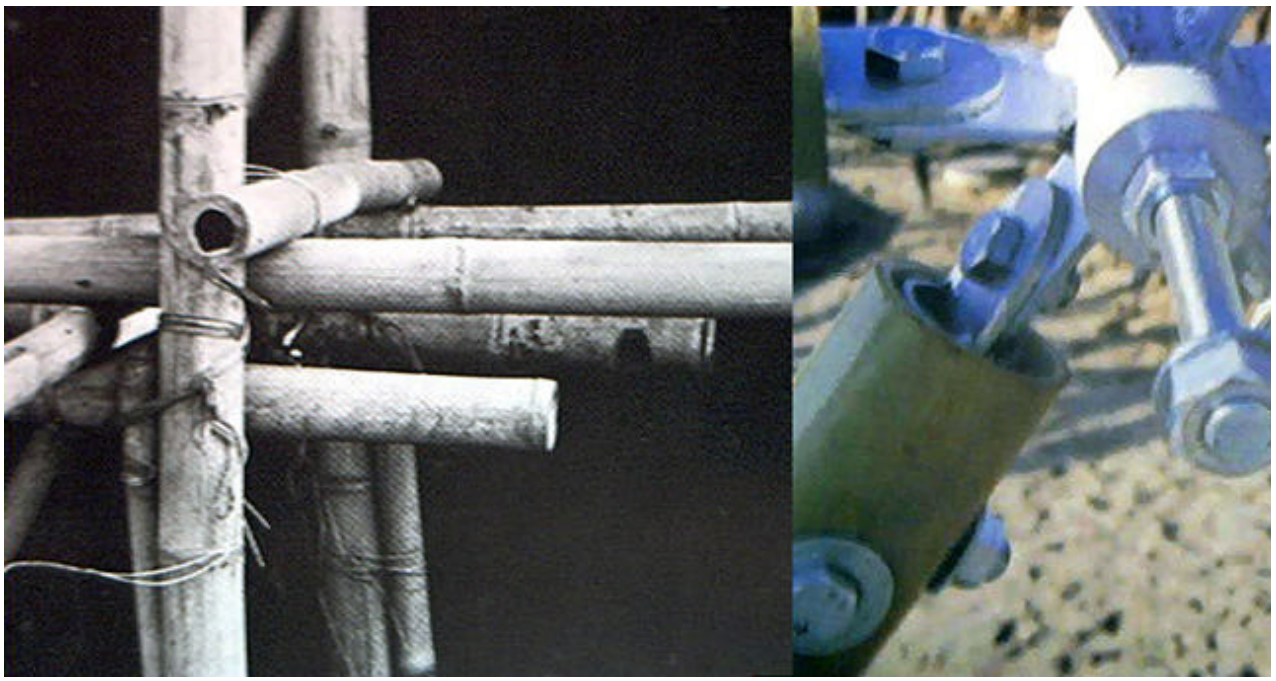
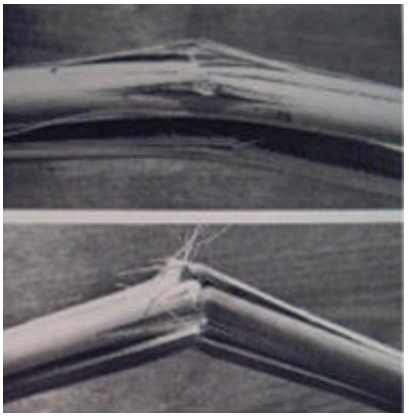
# Bamboo Connections



## Introduction

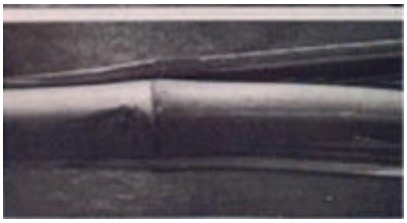
### Aspects of bamboo connections



#### The characteristics of bamboo induce parameters for processing

Bamboo itself has a lot of advantages using it for building houses, bridges... . It is a cheap, fast growing material with excellent statistics according to the mechanical properties. The connections are the difficult structures in bamboo constructions. Here are a few reasons:

- Bamboo has got a *round profile.* Creating connections with round profiles are leading to difficult geometric structures at the knot.

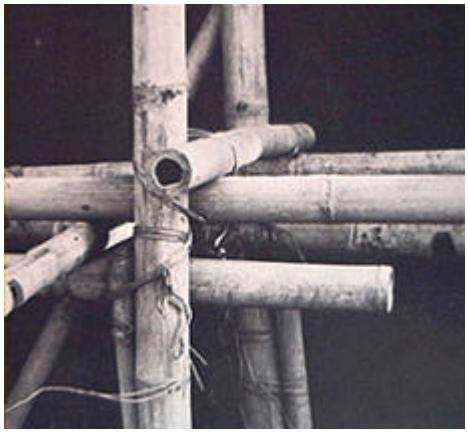


bending and impact fractures

- Bamboo *fibres* only grow in the *longitudinal* direction.
- Bamboo is *hollow.* There is no material to tighten the bamboo in the middle of the cane.
- The face of the cane is very *slippery and hard.*
- Bamboo is not suitable for loads in cross direction, because there are *no cross fibres.*
- Bamboo is a natural material, that *varies in diametres, lenght and quality* according to the climate.

nail splitting the bamboo

This report tries to show, how these problems are solved in several examples of different kind of connections.



Traditional least-tech connection

## Least-Tech versus High-Tech

There seem to be two parties in modern bamboo architecture:

- those who use bamboo as an alternative material connected with industrial standard elements like steel plates, nuts and bolts
- and those who try to find a modern least-tech connection which can be produced very cheap and assembled by unskilled workers.

A modern steel connection by Shoei Yoh

Different aims followed by the use of bamboo lead to different connection layouts. We chose the way that power transition is done as a criterion to seperate them from each other.

Note: This paper is especially about connecting full bamboo canes. If you use splitted bamboo, there are of course far more possibilities.

## Overview

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## types of connections

### friction-tight rope connections

connection with bamboo strips

Friction-tight rope connections are the common connecting method. Traditionally natural materials are used:

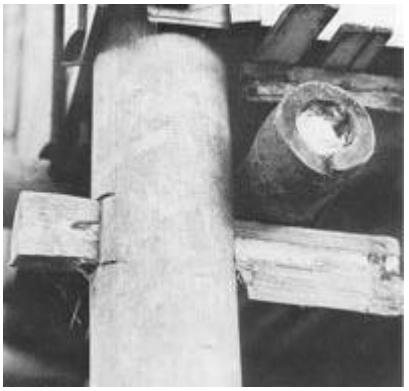
- cocos/sago palm fibre
- bast
- strips of bamboo
- rattan

For tight connections green bamboo strips are used, the fibres are watered before tying around the bamboo. While drying, the fibres shorten and the connection becomes stronger.

Nowadays also industrial materials are used:

- iron wire (zinc coated)
- plastic tapes/ ropes

## plugin/bolt connections

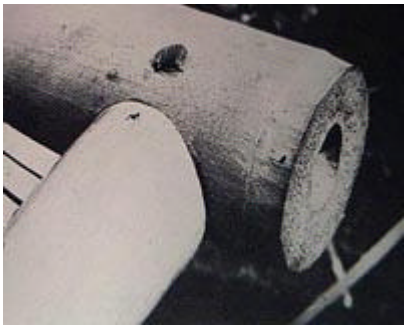


bracket interlocking stud

**Plugin/Bolt connections:** Constructions with secondary interlocking elements are often used in context with rope connections. In this case the bolts have to transfer tractive and compressive forces. In wooden connections this is done by different kinds of profiles.

The **metallnail** is a perforating element. If the bamboo is not fresh at all, the bamboo is often splitted by the wedge shaped nail. There are two exceptional cases: The Guadua angustifolia and Chusquea bamboo from central and southern Amerika.

## positive fitting connections



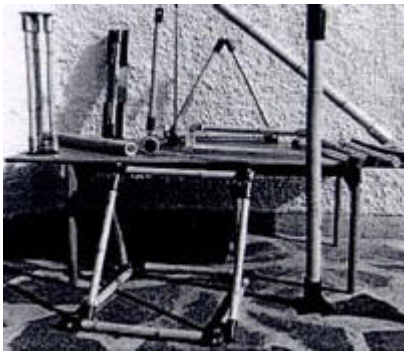
positive fitting connection

Wooden connections with slit and tenons, like they are traditionaly used for carpenter-like constructions in Germany, are rare. There are three reasons:

- bamboo is round
- bamboo is hollow
- bamboo splits

But although there are these problems, positve fitting connections are used in traditional bamboo buildings. Different kinds of holes are cutted into the bamboo and make it possible to connect the round bamboo rods.

## interlocking connections

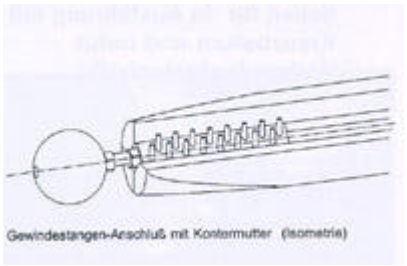


construction elements in bamboo

**Constructions elements** made of bamboo are suitable for lots of uses. Bamboo has different diameters and is thicker near the knots. Within bolting together or wedging the bamboo, lots of its tightness won't be transfered by the construction element. **Bambu - Tec** solves this problem. Prefabricated bamboosticks with certain length are covered with a cap and connected with synthetic resin. For a tight connection of the cap and the bamboo are covered with circular grooves. Because of that the grounting mass runs between the materials and confirms this construction.


**Pan-knots** for spatially frame-works

**Pan - Spatially frame-works.** This frame-work works on bamboo with diameters small than 80mm. These threaded bolts can transfer about 50% of the tractive force. For compressive forces is a front plat necessary. For overhead construction this system has to be examined by an official institut.




Induo-compound tie

**Induo - System.** This system makes it possible to transfer about 100% of the maximum rated load of large bamboo diameters.

Transportanker - cable tie mount

Other industrial products:

**cable tie mount with concrete reinforcement steel**

**reinforcement-screw connection with concrete steel**

## combined connections

double post

**Double post**, here with bounded knot and continuous handle. Within this construction the tube wall is not weakened bei drillings.
The advantage of this system is, encumbrances of the roof and the floor are absorbed by different posts. Because of this, you can easier do repairs of defective posts.

ZERI Pavillon EXPO 2ooo

At the Zeri-pavillion at the EXPO 2000 were used combined connections:

**Threaded bolt tightend with mortar** - typ A

**Steal mounting link with mortared bolt** - typ B

## Friction-Tight Rope Connections

Connection with bamboo strips

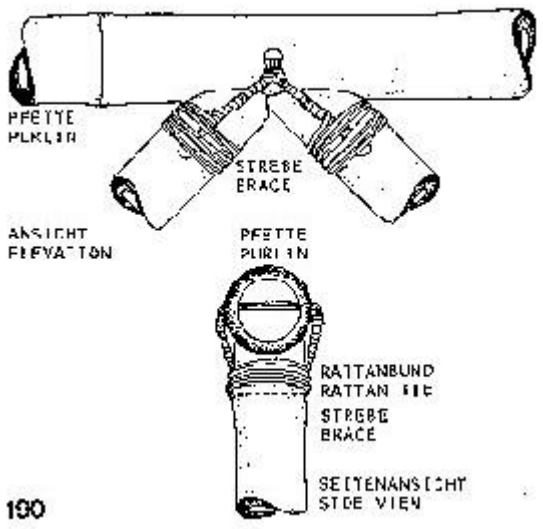
**Lashing ties:** The common type of connection at a joint is lashing. The ties are also of organic material and therefore provide optimal compatibility between the elements of the construction system.

**Cords and ropes** are made of bamboo bark, bast, coconut- or sagopalmfibres. Nowadays also plastic cords are used.
Bamboo ropes of twisted bamboo fibres are produced in lengths up to 350m. They are more wear-resistant than standard ropes. With a tensile strength of 720 kp/cm³ a rope of an arm´s thickness can bear up to 14 tons.

**Binding wire** is (as plastic cords are) an industrial product.
Zinc coated wire has the same lifetime as bamboo.

**Plait strips:** Usual plait materials are rind strips of bamboo, rattan or lianas. Soaked before use they are more pliable. When drying, the fibres shrink and the connection tightens.

Fine handwork rattan connection

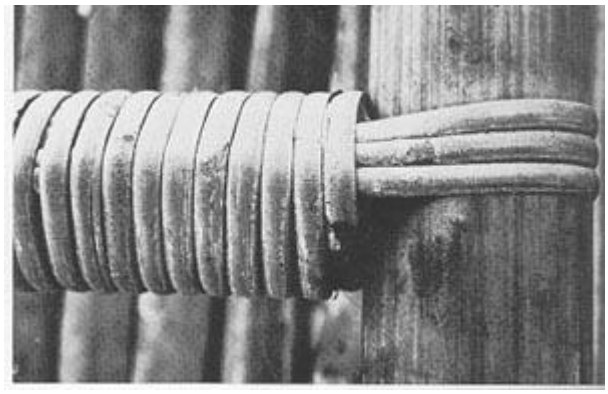



**Lashing ties** - connection of a purlin and two braces with three drill-holes.

Purlin and braces connection

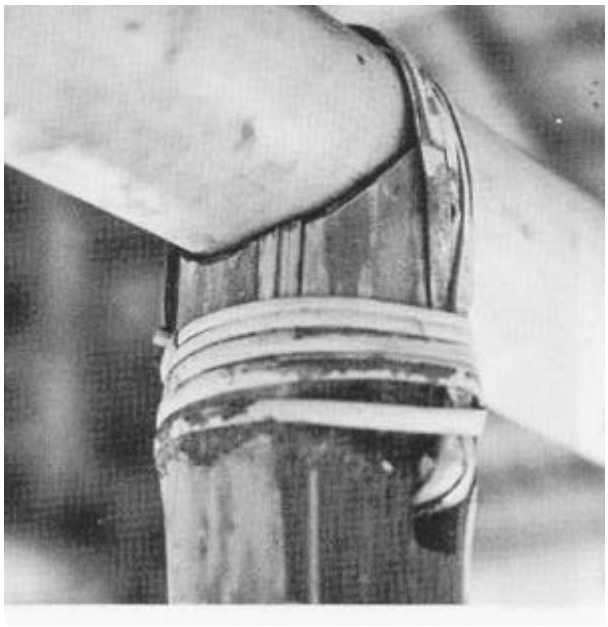
Rattan tie to fix a plug connection

Rattan connection through drill-holes



Another rattan connection

**Friction-tied rattan connection.** The end of the beam and the tie do the power transmission. If the connection is not tight enough, the beam may crack at the drill-hole. The additional bandage prevents the sling from slipping. If connected at a post nodium, the broader nodium in addition complicates slipping of the beam.

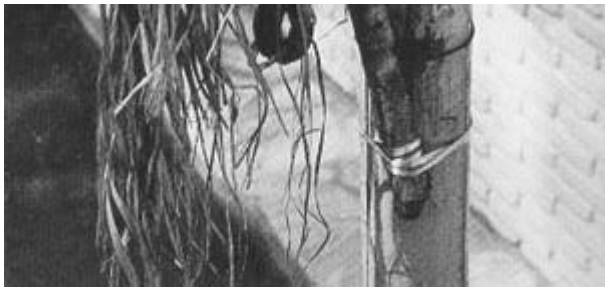


Variation of the connection above

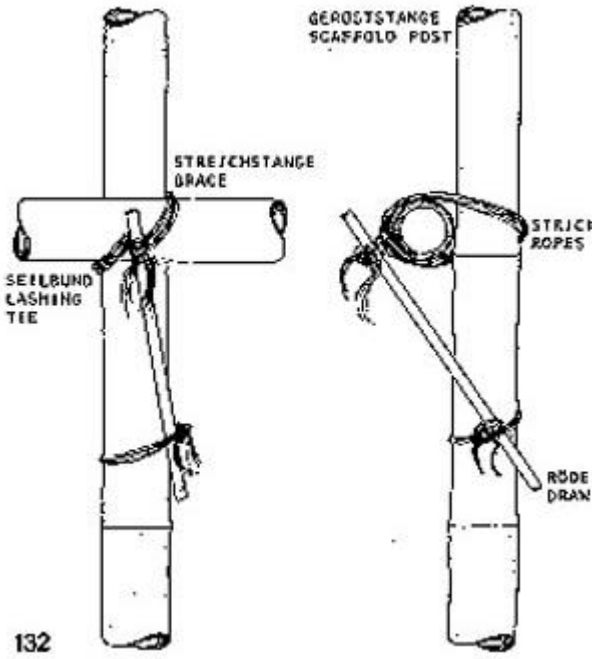
**Top of the post with drill-hole.** If post and cross-beam are of the same diameter, the lashing tie replaces a stop at the side. A croossing bandage shortens the sling and prevents the post from sliding.

## Traditional scaffolding

**Bamboo canes connection with lashing ties and a draw stick -** with the help of the draw stick the lashing tie is tightened. Then the stick is fixed to the post.



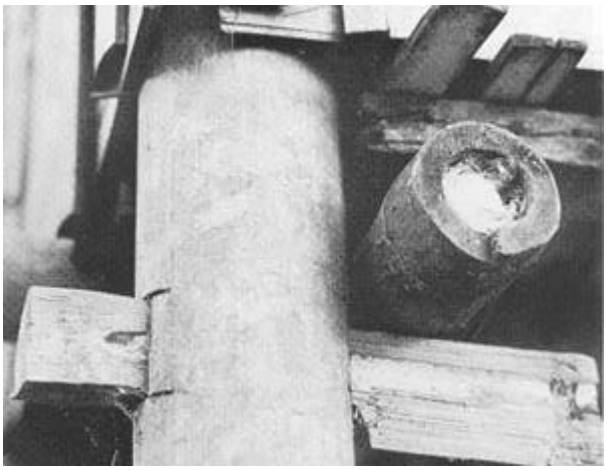
Lashing tie with drawing stick




Lashing tie with draw stick

**Scaffold braces** - are bamboo canes which often are only fixed with the lashing ties.

## Plugin Connections and Bolt Structures



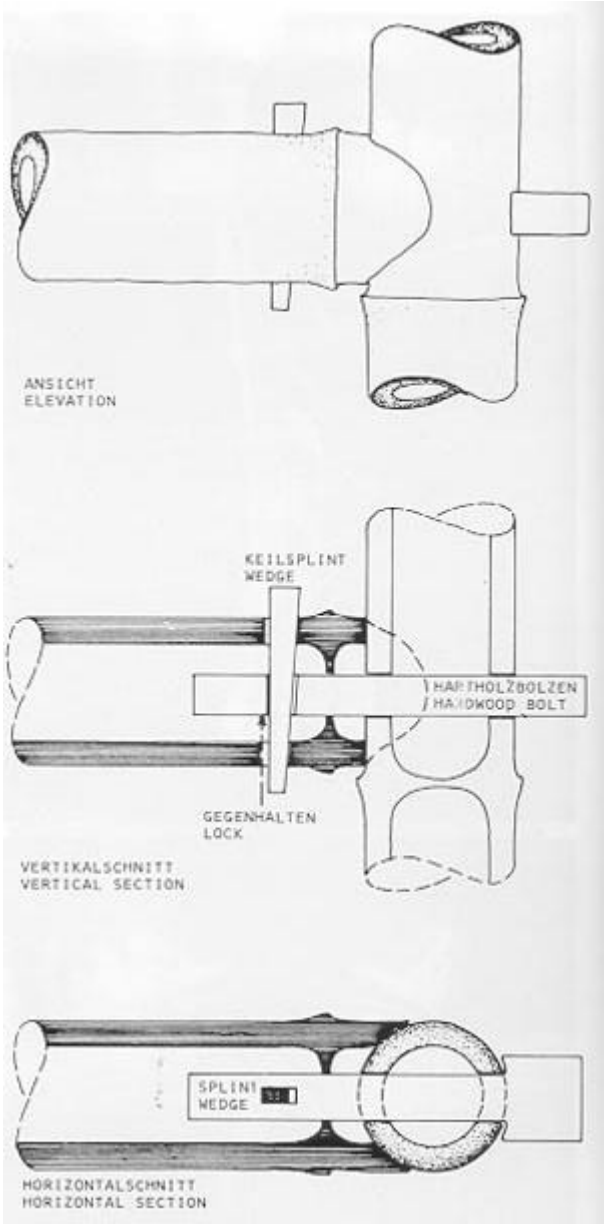
**Plugin connections:** Carpenterlike connections with mortise and tenon are seldom used in bamboo structures. On the other hand plugin elements like bolts or consoles you find very often. Additional lashing or wedging keeps things in place.

A disadvantage of these connections is that you don´t use the whole diameter for power transmission. Also you must pay attention that the holes are not too close to the end of the canes. Otherwise the plug may break out.

The use of **nails** may split the bamboo

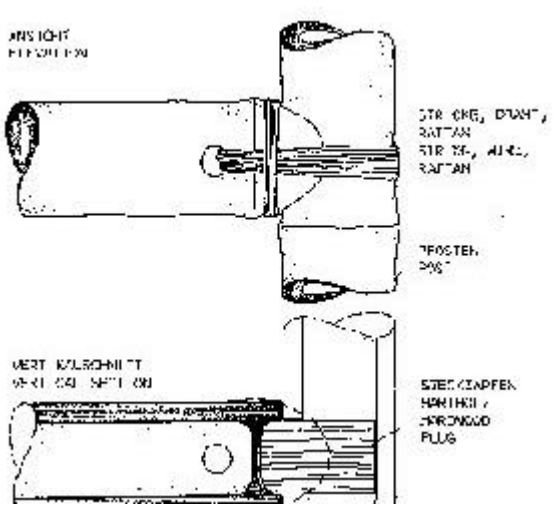
Plugin console

particular old and dry canes. Pre-drilling is a method to prevent splitting. There are two bamboo species which can be nailed: Guadua angustifolia and Chusquea.

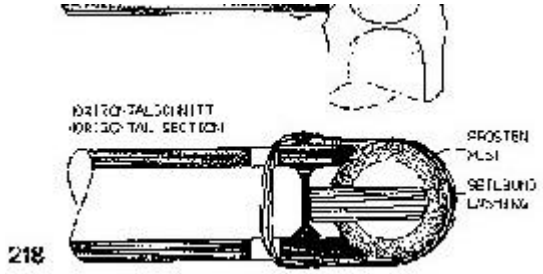



Bolt structure

**Plugin connection:** This is a type of connection for greater diameters with a hardwood bolt and wedge. Five holes, the bolt and the wegde - a more extravagant connection. If the bolt is conical, the connection is save in all directions.



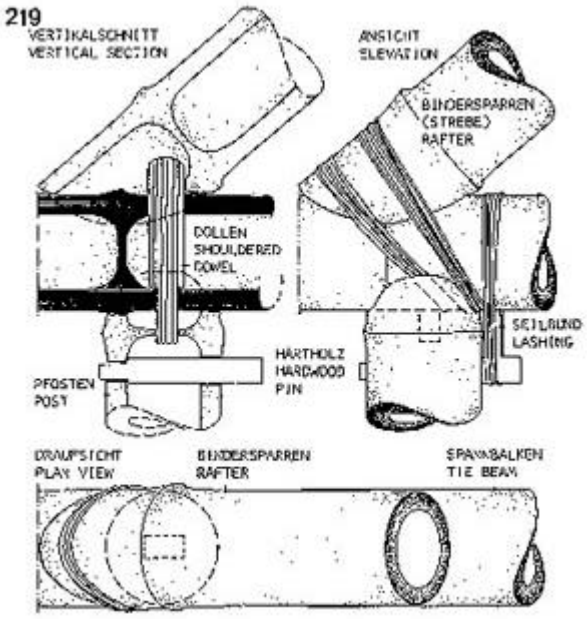
**Connection with inner plug** and a horizontal drill-hole to fix the connection with a lashing tie. If the lashing is tight and the plug fits quite good into the opening, both plug and lashing can do the power transition. But even if not, this connecting method can be very durable at less force. The inner plug prevents the beam from slipping down the post and the lashing is against unplugging.




Connection with inner plug

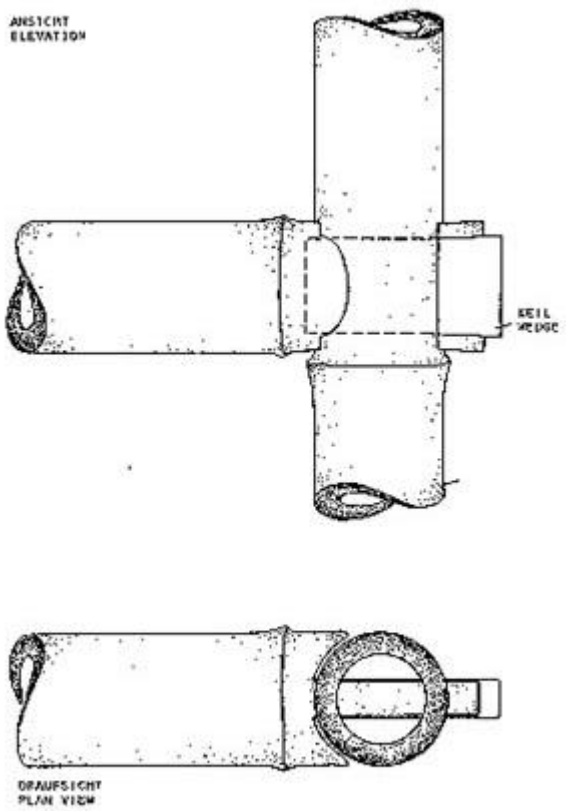
Rope connection fixed with bolt

**Rope connection fixed with bolt.** The bolt keeps the conncetion in place even if the rope or cord lenghtens .



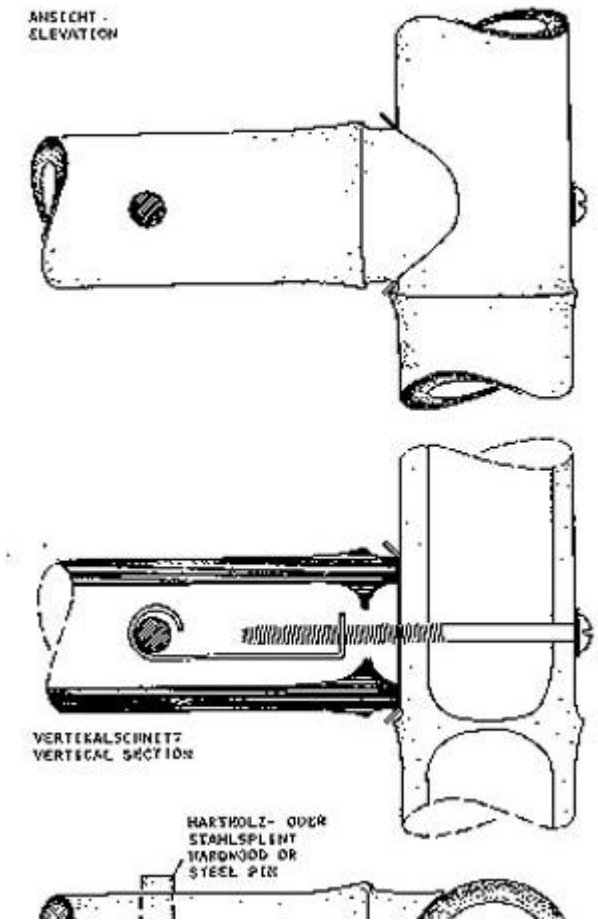

Complicate joint

**Joint with two connections.** Again a combination of bolts and lashing to connect the canes.

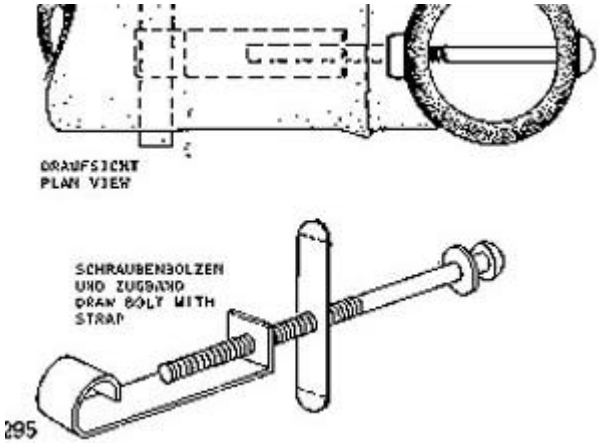



Interlocking connection with wedge

**Interlocking connection with a wedge.**
With the wedge driven into the opening, the strips of the horizontal beam are pressed into the hole and fix the beam. If the wegde shrinks, the beam can be easily pulled out of the opening. So additional arrangements like lashing or bolts are necessary for a save connection.




**Connection with a steel tension clamp.**
Leaving the low-tech sector, with the use of steel elements a lot more connections become possible. Avoid connections which produce great forces vertical to the cane axis. They can destroy the bamboo cane.




Connection with steel clamp

Connection with steel tube and bolts

**Modern connection by Shoei Yoh in 1989.** For his bamboo roofs in Fukuoka, Shoei Yoh used a steel tube put into the bamboo and which is connected to the cane with bolts. The steel tube is strong enough to withstand the pressure of the tightened bolts. In addition there are two bolts in vertikal direction. For the connection to the knot a steel bar is welded into the tube and again it is screwed to the knot. Because of the numerous bolts the connection is also suitable for greater loads. The result is a very technical but strangely overstyled looking connection.

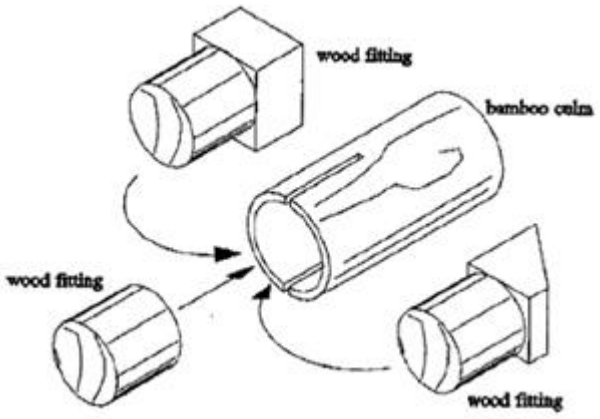
Connection with steel wire

**Modern connection by Renzo Piano Building Workshop in 1997.** The canes are connected to a special designed steel element via binding wire. Instead of a bolt driven through bar and cane, a wire is tied through the holes and tied around the bamboo. A fine artwork but because of the fine wire seemingly only for small forces.

## Interlocking Connections

**Interlocking Connections** are achieved by glueing or sheding connection elements in or around the bamboo.

## Woodcore Connection

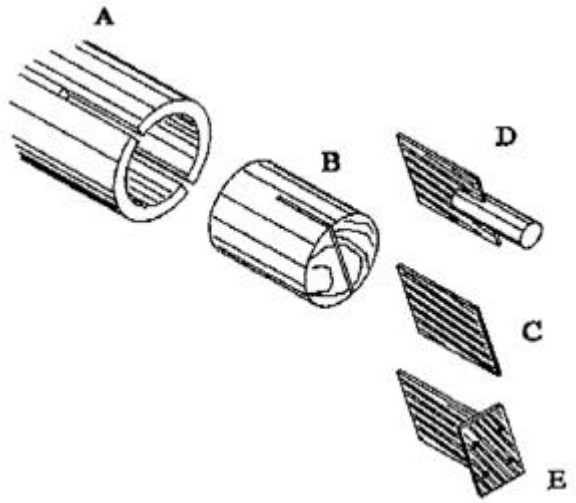



possible inner parts

**Woodcore connection.** A piece of wood can be used and glue can be employed to stick it to the inner surface of the bamboo. Any normal glue provides a capaity far larger than that of bamboo in the tangential direction.

Two slots are needed in the bamboo cane to control cracking during the insertion of the wood cylinder.

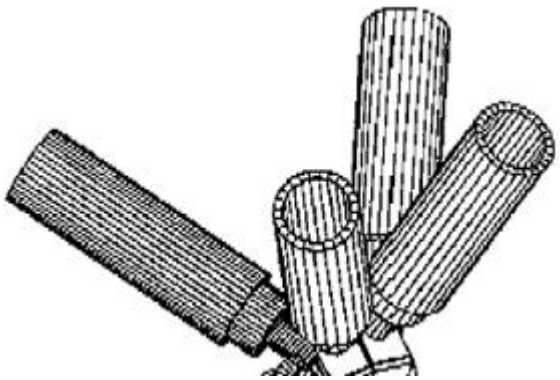
The wood fitting can be extended outside the culm to meet the outcoming piece of wood from other elements, then normal wood construction methods can be used for connection.




connecting system

**Woodcore connection.** The steel plate C is introduced in the slot of the wood cylinder and glued to it with a mixture of epoxy resin and portland cement. The plate is projected, so that its outer extreme can be adapted for different applications, as indicated in the details D and E.

**Systemadvantages** are its low price and the availibilty of the parts.



**In plane or space trusses**, the plates from two or more incoming elemets can be pre-welded to eachother and then the rest of the connection can be assembled.

The figure shows a connection in which a small box is made of steel plates, so that the faces are prependicular to the axis of the incoming elements. The steel tips are then welded directly to those surfaces. Welding is thought of here because it is cheaper than machining of the tips, but in some cases tis can be achieved

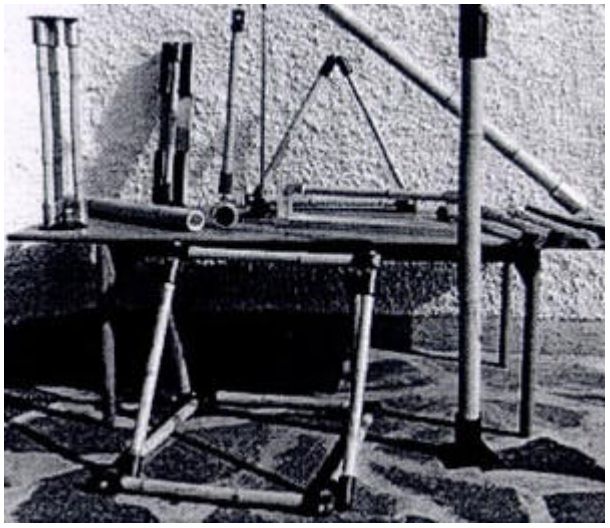
space truss, with centre steelbox element

as well.

**Information:** Fundamentals of the Design of Bamboo Structures [pdf]

by Oscar Antonio Arce-Villalonos (Costa Rica/ at TUEindhoven)

## Bambu-Tec Constructionelements



constructionelements made of Bamboo

**Constructionelements** made of Bamboo that can be used for various tasks. Bamboo often grows slightly bend, the diameter of the bamboo cane varies and it is a little oval. At the knots it is a little thicker. If you try to skrew or wedge the bamboo its high strength won´t be transfered. **Bambu - Tec** constructionelements eleminate these weak points. - The bamboo canes are cut into the desired, unique length (e.g.0.5m,1m,2m). Both ends are covered with caps that are connected with artificial resin or another fillingmass. To give the connection cap/bamboo a high tensile strength the bambooends are given circular grooves and the inner cap is covered with circular notches, so the connecting mass acts like a claw between bamboo and cap.

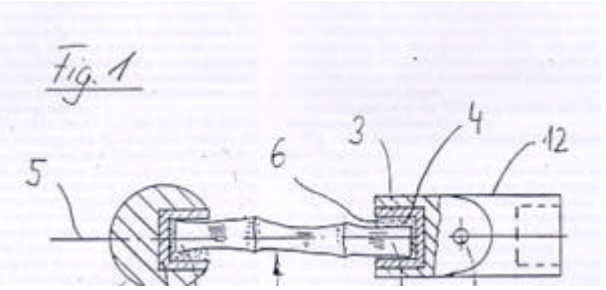

the inventor Bruno Huber

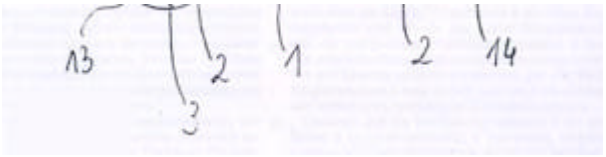
**The capfastening** is done with a gauge, so the caps are aligned exactly parrallel and in a reproducable distance. The caps can be made of synthetic, aluminium or steel. It is even possible to produce them, by using the synthetic spray technique, directly on the bamboo. There can be bores, threads or flanges fixed to the caps. If you use steel or aluminiumcaps they can even be welded to other metalparts.

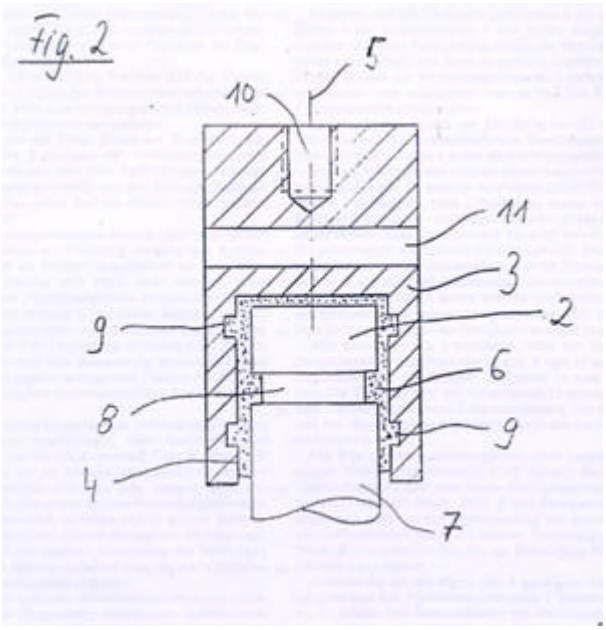
**used for: . . .** scaffolding, tentconstructions, house building, roof and half-timbered constructions**,...**

**Information:** Bruno Huber - Ordenslandstr.39 - 82140 Olchingen, Germany

**drawings from the patent.**



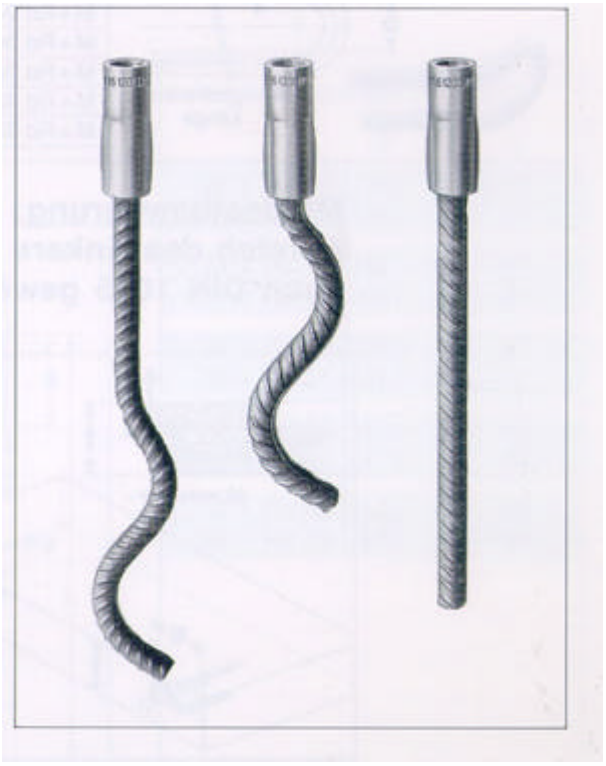



**legend:**
**1** single strunt
**2** free end
**3** connectionelement
**4** bore
**5** struntaxis
**6** adhesive
**8** notches
**9** notches
**10** threadbore
**11** crossbore
**12** jointelement
**13** sphere
**14** rotationaxis

**The following bamboo connections are not yet tested**, but seem to be possible. They all deal with sheded armature, so the strenght of the connection depends mostly on the connection between bamboo and fillingmass. Most of the introduced products are german, it will be to the constructor to find similar or better local products.

## Transportation armature/ Skrewconnections



transporation armature

**Transportation armature with pressed concrete.** The sytemstrength depends on the concrete/bamboo connection, on the concretes (or fillingmass) compressive strength, on the thread diameter, the production series (long or short shaft, straight model) aswell as on the tractive direction (axial, slantwise , athwart) and the jointdesign.

**Systemadvantages** are its price and its deliverability from stock. The installation can start immediately without long prefabrication of the dowels.

**Information:** Firma Friedrich Schroeder GmbH & Co.KG

armatureconnections

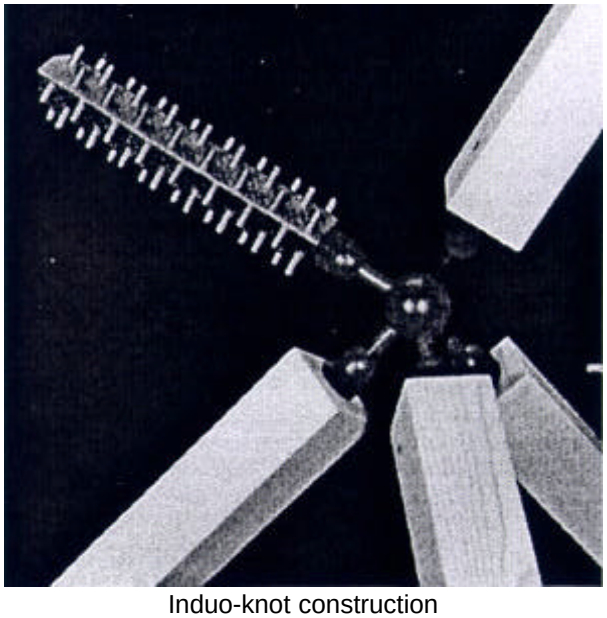
**Reinforcement Continuity Screw Connection System.** The optimal sollution for all static component connections. Static, constructive and economically. The sleevestick (with sleeve and connectionflange) - and the connectionstick (with furled metric thread) are sheded with the bamboo and therefore reach an interlocking connection. The connection is carryed out via an adapter with right/left outerthread for the doublesided sleeveconnection.

**Systemadvantages** are [like transportation armature] its price and its deliverability from stock. The installation can start immediately without long prefabrication of the dowels.

**Information:** Halfen GmbH & Co. KG


armatureconnection via adapter

## Induo-anchor technique

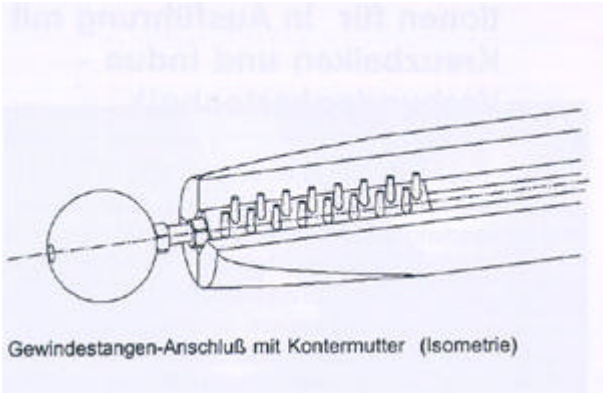


Induo-knot construction

**Induo-anchor.** For big bamboodiameters the Induo-anchor can transfer nearly 100% of the maximum load of the cane cross section.

**The Induo-anchor** consists of a cast iron core with connectionteeth on its sides. It can easily be sheded with a bamboo cane. Concrete or artificial resin can be used for that.

**Information:** In-Duo.de

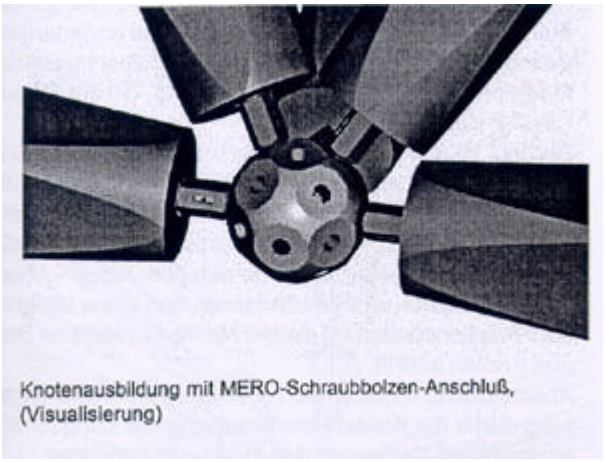



threadrod connection

**Advantage** of Induo is that any available knot-connection-system can be used with it (e.g. Mero, Pan).

A simple connection can be manufactured with a threaded bar and two counter nuts. Steelballs with threadbores are used as jointpoints.

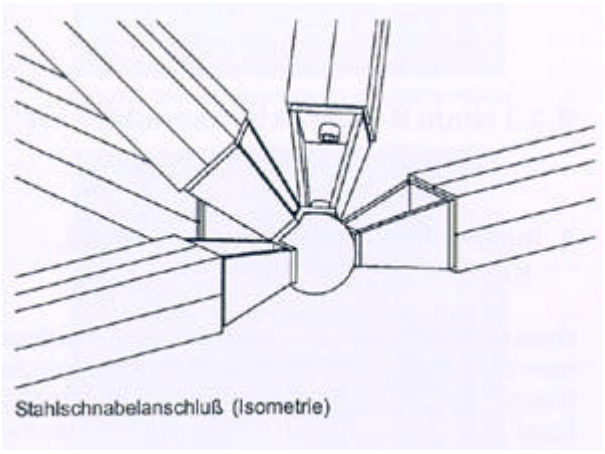
**Disadvantage** of Induo-anchor is its high price.




Mero - knotconstruction

If used with the Induo-anchor the cast iron core is drilled in the perpendicular axis with fitting diameter to connect the screwbolt.

**Information:** mero.com




steel-neb-connection

**Steel-neb-connection -** This connection method uses the Induo-anchor in its usual state with bores and threads. The base element of this connection is a conical steelconnecter which is centric screwed from the inside to the Induo-anchor bore on the one side and to the threadbore of the jointelement on the other.

## Pan-knot spacetruss


**Pan-spacetruss.** Small bamboo canes (diameter up to 80mm) can transfer ca.50% of the maximal tensile force if threaded bars are glued or sheded into the caneends. For compressive forces the maximum force is where the cane breaks if connected with a headplate. If overhead working is necessary tests by an officially recognized material-testing-institution and special permission of the building departement are required. (germany)

Pan-knot


range of products

**Pan-spacetruss** consist only of two elements - the Pan-ballknot and the cane with sheded threadrod. That means more economic statics, drawings and production. Furthermore they can be dismantled and reused.

**Information:** Panholz.de

## Combinations

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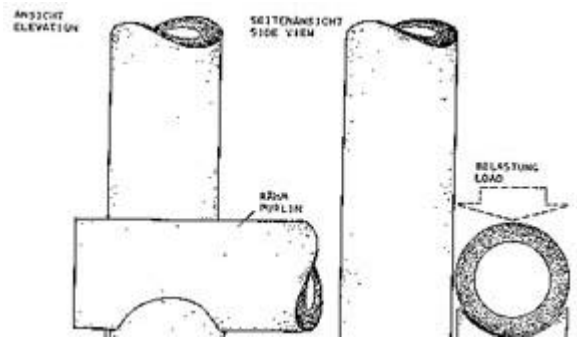
### Doublejamb connection

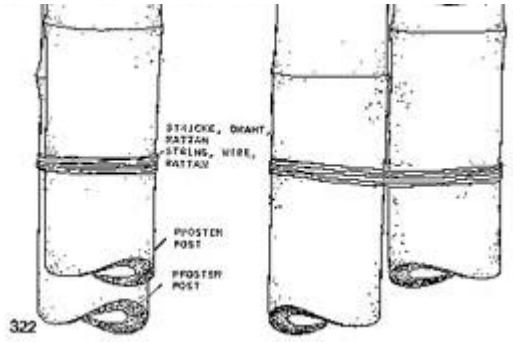
doublejamb as support



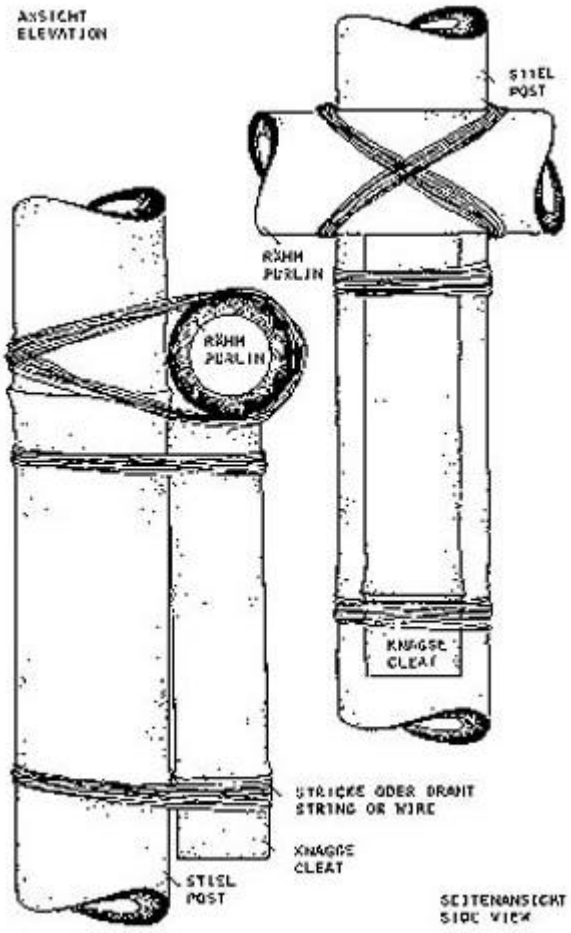

**Doublejambs,** tied knots, transitional cane, purlin with cleat. The second pole is replaced by a cleat. Advantage is that the wall of the cane is not weakened by bores. There is no reinforcement of the polebase.

**Doublejambs**: The roof and floor-loads are absorbed by different poles. Hereby damaged canes can be exchanged more easily. The rot endangered polezone is reinforced.

**doublejamb with support.**




doublejamb with support



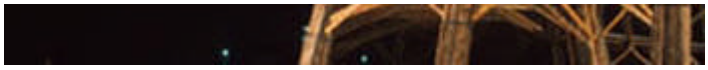

**Doublejamb with support.** tied knots, transitional cane, purlin with cleat. The second pole is replaced by a cleat.

## ZERI Pavilion EXPO 2ooo

A similar connection was used for the ZERI pavilion at EXPO 2ooo. To guaranteeing tensile strength, there are used two different types of connections:

**sheded threadrods** - Type A

For this connection the bamboo needs to be drilled. The threadrods are sticked into the holes. In these internodias, where the threadrods are

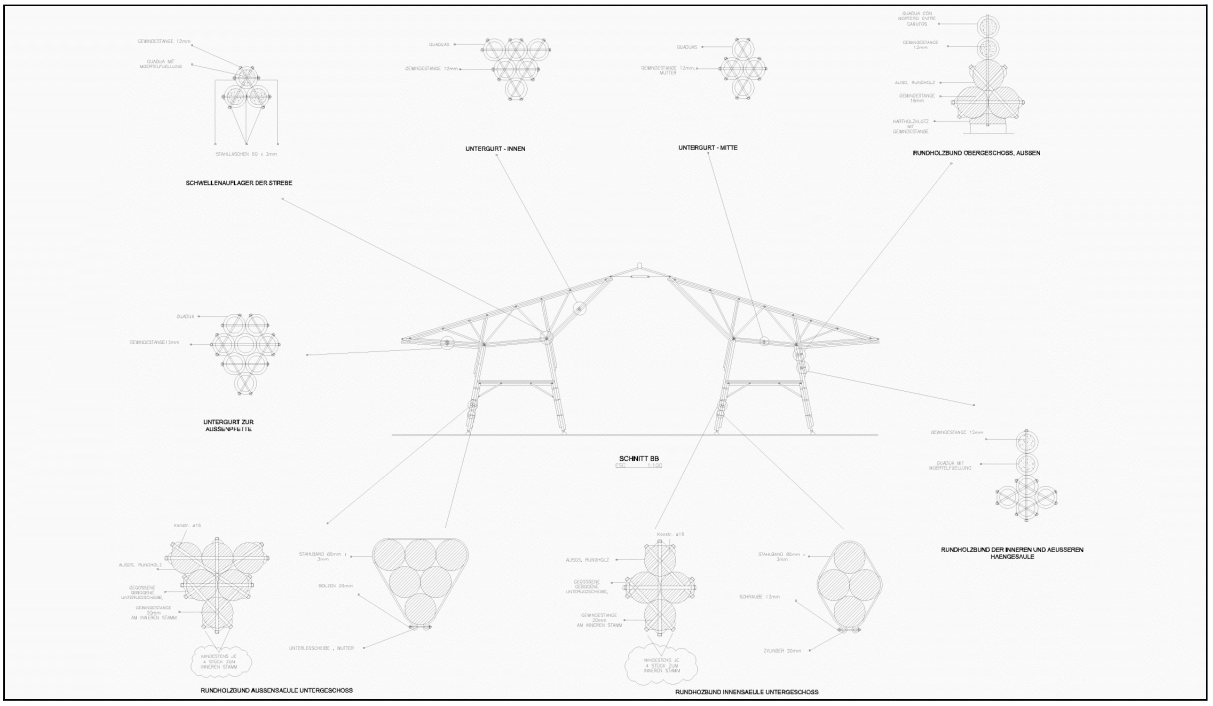


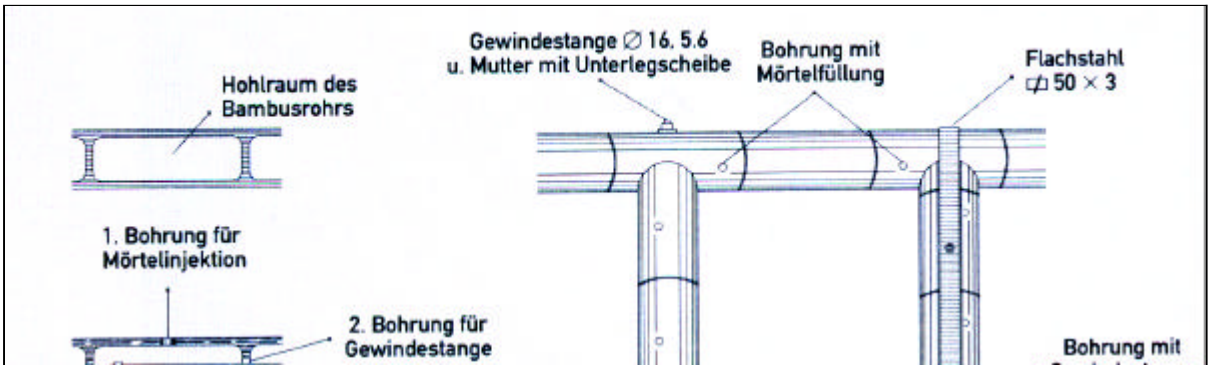
ZERI Pavilion EXPO 2ooo

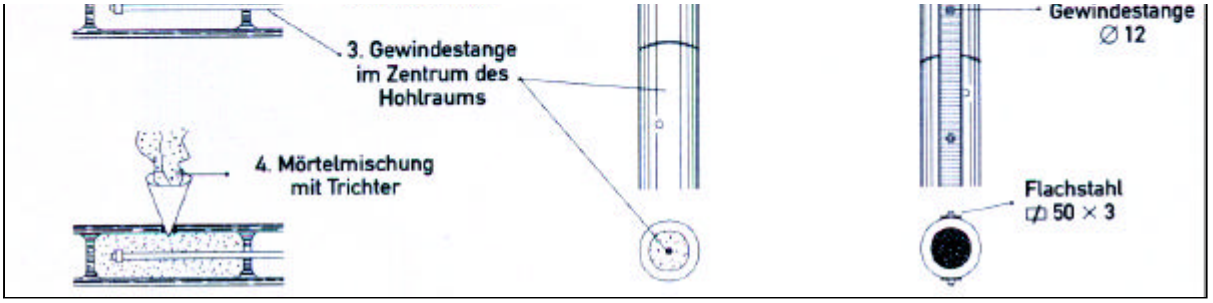
in, the bamboo is filled with mortar. With the ends of the threadrods you can creat different kinds of connections. For the connections it is important to use special dishes, also to fill the bamboo with mortar. Otherwise the bamboo would splitter, because of the force transmission at only one point.

**lateral steel flanges and sheded bolts** - Type B

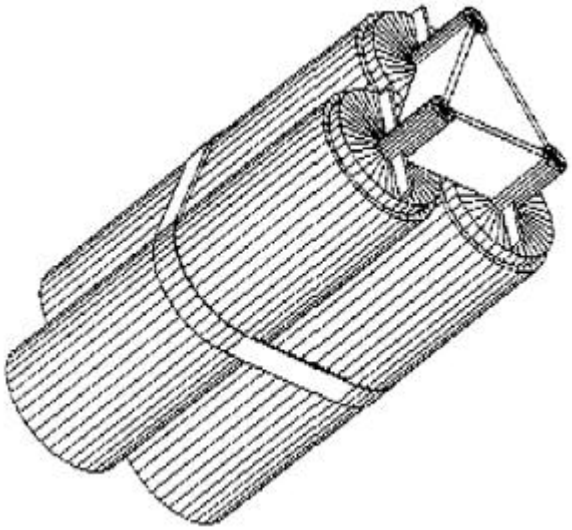
This connection is similar to type A. The bamboo is drilled. The sheded bolts are insert into the bamboo in crossdirection, the bamboo is filled with mortar. The connection itself is constructed by a lateral steel flanges, that is tied around the bamboo and joint with the sheded bolts. This connection transmits the forces to different parts of the bamboo and avoids the debit of only one point of the bamboo.



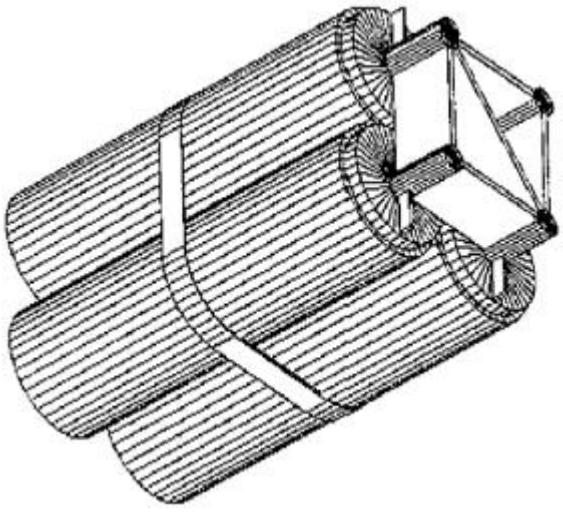



## Cane bundles



structural element composed of three canes

**Cane bundles** must be used for bigger loads. When using them for construction a possible connection can be achieved by projeting steel tips out of a wood cylinder (see interlocking connection), so that these tips can be welded to a plate or any other cetral component, to fix the relative position of the canes.



structural element composed of four canes

Probably it will be necessary to keep the canes together at midspan. A steel band can be used for that.

**Information:** Fundamentals of the Design of Bamboo Structures