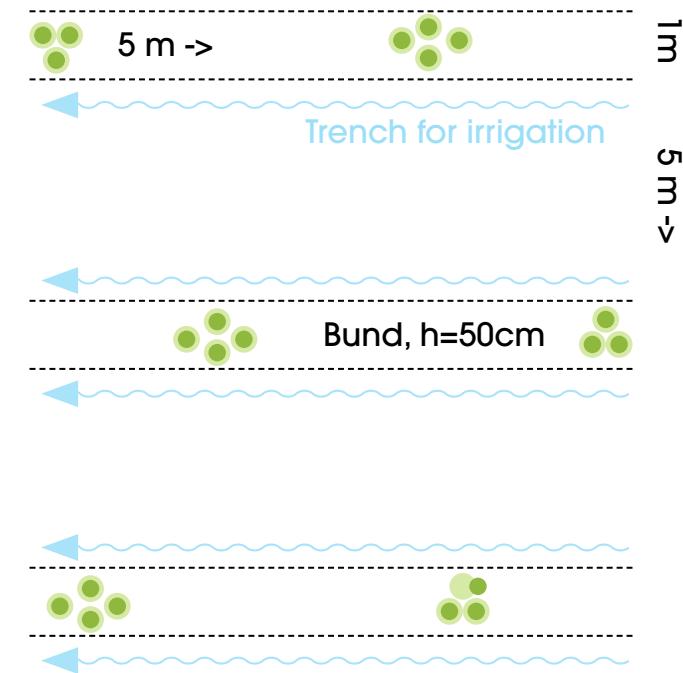
High starch content (end of dry season) increases the chances of borer and fungi attacks and high moisture content (during rainy season) increases cracking during drying.

It also matters in which time of the month and day bamboos are harvested.

The moon phase: the starch content is lowest between the 6th and 8th day after full moon due to the higher gravitation of the moon.

Time of day: best time to harvest bamboo, is before sunrise (between 12pm to 6am), when most of the starch is still in the roots and photosynthesis has not yet started.

Bamboo harvested in this manner has 3 advantages: they are less attractive to insects, are less heavy to transport and will dry faster.



Planting bamboo

To plant your own bamboo grove of medium-diameter, thick-walled species: 5 x 5 meters spacing is optimal. This requires 400 clumps per hectare, or 160 clumps per acre.

If the objective is to plant bamboo for erosion control along riverbanks or to protect an area from landslides and avalanches, the spacing can also be 3 x 3 meters or even 2.5 x 2.5 meters. In such cases, bamboo can be mixed together with appropriate, fast-growing timber species.



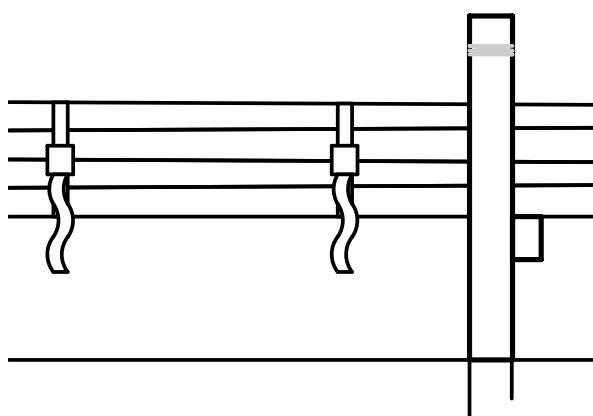
Cord (D=6-8mm, L=100m)



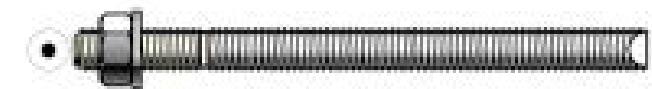
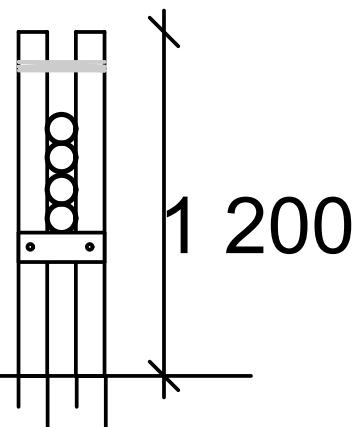
Smooth steel bars D=10-12 mm



10 gauge steel wire



Wood or metal stake material for 7 stands



Threaded steel rod D=10-12mm
+ washers and bolts



Wooden pins D=12mm

Useful tools for bamboo work



Electric saw



Angle grinder with cut off wheel(s)



Cutters for the wire



Power drill



Sledge hammer



Arborist saw



Drill bits (w/blunt end L=500mm D=12mm)



10 ratchet (cargo) straps 3cm wide



String line for marking distances



Insect attack on untreated bamboo



Treatment

Bamboos must be treated properly before building and preferably protected against UV. The goal of the treatment is to fill the cells of the bamboo with salt to prevent insects etc. from eating their way through it. Traditionally bamboos have been soaked in a local body of water, (preferably sea water) for some weeks, soaked for months in mud or smoked on a fire.

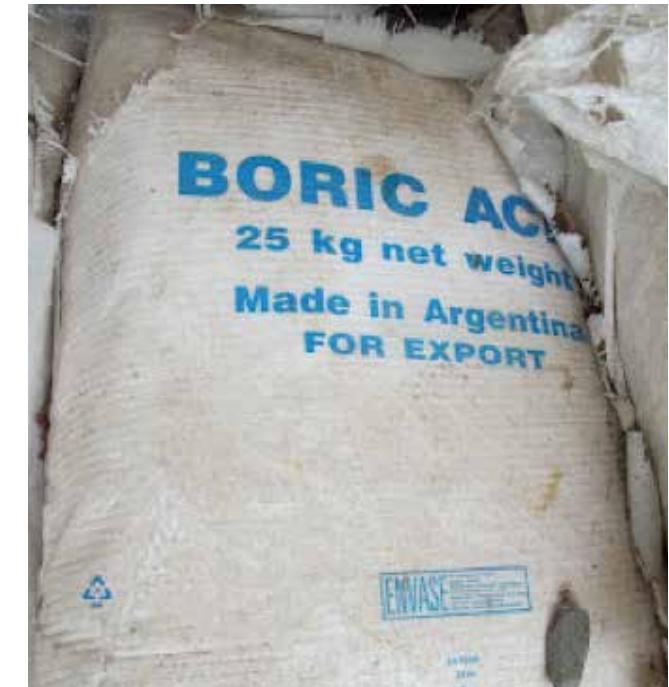
The most commonly used modern way is to use borax/boric acid immersion, which is a non-fixing preservative.

Other ways to treat bamboos:

- Boucherie method
- Vertical immersion
- Copper Chrome Arsenic (CCA)
- Copper Chrome Boron (CCB)
- Zinc Chrome
- Creosotes and LOSPs

Remember:

- Bamboo should still be fresh and green when treated.
- If bamboos still have branch stumps on them when they arrive on site this is a good thing – freshly cut surface along the length eases the penetration of the treatment to the middle part of the bamboo trunks.



Borax

In the Kouk Khleang Youth Center (KKYC) and CBET project in the Chi Phat Village, two chemicals were used for protecting the bamboos against the insects: Boric Acid and Borax Pentahydrate ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$). This combination of boric acid and borax in a ratio of 1:1.5 forms an alkaline salt called Disodium octaborate tetrahydrate ($\text{Na}_2\text{B}_8\text{O}_13 \times 4\text{H}_2\text{O}$). It is also available in pre-mixed powder form, usually under the commercial names: Tim-Bor or SoluBor, among others.

The recipe for the bamboo bath is 95% water, 2.5% Borax and 2.5% Boric acid.

Borax is a salt and a commonly used preservative. Boric acid is an acid used in e.g. rat poison. These chemicals are irritant so proper protective equipment should be worn when dealing with them.

In many countries including Cambodia these chemicals need to be imported and thus the delivery time can be up to 4-5 weeks. The chemicals come in granular form so it is best to dissolve them in boiling water first. How you do this depends on the circumstances you're in. At KKYC, an open fire was made and a barrel of 100 litres was placed on top.

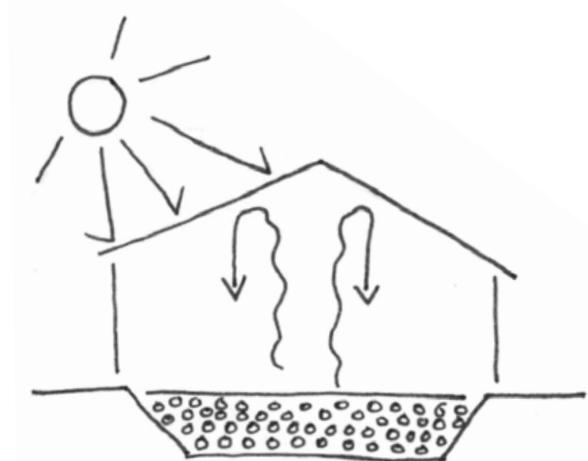
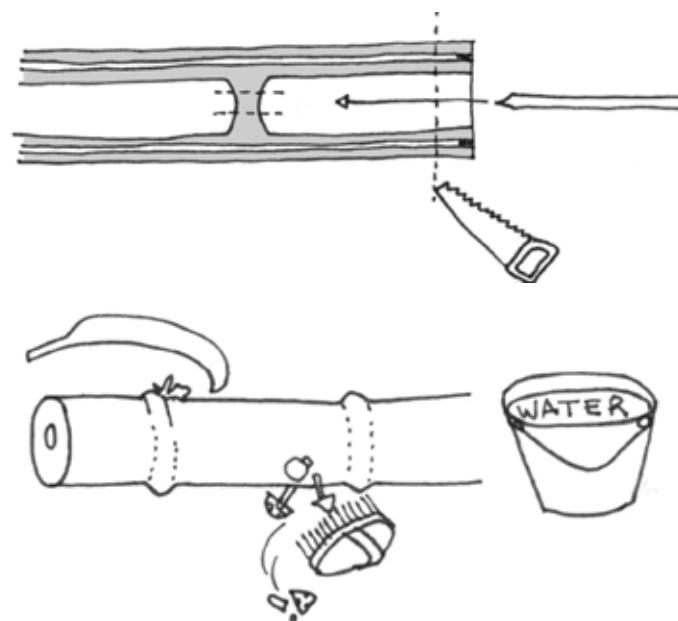
At KKYC two treatment pools of $8 \times 2 \times 1\text{m}$ were built. Excluding the volume of the bamboos this means more or less 5000 litres of water. Having to use a regular hose it took some 8 hours to fill both of the pools.

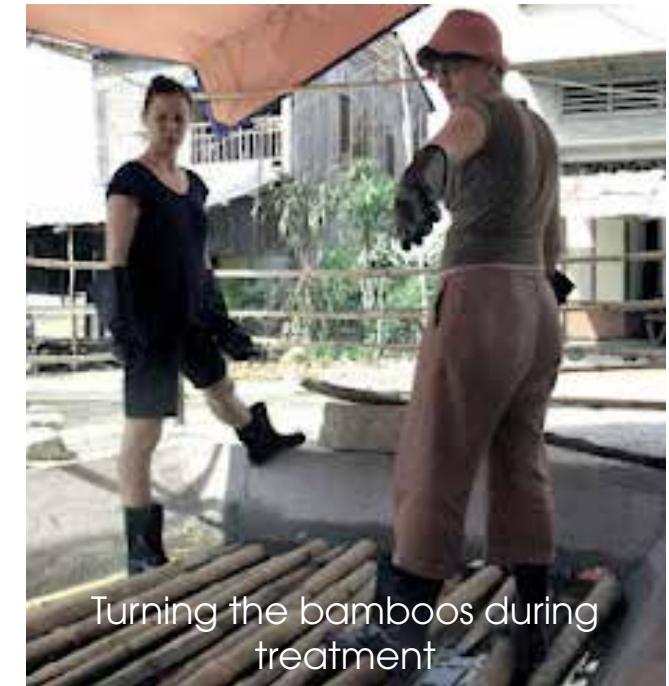
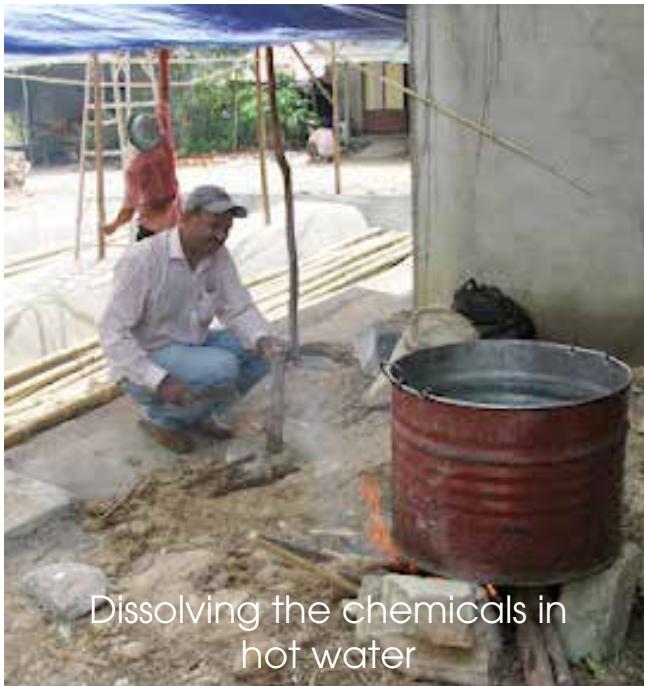
The bamboos and the water in the pools must be mixed every now and then to make sure all the bamboos get evenly treated and to ensure the salt does not start crystallizing on top of the water. Also some mixture should be added every now and then.



Treatment process

1. Build a concrete pool big enough for the bamboos and cover the pool with a light roof to minimize evaporation
2. Punch a hole through all node walls with an iron bar
3. Clean fungus etc. away with a brush, water (and soap)
4. Clean traces of branches and leaves from the nodes
5. Cut the ends of the bamboos to facilitate absorption

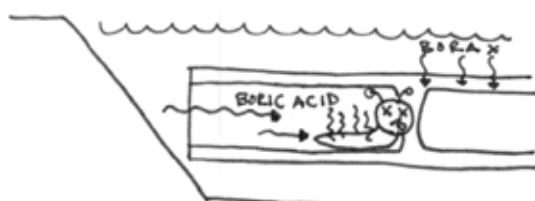




Mixture for the soaking:

Water 95%
Borax 2.5 %
Boric Acid 2.5%

In a pool of 2x8 metres and 0.5m deep, this means 7500 litres of water, 200 kg of Borax and 200 kg of Boric Acid
(The chemicals are very irritant so please use protective equipment.)



6. Fill pools with clean water, leave enough space for chemical mixture
 7. Boil mixture of water, Borax and Boric acid in a barrel of 200L until chemicals have dissolved and pour into the pool
 8. Soak bamboos for 10-14 days (minimum of 7 days) and add mixture when needed
 9. Clean the chemicals off bamboos with running water
- (NB: Solution in the pools can be used for two or possibly even three treatment batches.)

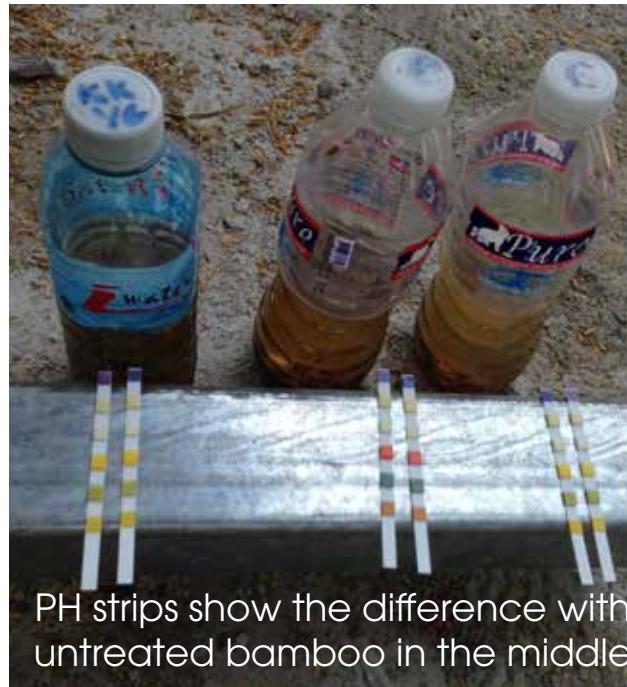




Jar Test

A simple jar test allows us to see how much chemicals there are in the bamboos after a week of treatment.

Take a small piece of the wall of the bamboo from next to the second node. Remove the outermost and innermost layer of tissue and chop into small pieces. Put clean tap water (test to be neutral) into a jar and put the bamboo pieces in. After a few hours test the water again and you can define the amount of borax in the tissue. Repeat the test if you don't first see any absorption.



pH strips show the difference with untreated bamboo in the middle

Tools for cutting

The difference in the cuts made by different saws. The top one has been cut with a fine arborist saw so the surface is smooth and the open ends of the vascular tissue can still be seen. The bottom has been cut with a rough frame saw and no open tissue can easily be seen.

The finer cut with its open tissue makes absorption of chemical water easier.





Treatment

After 7-14 days of treatment, first lift one end of the bamboos from the pool to let most of the water flow out of the other end. After most of the water has come out, lift the bamboos onto the cleaning racks and wash the excess salt away with water.

Dry bamboos vertically for 2-3 days, protected from rain and direct sunlight to avoid cracking.

The same mixture can be used 3-4 times with some chemicals and water added when needed.

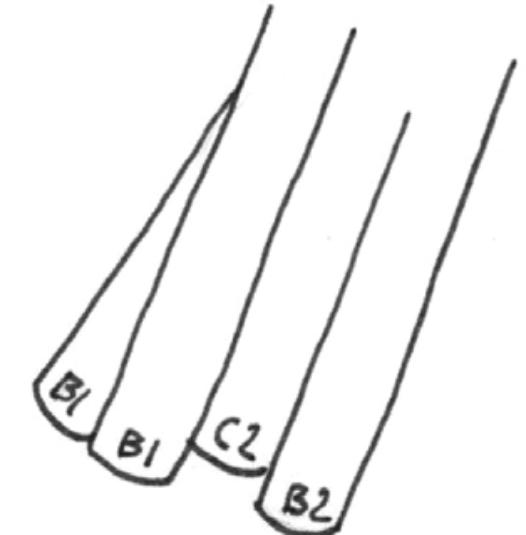
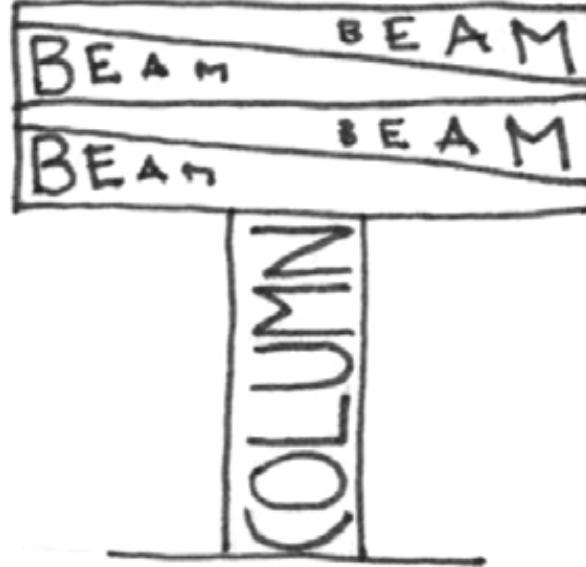
Store the bamboos away from direct sunlight, mud and rain.

When treatment is finished, remove the roof and let water evaporate. Don't transfer the water to a lake or a river as animals and plants will suffer.



Measure with moisture the fresh, the treated and the dried bamboo and see when it has stabilized after the treatment and is therefore safe to build with. If you start building too soon after the treatment, the bamboos still have extra moisture in them and there is a risk of shrinkage and the joints failing when it stabilizes.

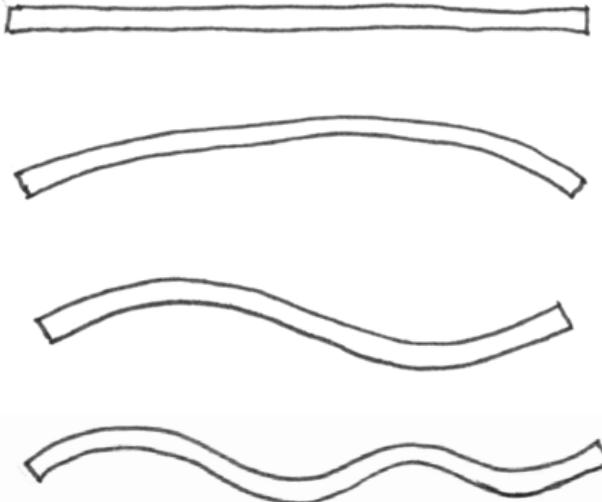




Columns or beams?

Divide the treated bamboos into the ones that qualify as beams and the ones that qualify as columns and mark accordingly.

Roughly described, the column poles need to be sturdy, straight and as evenly thick as possible from top to bottom to carry the vertical loads through them. With the beams, even in the poles that curve from one end. There might be a long enough piece of straight pole in the other.



The bamboos can be put into four categories:

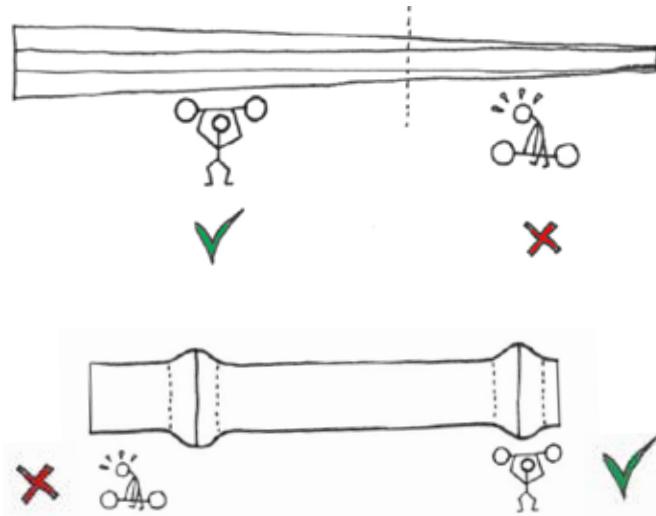
Straight - can be used for anything, perfect for columns

Curved - one arc in one plane, usually can be straightened to be part of a beam

Swerve - several arcs in one plane, can be used for short elements

Wiggle - arcs in two planes, can't be used for structural elements.

(NB: Don't throw away, this can be used for splits etc. later!)



Measuring elements

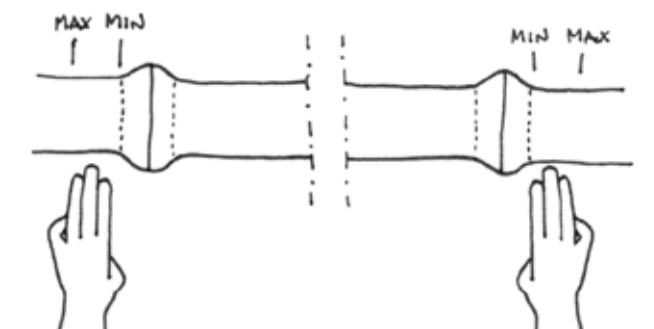
The nodes are the strongest part of the pole. Internodes are weak. This is why there should always be a node at both ends of the pole.

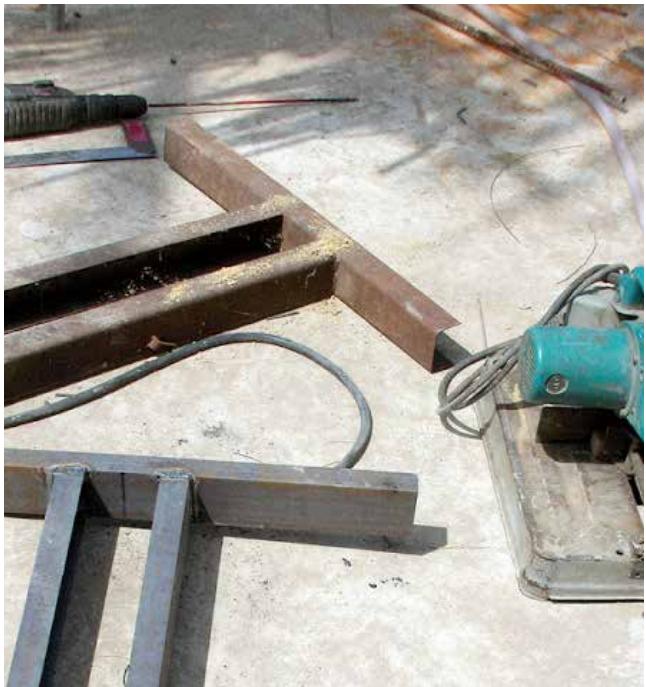
1. Have one person at each end of the measuring tape and find the measure you need from the tape.

2. Start measuring from the first node in the thick end of the pole. (Look out for "the end kick" which means that the first half a meter is often quite curvy. Don't use it!)

Remember there must be a node in both ends of the element. The three-finger-rule means that the width of three fingers is the furthest you can cut from a node. Otherwise the end will be too weak.

Did you hit a node (or max 3 fingers from a node) in both ends? If so, good, mark it! If not, go to the next node.

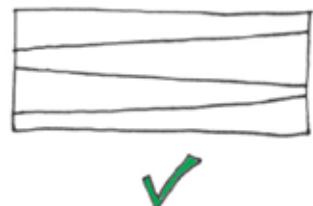




Making a beam

Beams can be made of straight and curvy pieces. Swervy poles can be used for short elements.

It is better to make beams with an even rather than odd number of poles. This will make them level (because one end of the pole is always thinner than the other).

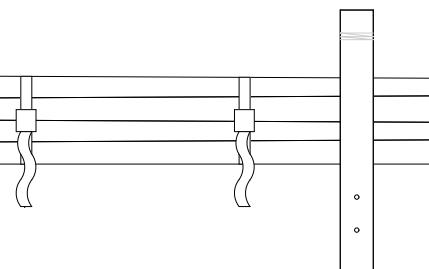
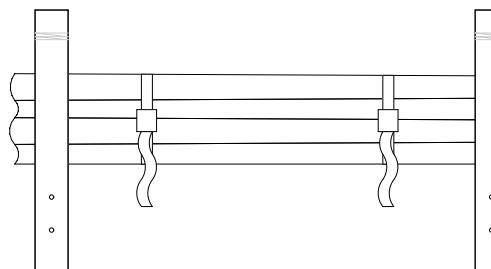


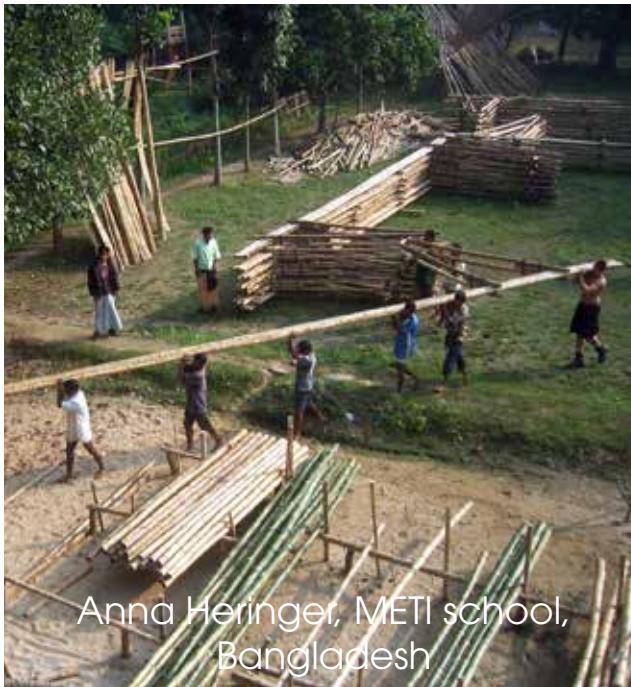
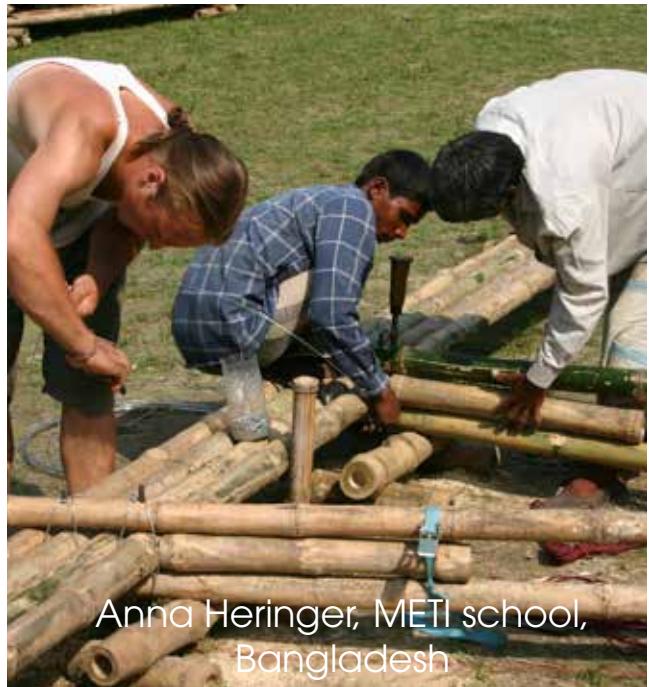
1. Set the poles into the rack so that the thick end of the first and the third one face one way and the thick end of the second and the fourth face the other.

2. Check that the poles are exactly on top of one another and that curvature happened in the plane off the beam and not out of it.

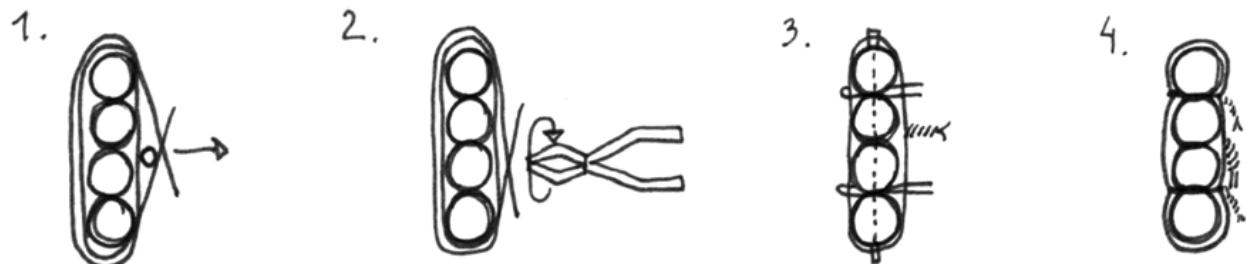
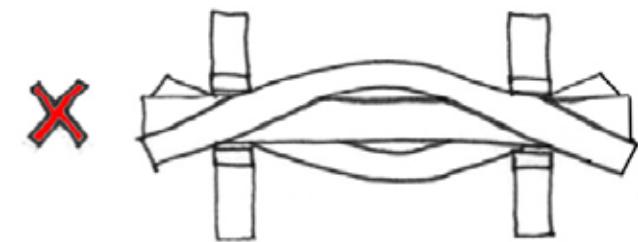
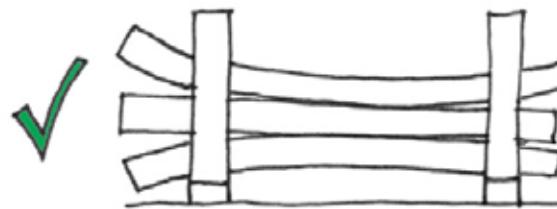
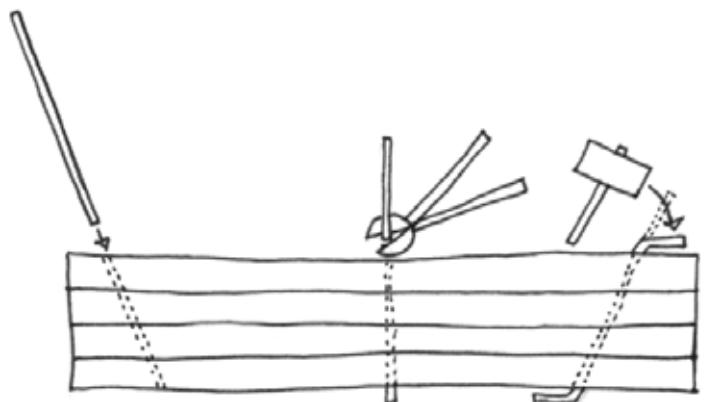
3. Use ratchet straps to press the poles together. Hold them together while you strap to avoid them from moving.

4. Drill holes for the pins (smooth steel bar). The pins in the ends of the beams should be diagonal and the middle one should be perpendicular to the poles.





5. Put in the pins, cut them and bend the ends.
6. Tighten with steel wire at each pin.



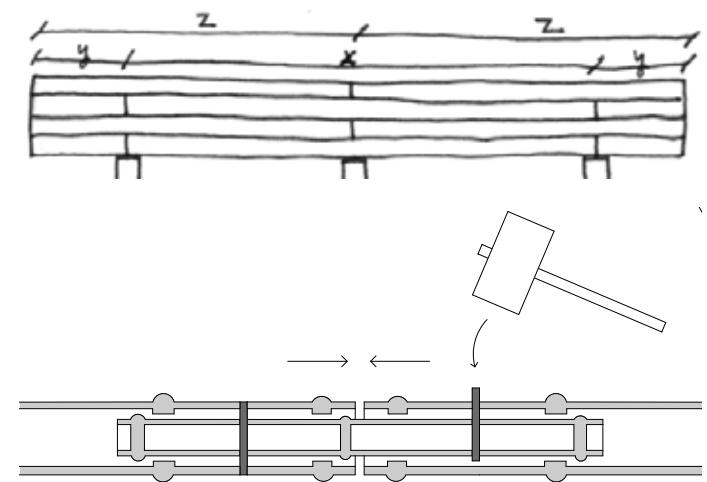


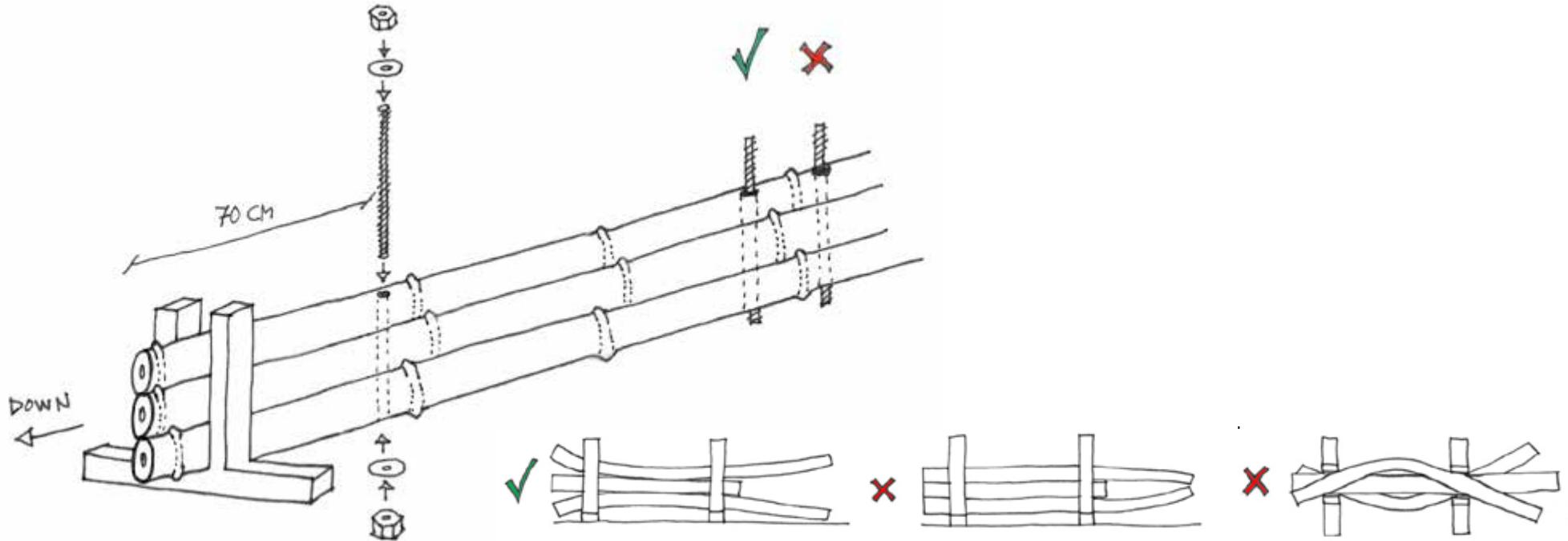
Continuing a pole for longer beams

1. Design the joints. The joints must always be on top of a support and the joints in all the poles can't be at the same spot.
2. Measure and cut the pieces you need. Remember there should be nodes in the ends.
3. Put the pieces of one pole into the racks and place the ends together.
4. Cut pieces of smaller bamboo. The piece that comes inside the joint should reach through 2 nodes in the pole bamboos.

The smaller bamboo should have nodes in its ends as well.

5. Carve out the node walls that the smaller bamboos penetrate with a chisel.
6. Put the smaller piece inside the poles.
7. Drill holes through the pole and the smaller bamboo and put a bamboo peg through. Cut the ends of the peg.
8. Make a beam normally. Diagonal pins should be placed on both sides of each joint.

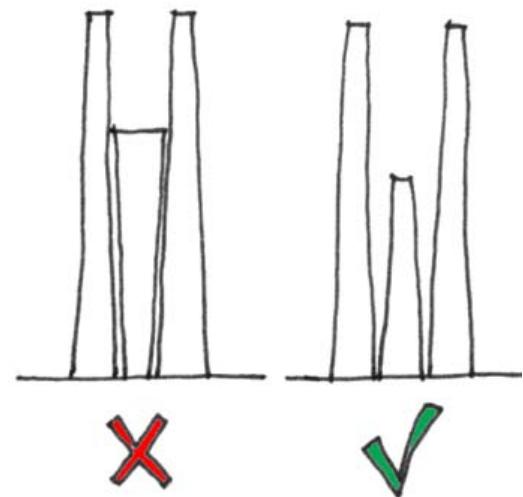


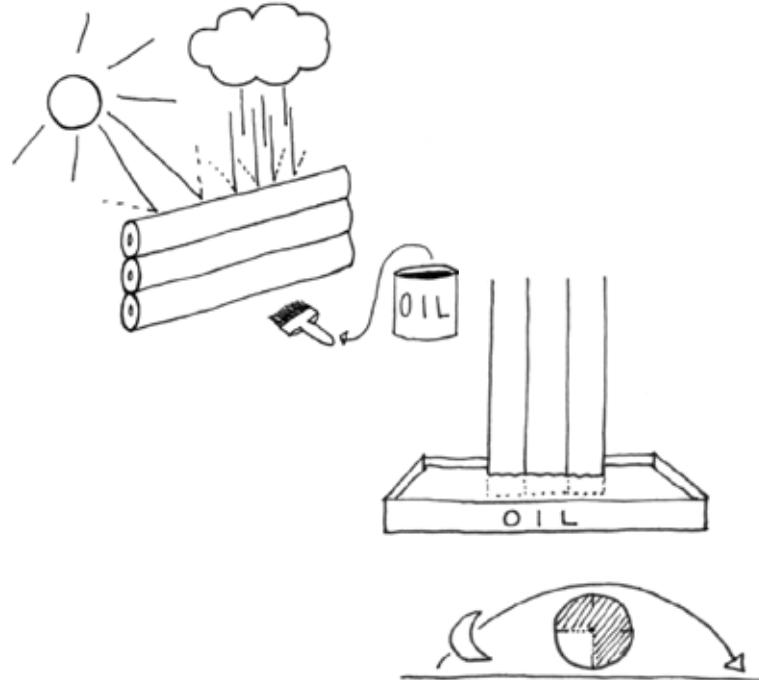
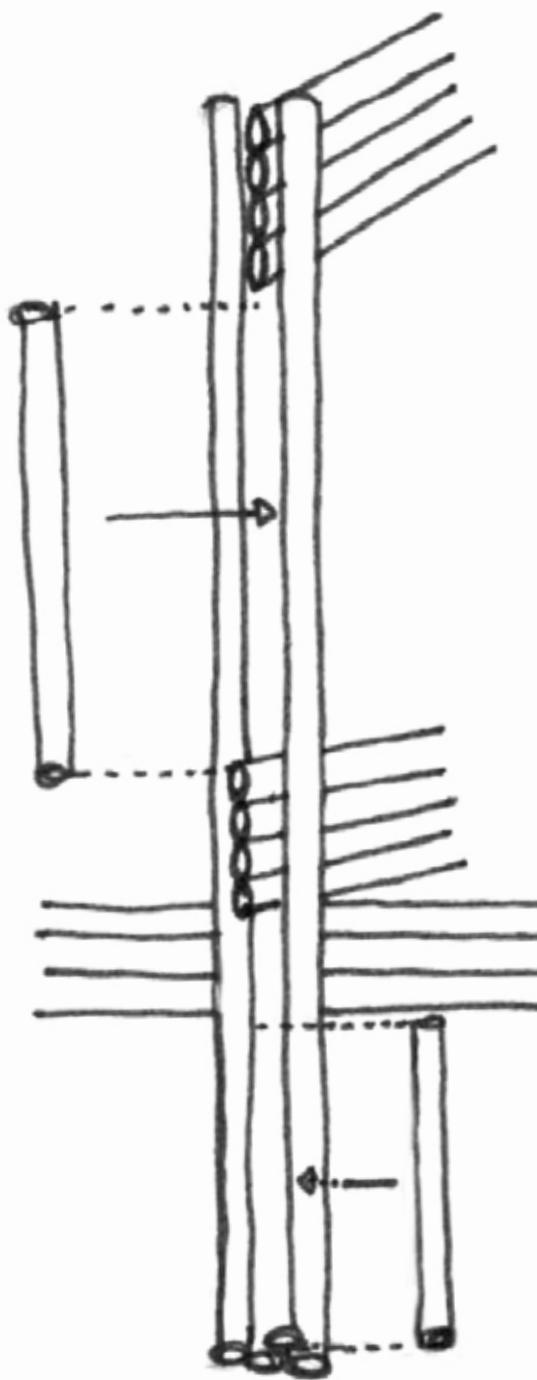


Making columns

1. Set the poles into the rack so that the thick end of all the poles face the same direction.
2. Check that the poles are exactly on top of one another and that curvature happens in the plane of the column and not out of it. It's better for them to curve outwards than inwards (to make installing the beams easier).

3. Use ratchet straps or rope to press the poles together. Hold them together while you strap to avoid them from moving.
4. Drill holes for the pins. All pins are perpendicular to the poles. The pins should be just below nodes to avoid cracking. Attach the pins to metal parts connecting the columns to the foundation (i.e., height 70cm)
5. Put in the pins (threaded steel rod), cut them and add washers and bolts.





...Connecting beams and columns

6. When columns and floor or roof beams have been installed, a central pole should be measured in place and added to support the upper part of the column.
7. When the columns and the upper floor beams have been installed, a fourth pole should be measured in place and added behind the central pole to support the side beam.



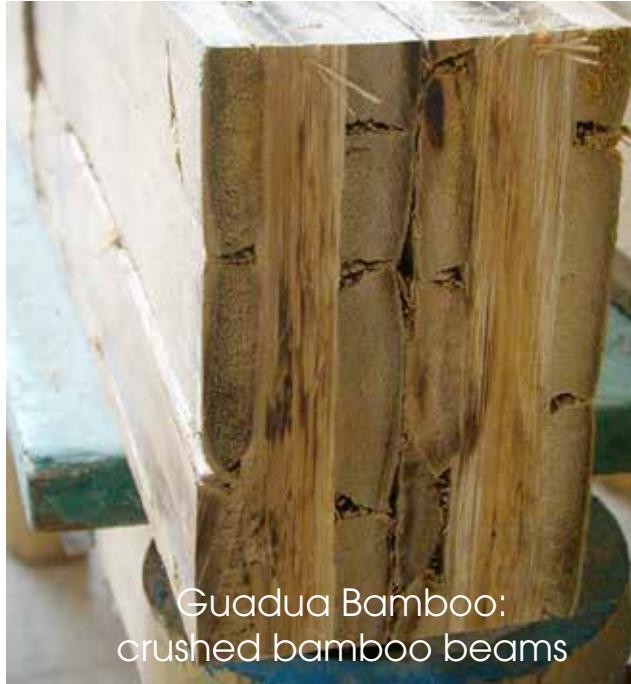
Element Treatment

The bamboos must be treated with a UV-protective wood oil (i.e.. Linseed oil) to protect them against water and sun. It is best to do it to the ready-made elements to avoid oiling parts you will not use.

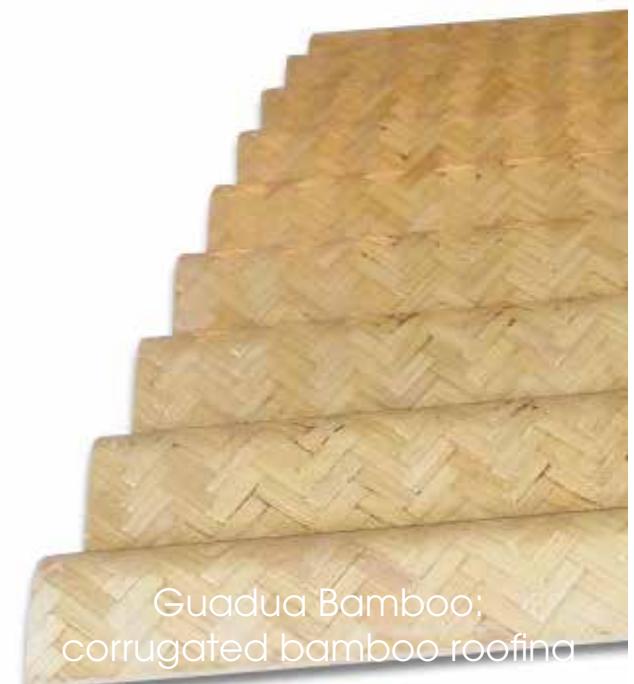
1. Treat all visible parts of the entire elements carefully by using a brush. Sponges and brushes can combust so keep them in a well ventilated space.
2. Treat the ends of the elements by soaking them in a small pool of oil overnight to seal them from moisture.



Guadua Bamboo:
crushed bamboo flooring



Guadua Bamboo:
crushed bamboo beams



Guadua Bamboo:
corrugated bamboo roofing

Other uses of bamboo

Bamboo plays an important role in local economies and is growing in national and international commercial importance in the Asia-Pacific region. Worldwide, more than 2.5 billion people trade in or use bamboo.

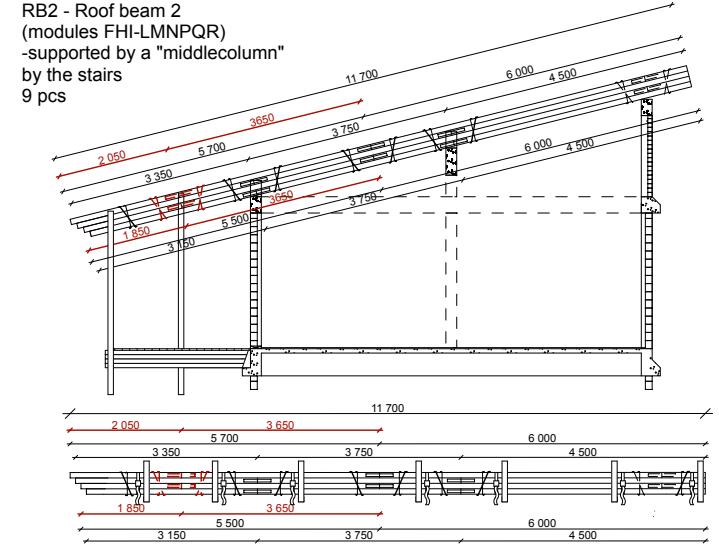
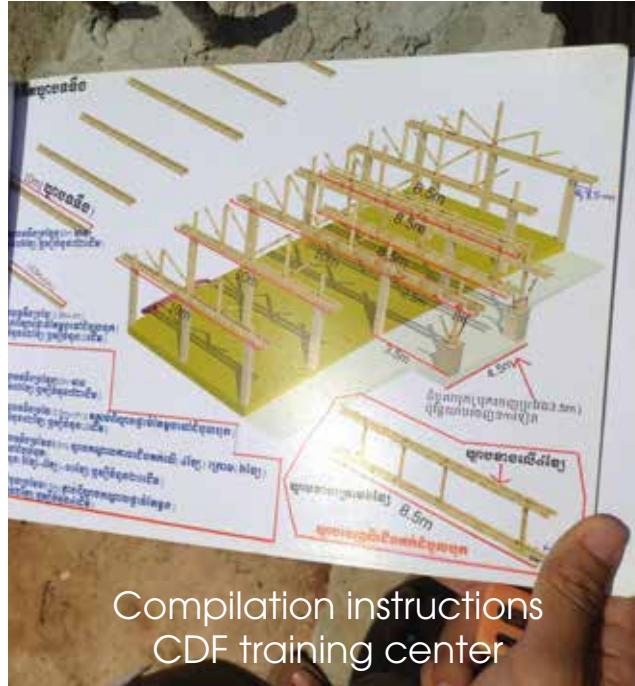
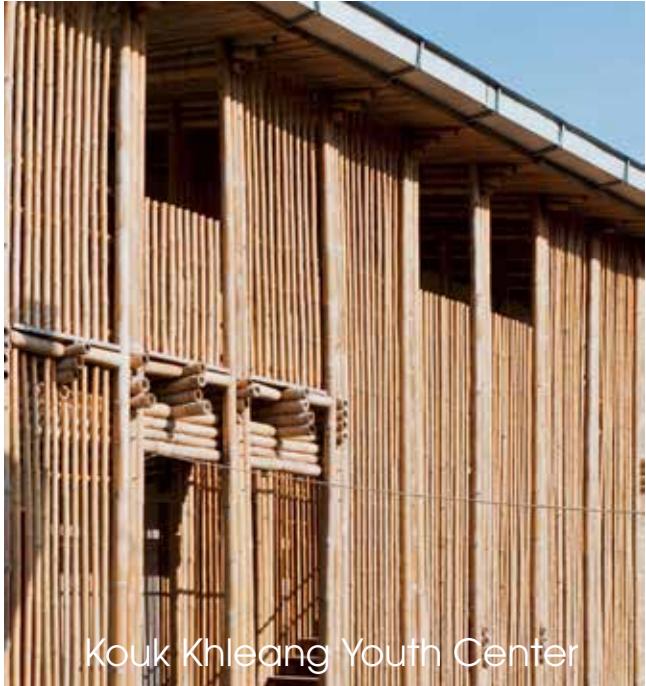
Bamboos are multi-purpose crops, with more than 1500 documented uses. The most important traditional uses include housing, food and material for handicrafts.

Modern manufacturing techniques allow the use of bamboo in timber-based industries, to provide bamboo flooring, board products, laminates and furniture.

Developing composites would allow the use of bamboo in a more controlled way and thus make it more compatible against more developed building materials. Compressed bamboo roof sheets set an attractive option for metal sheet roofs.

Bamboo is also becoming a substitute for wood in pulp and paper manufacturing; about 25 per cent of the fibre used in the Indian paper industry each year comes from bamboo (FAO 1998).

Bamboo shoots are an important food crop on the international market as well as locally and nationally. Bamboo furniture is an expanding business in many countries. Worldwide domestic trade and subsistence use of bamboo are estimated to be worth US\$ 4.5 billion per year.



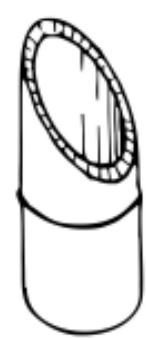
Compilation instructions
Kouk Khleang Youth Center

Designing with bamboos

Bamboo joints need to be designed with great detail due to the hollow core of the bamboo poles. Bamboo has linear fibres, so when a nail is hammered into a bamboo culm, it invariably causes splitting.

To avoid splitting, pre-drilled holes should be used at the required points. One can then use a variety of mechanical joineries such as rivets, nut-bolt, screws. For non kinetic joints, bamboo dowels can be used in place of nails. Most preferably, tied joints cause the least amount of splitting.

MAIN TYPES OF BAMBOO JOINTS



Beveled joint



Scarf joint



Fish mount joint



One flange joint



Two flange joint

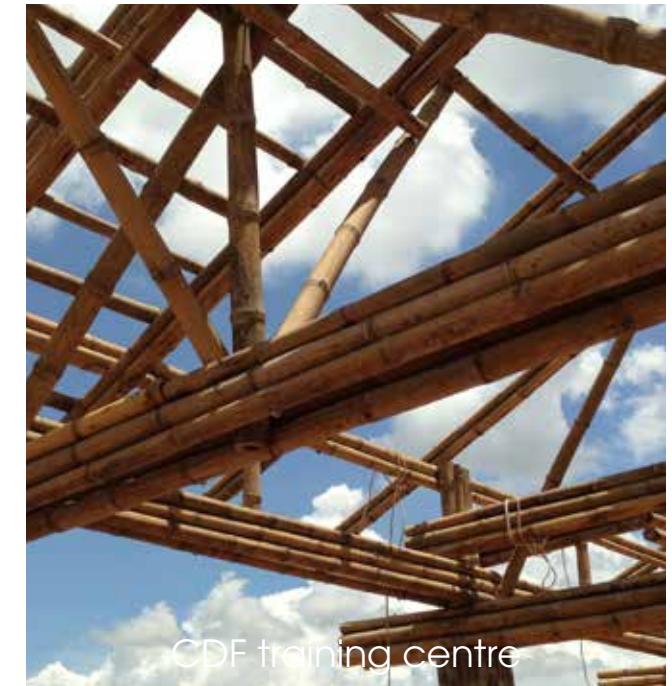
Bamboo in Sustainable Contemporary Design:
Bamboo joints. Rebecca Reubens, INBAR



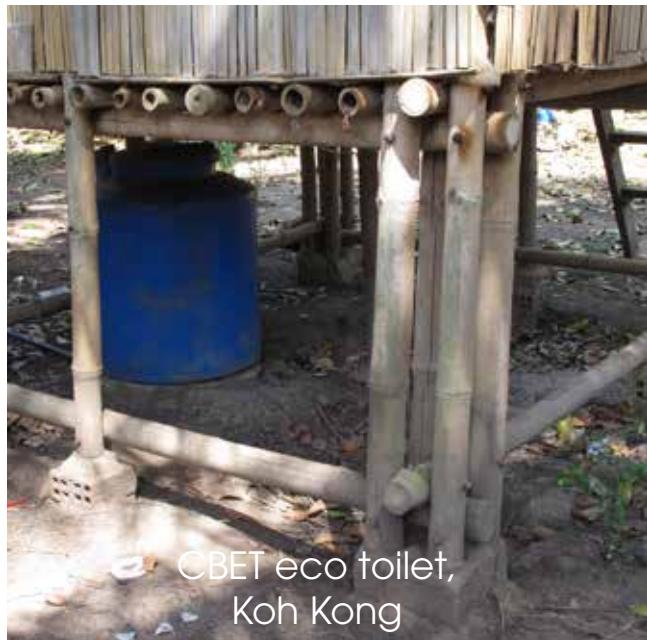
CBET eco toilet,
Koh Kong



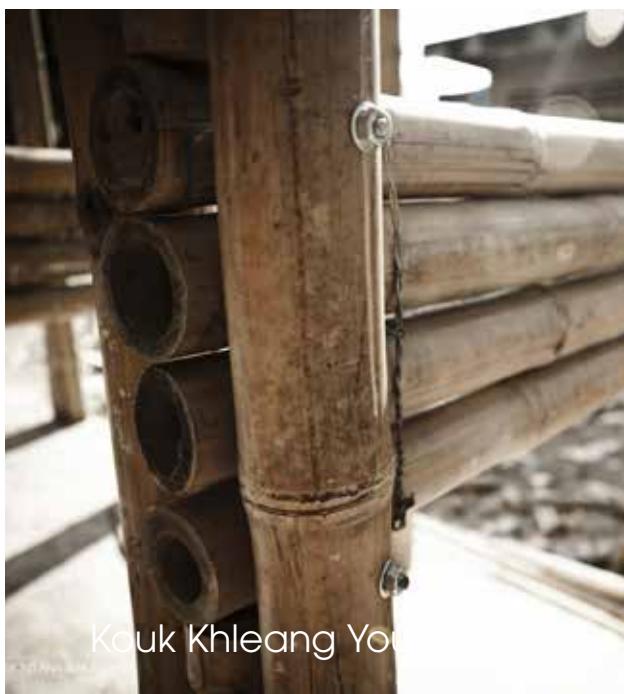
CBET visitor centre,
Koh Kong



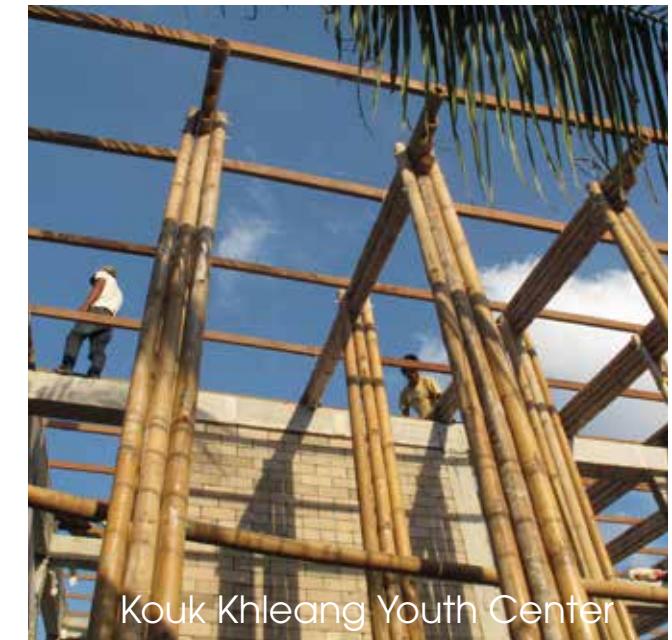
CDF training centre



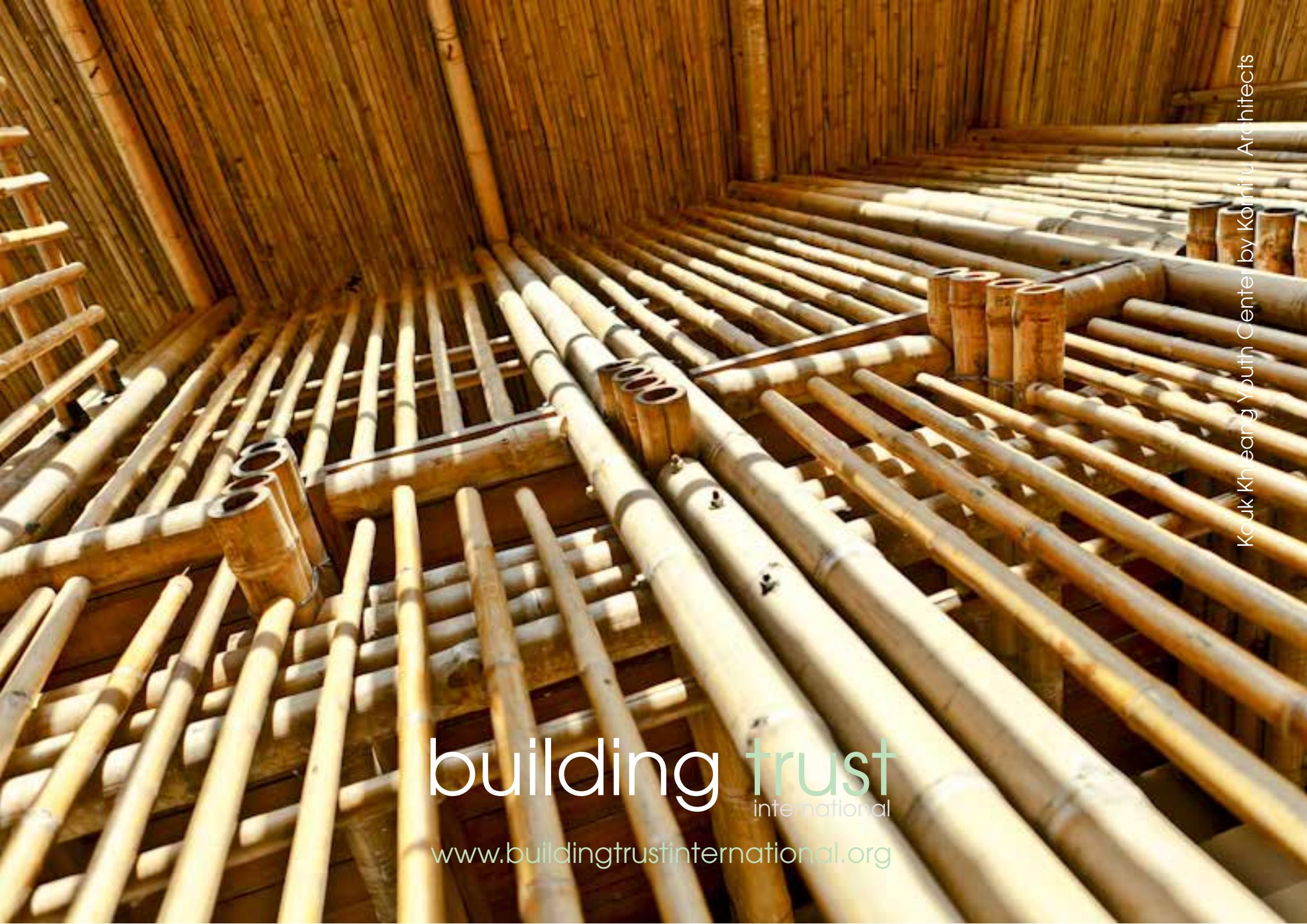
CBET eco toilet,
Koh Kong



Kouk Khleang You



Kouk Khleang Youth Center

A photograph showing the interior of a building constructed from bamboo. The floor and walls are made of a dense grid of bamboo poles. The bamboo is a mix of light yellow and brown colors, with some poles having their ends cut into a cylindrical shape. The lighting is warm, creating strong shadows and highlights that emphasize the texture of the bamboo.

Kouk Khleang Youth Center by KohnIlu Architects

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