

## Projects of IL 31

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### Introduction



These internet sites present the publication IL 31 "Bamboo", edited in 1985 by the ["Institut für leichte Flächentragwerke"](#) (IL), University of Stuttgart.

The main theme is the construction with vegetal rods with a special view on bamboo. In different chapters the building material bamboo, straight or curved, will be divided in different shapes.

Rod shaped building materials possess very different, positive properties. On the one hand it's economically interesting because of its low prices, on the other hand it grows fast.

Especially bamboo has statical properties that are superior to the classical wood-construction.

Nevertheless bamboo is considered not very high. It's seen as the building material for the poor people. Besides showing the constructive possibilities the publication wants to increase the people's acceptance for this building material.

## Straight Rods

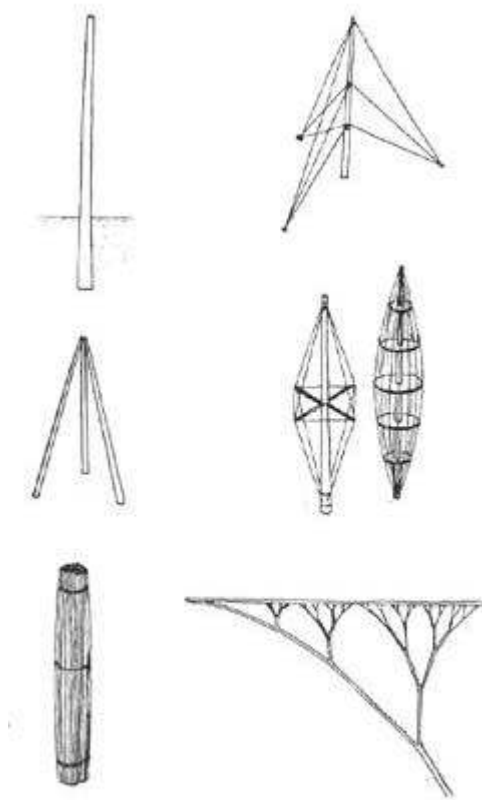
### Introduction

Under the headline "straight rods" the documentation LI 31 treats construction systems with straight rods and the constructive possibilities of the single rod.

In several sketches and photos of models constructions are shown which fit to the building with straight rods in a special way. Further a way of dimensioning, the BIC diagram, is explained. Besides the traditional manner of construction of South-east Asia the south American manner of construction is described by examples of a bamboo settlement in Manizales that is influenced by the Northamerican platform way of construction. The bamboo tower of the Phänomena in Zürich connects the traditional chinese way of construction with european technics. The transition from straight to bent rods is shown by the example of the development of traditional bamboo umbrellas to tent frames.

It may be anticipated that it's tried to keep the deformant under weight small by using short lengths of the lower stiff section of the bamboo. In addition, short spans and little weights are taken. Only in special cases the full length is used, which means, that you have to pay special attention to the development of details.

## Structural Systems

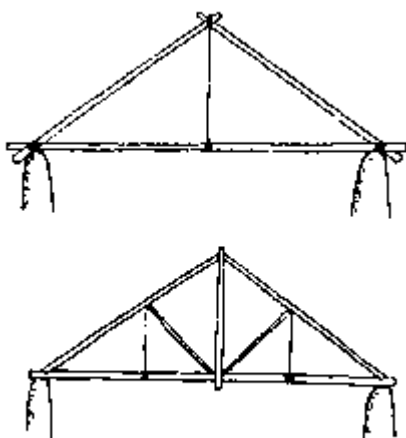


### Structural systems with conical rods.

Straight rods can be arranged in a variety of ways. If it is fixed at the base, the characteristic bending curve for conical round poles results under a horizontal load acting on the side as in the case of a fishing rod. The pole can be mounted in an articulated manner, if its stability is assured by means of stays or other structural measures. Highly stable loadbearing systems are produced by joining poles to form tripods. When these are invented, they form a table-like structure which, with minimum contact with the ground, is stable.

In view of the fact that vegetal poles are generally relatively slender, measures to increase the loadbearing capacity are often required. Bundled poles are extremely common in order to transfer larger forces over small paths since bundles achieve a larger loadbearing capacity than the pure addition of individual poles. The cantilever girder, as "half\_beam with central support" requires a support capable of assuming bending moments from the restraint.

Several Systems of Construction

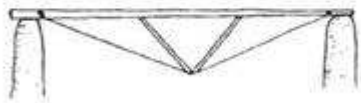
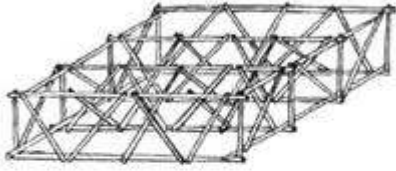


The combination of suspended and strutted frames is a relatively common feature of roof structures and even bridge structures, the struts being passed on under the tie beam, thus forming further supports for the tie. Trusses can be described as a further development of suspended structures and, like these, have only vertical reactions from vertical loads. Parallel-boom girders are suitable for bridge and wide-spanned deck structures.

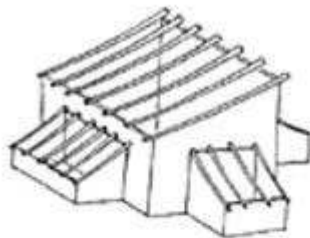
Half timbering etc.



Trusses arranged parallel to one another can be connected by means of spatial diagonals or crossing to form framework gratings.



Framework gratings



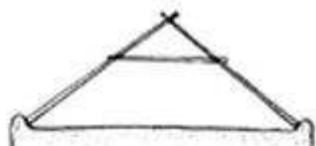
Pitched roofs are typical pole structures. Shed roofs are often placed in front of solid buildings as lightweight, hung-in structures; the front support can then be designed as a suspended column mounted in an articulated manner.



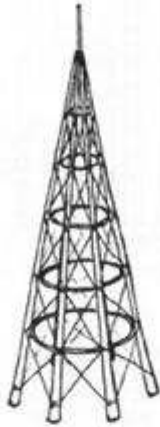
Poles joined to one another.



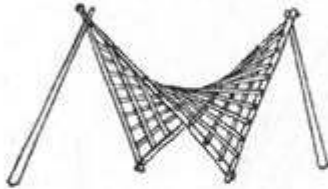
In case of larger spans, the loadbearing capacity of the poles can be increased by means of collar beams which reduce the spans of the rafters and, thus, their sag.



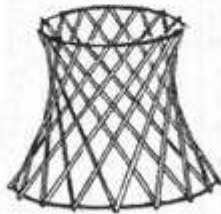
Several roof forms



Spatial reinforcement by means of diagonal poles is required in order to transfer the often considerable horizontal loads which occur with towers.

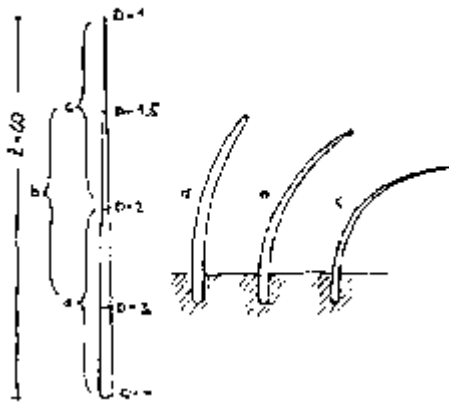


Straight poles can be used to produce curved surfaces, so-called ruled surfaces. As far as building with poles is concerned, the anticlastically curved surfaces of the hyperbolic paraboloid and the hyperboloid of revolution are particularly interesting. The geodesic dome forms an approximation to a synclastically curved surface. In the case of this structure, special importance is placed on the joint with the connections for the poles which are not situated in one plane.



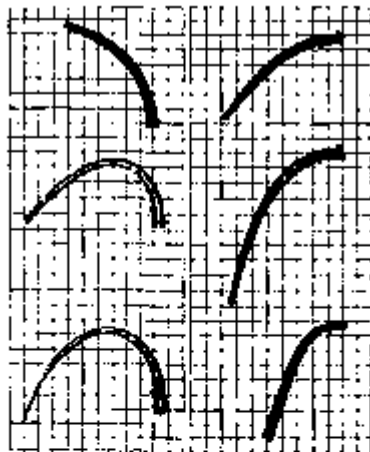
Curved surfaces with straight rods

## Deflection Curve

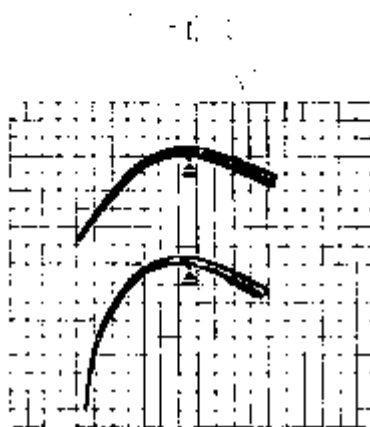


Conical forms

Uniform bending results in optimum structural arch and shell forms, as well as suspended roof forms which is basically differ from structures made up of poles of an even thickness. Poles with an even amount of taper do not necessarily have the same deflection curve, even if the material properties are the same. The pole sections a, b and c have the same amount of taper; however they have different deflection curves. The cause of these differences in their deflection curves lies in the fineness of the poles.



In order to clearly indicate the general regularities of the deflection curve, trials were conducted using poles made of foamed material. Foamed material is free from the inherent irregularities of natural poles. The advantage of this is that even under their own weight, the deflection curves are more pronounced than in the case of wood or bamboo.



Beams with one support

The centre of gravity of the curved pole is not the same as that of the straight pole, since the length of the lever arms is reduced as result of deflection. The highest point of the deflection curve is higher than the support point.

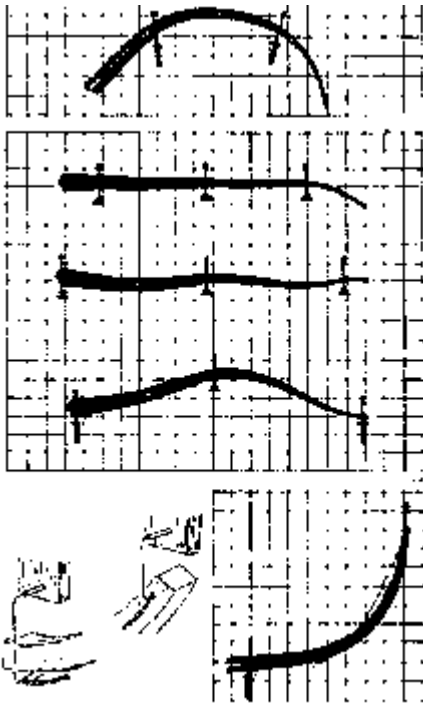
Trials with foamed material



Beams with two supports

There are many different possibilities:

1. A certain support position exists at which only vertical reactions occur (both in the case of fixed and movable supports)
2. In the case of movable supports, the sag of the beam can be varied within a certain range before it falls



STrials with foamed material, two beams

### 3. Reduced space between the supports

#### Inclined beams

The catenary is above the deflection curve in the upper section and below it in the lower section. This shape is well known. It is typical for temple roofs in the far east.

The IL has developed a procedure that makes it possible to provide a sufficiently accurate estimate of the loadbearing behaviour. The BIC-diagram is capable of doing just this.

## Constructive details

At the university in Bogota, Colombia, there is the bamboo research centre CIBAM, organisation whose aim is to use South American gadua for construction purposes. The highly resistant stalks of these bamboo species have a relatively low tensile strength in the transverse plane, thus meaning that when forming details little consideration need be given to the risk of splitting as is usually the case with bamboo

In order to put this building material to effective use, the CIBAM have published a manual of bamboo structures in which individual pilot projects are represented. Therefore is this [site](#).

[Fundamental detail connections](#) for a variety of joints for columns, beams and struts have been developed and tested on the basis of the material properties of this species of bamboo.

Here are some examples:

[A frame structure](#) with braces, the arrangement of any required reinforcements in the case of large spans or heavy loads, as well as the necessary detail connections.

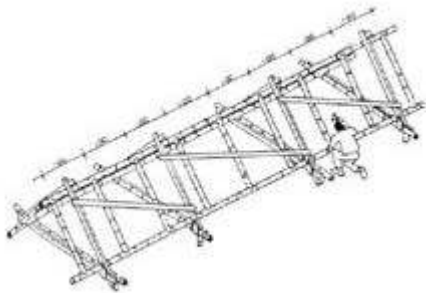
[Effective connections](#) for diagonal struts and posts in a frame work girder.

Umbrella-like [tapered roof structure](#) with a suspended column, as well as the arrangement of the struts.

[Manufacture water pipes](#) using bamboo tubes with diaphragms which have been drilled open.

Complex [bridge structure](#) which operates according to the scissors principle and is suitable for crossing ravines.

## Triple Boom Trussed Beam



Triple Boom Trussed Beam CIBAM has developed a new lightweight bamboo beam which can be easily produced. The prototype presented here has a width of 2m and is 8m long. Because of the stability and flexibility of bamboo it is highly resistant against earthquakes. The beams can be covered by various materials.

Dreigurt Fachwerkträger



## Residential buildings

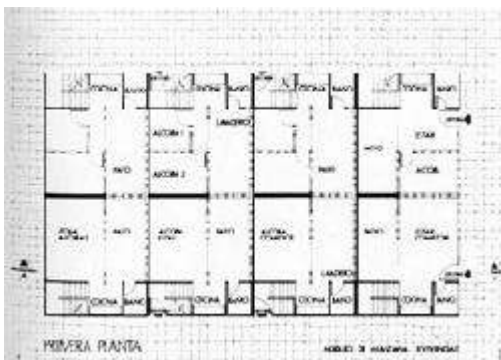


Bamboo buildings in Manizales

### Residential estate constructed with bamboo in Manizales

Manizales is a small town ca.2500 m above sea level in a coffee growing area west of Bogota.

In order to reduce the housing shortage, the Instituto de Credito Territorial of the Manizales region is pursuing a policy of developing new housing estates which often have a low housing density and are located on expropriated ground and on steep slopes. The ICT is a state organisation for the development of housing programmes for the socially most deprived groups of the population.

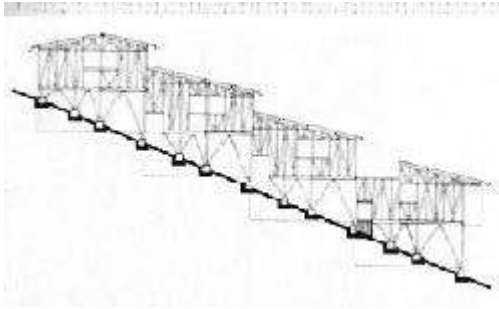


### Malabar Project

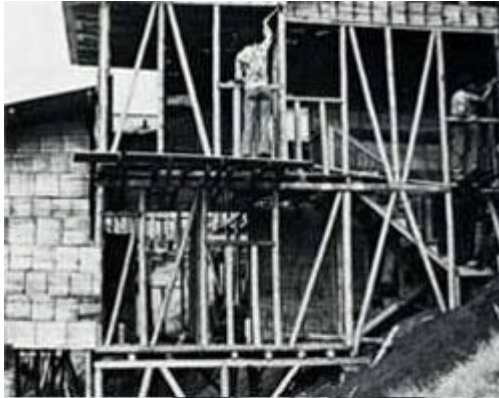
The Malabar project is one of the residential building projects of the Instituto de Credito Territorial.

They tried to build under consideration of social and cultural values on the one and the use of regional building materials. Most of the building material is bamboo. It grows nearby and its handling is well known by the inhabitants.

Each dwelling unit has a surface area of 6 to 7m<sup>2</sup>. The dwellings consist of living room and bedroom, kitchen



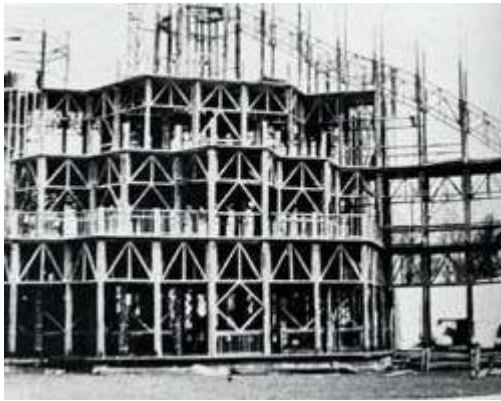
and WC. They are lit and ventilated via a patio. The main columns stand on concrete foundations. They are stiffened by diagonal braces. The dwellings were erected by the residents themselves who had no special training. They organised themselves, however, in an association and carried out the building work under the supervision of the ICT. On completion of the building work, which had progressed swiftly, the individual dwellings were allocated to the members in a raffle.



Malabar Project

## Engineering





Bamboo tower

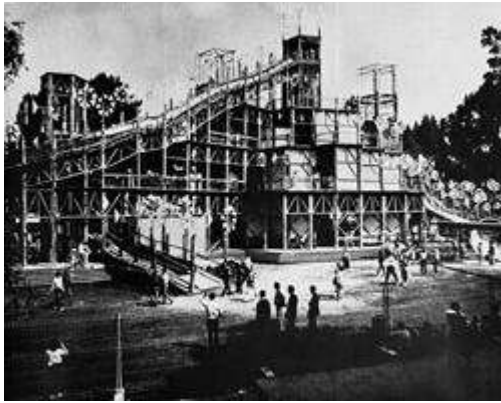
### Bamboo Tower At The "Phänomena" In Zürich

Among numerous other interesting buildings exhibited at the "Phänomena" 1984 in Zürich, an enormous bamboo structure designed by the Zürich artist Johannes Peter Staub was erected. 250t of bamboo were used over a building period of four months. The canes had been felled in China in previous autumn. The design and size of the building required canes of 6 to 11 cm diameter. Such dimensions are only achieved by bamboo plants whose rhizomes are about 20 years old. They erected a structure consisting of a hexagonal 3-storey building covering an area of 21 to 21m from which two staircase towers projected up to 20m. The design was based on a precise hexagonal grid having an edge length of 2.40m. Single-storey elements fabricated in situ were placed on this grid and on top of these further elements, which also had been fabricated at the site, were placed and suitable braced. The maximum span was 4.8m.



Details

In the previous years an experimental structure had been erected in Kunming. The tests were necessary because until then bamboo buildings in China never exceeded a height of 8m and because a bamboo structure the bamboo tower of Zürich can be subjected to oscillations because of its relatively soft joints and nodal points. The equipment of the structure was kept very simple. Since the building was intended to be used only during the summer, the open wall elements were either covered by cloth or left uncovered, and the top platform was protected against rain only by a thin foil cover. From its towers and terraces the building afforded a very good view over the exhibition ground. On the ground floor there was a permanent kitchen which supplied the associated restaurant. The restaurant furniture was constructed from bamboo waste pieces remaining after the completion of the structure.



Elevation

## Umbrellas

### Asian umbrellas

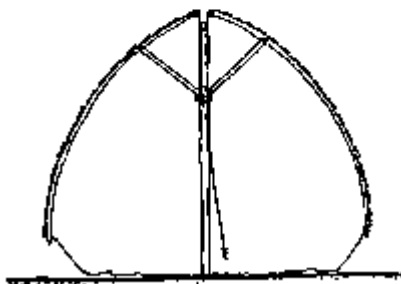
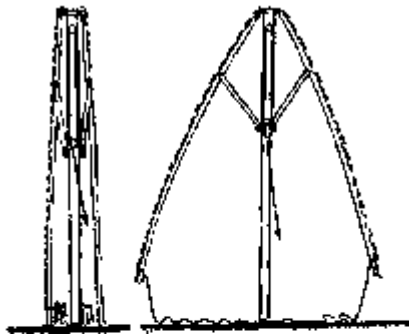


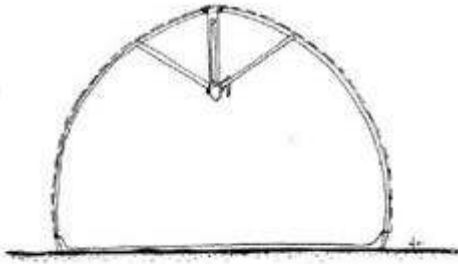
If the umbrella has a simple design, for which 38 bars are normally used, it is now ready for use. Finer umbrellas, for which the bars (up to 60 in number) have a more slender cut, are often painted in an artistic manner, and the handles wound with rattan.

Asian umbrellas

### European Umbrellas

Extremely curved bars are possible in the case of European umbrellas with a textile covering which is also cut to size in individual triangular sections. This is possible due to the fact that the fabric is capable of sustaining considerable tensile forces transverse to the bars, thus enabling the bars to be bent considerably when the umbrella is open.





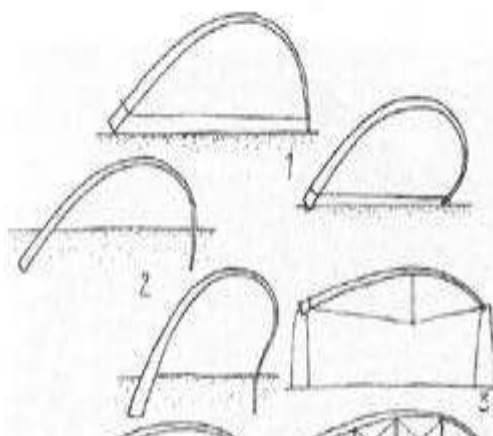
European umbrellas

## Curved Compression Rods

### Introduction

After [straight rods](#) and using the generic term "curved compression rods", we would like to supplement the comments on arches and grid shells made in "Building with vegetal poles" by offering examples of structures whose form is determined by installing curved rods.

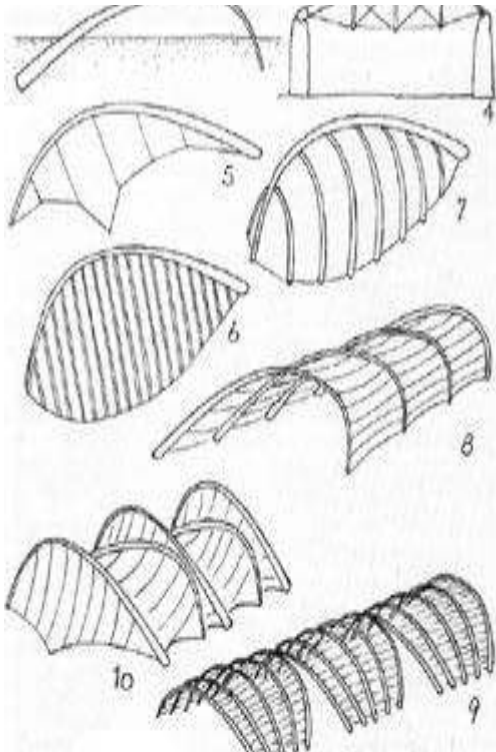
### Structural Systems



#### Arches

The form of a simple arch of conical vegetal rods is determined by the nature of the not symmetric deflection curve. As part of a structural system, the arch must be prevented from tilting. This can be achieved by anchoring it with tension-proof ropes or membranes, straight and even curved poles, or by restraining it. This type stabilisation requires an additional mass since the rod must be suitably rigid in the transverse direction.

Very different building forms can be produced by adding



arches.

Form wird durch asymmetrische Biegelinie bestimmt

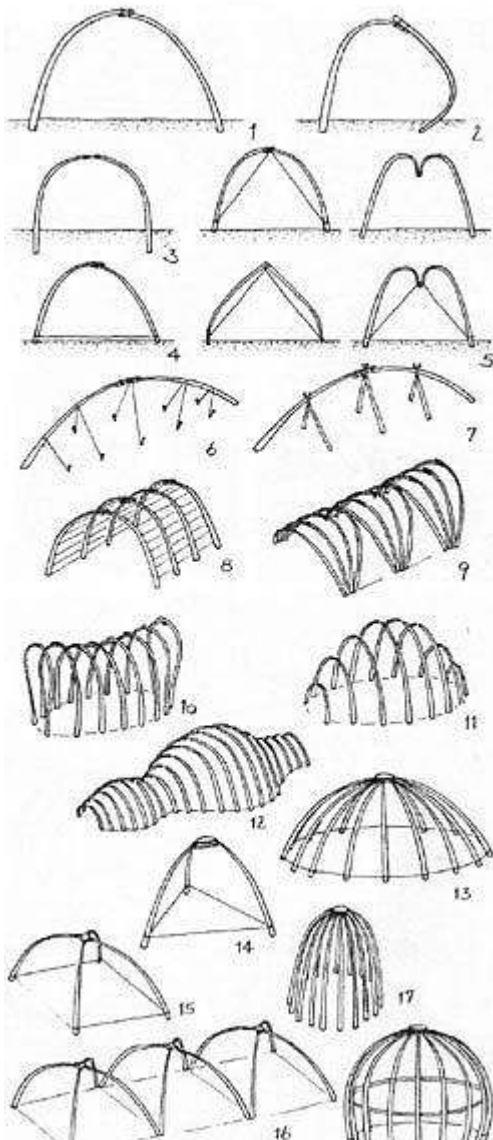
### Composed Curves

By adding several rods, you can achieve symmetric forms. The form depends on the way it's fixed to the ground.

Longer curves can be stabilised, which also reduces their structural length.

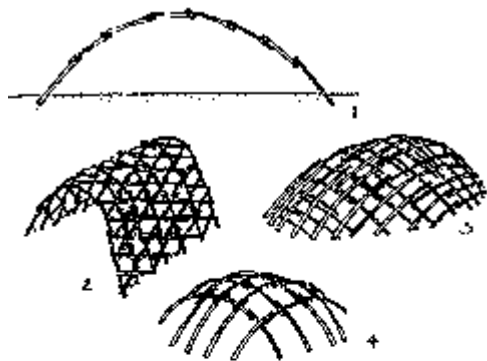
By adding several rods several room building constellations arise. By changing the length over elliptical floor plans, you can get domes.

Another possibility of shaping is the use of grid shells by crossing the rods.



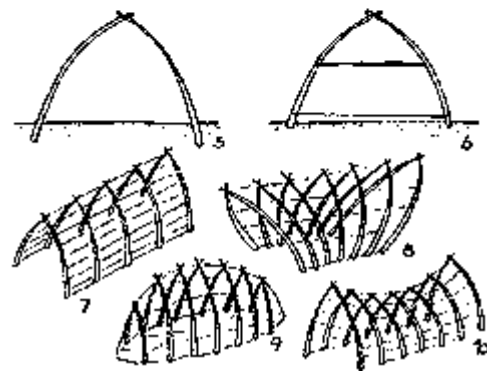


Symmetrie by addition of rods

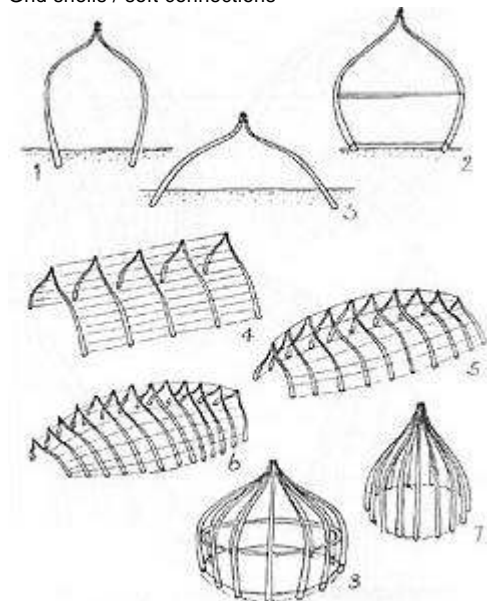


**Different Connections**

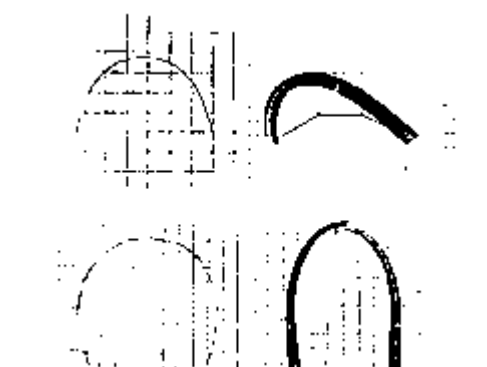
The way of connection of the singles rods builds up special kinds of shapes. For example you can use soft connections, which causes pointed arches. If you connect the rods parrallel, you get onion like geometries.



Grid shells / soft connections

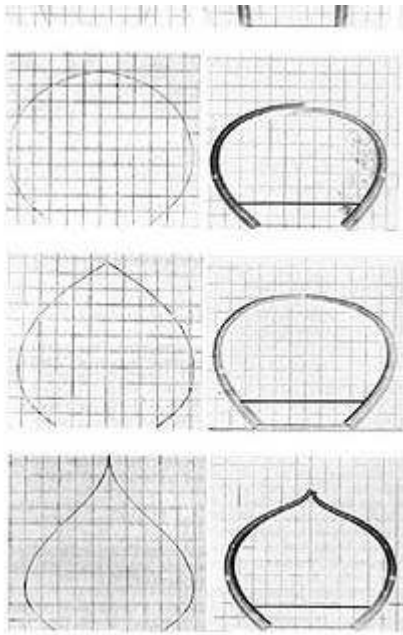


Parallel, stiff connections



**Survey**

The image at the left shows an overall view of different curves in comparison to curved rods with a constant cross section. They were examined by trials with spring steel and conical foamed material.



Constant / conical cross section



Bamboo bridge in Japan

### Building with curved bamboo

Normally only the lower half or lower third of the natural length of a bamboo cane is used to provide the load-bearing elements of a structure. With the majority of bamboo species, these canes are practically rigid and cannot be bent. When using bamboo cane in their full natural length, the bending of the upper sections of the canes with their relatively small diameter and wall thickness is possible and structurally sensible.

### Grid Shells

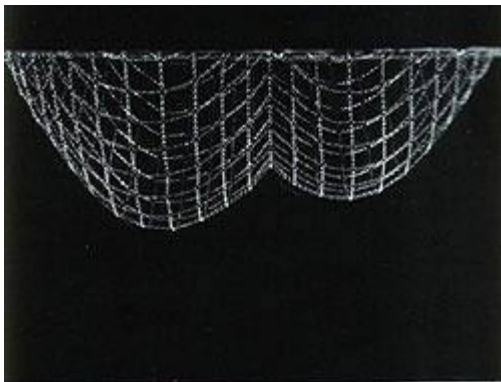


Bamboo Shed in South Ethiopia

### Modern structures made of split bamboo.

If split canes are used in the load-bearing structure, the curved shape is unavoidable. In this manner relatively large buildings can be erected from split bamboo canes. A traditional example are the huts of the Dorse tribe which lives on the Gamu high plateau in southern Ethiopia, Africa. The huts of this tribe have a very characteristic shape: a circular plan with a projecting entrance lobby

In collaboration with the School of Architecture (SA) of Ahmedabad, India, there has been the attempt to develop new constructional applications of bamboo by combining the great tradition of the bamboo craftsman with modern methods of lightweight construction.



### Grid shells

In grid shells, which are a method of construction developed at the IL, relatively thin bars form a spatially curved load-bearing structure. The constructional principle is based on the idea of reserving the catenary line of a chain and making it into the thrust line of an arch. These are some important questions:

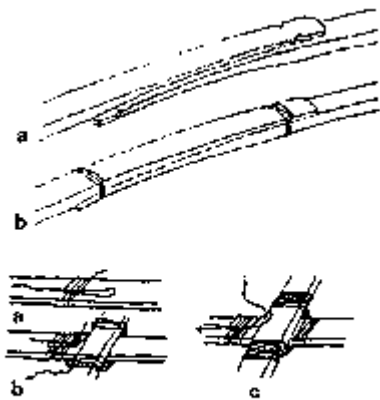
1. Determining the effect of irregularities in the bamboo grid bars on the shape and the load-bearing behaviour of the grid shells.
2. Development and testing of constructional details suited to the material such as the joining of the grid bars, the butt end joints of the grid bars, the design of the edge or boundary, the fixing of the grid to the boundary, options for fixing the form, etc.
3. Adapting the assembly and shaping methods to the requirements of the tied grid.
4. Determining the load-bearing capacity of such structures and their feasible spans.
5. Developing and testing of possible roofing material and interior fitting equipment.



Grid shell as transitions of the chain line



Finished grid shell

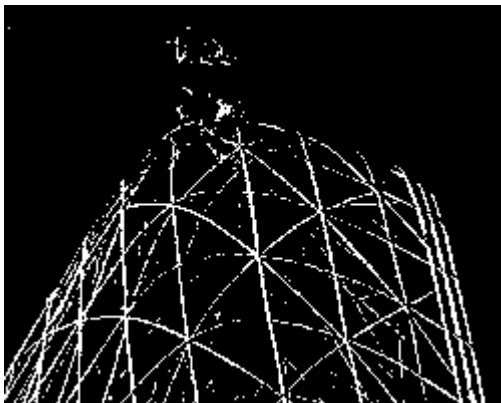


Details

The studies have so far been carried out mainly on three experimental buildings:

Experimental 1:

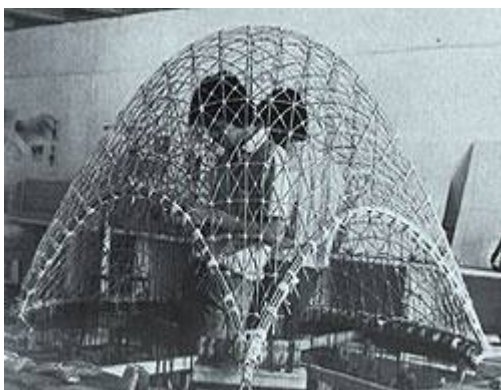
With the first experimental building (1/8 full section,  $l=7,5m$ ) the possibilities and possible problems of such structure were examined. The material costed 80 DM. During this work the butt and tied joints of the grid bars were developed successfully. The deformation was smallest at a surface of ca.  $122N/m^2$ .



Stabilisation

Experimental 2:

In November 1981 this experimental structure was altered. The smaller shell was overlaid by a diagonal secondary grid. The loading tests showed that the load-bearing capacity of this grid shell had trebled. The shell was also subjected to a concentrated load.



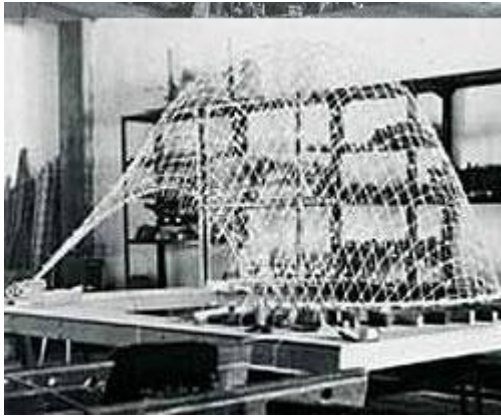
Experimental 3:

The third experimental building is a model of a grid shell with a span of 9 m and scaled 1:5. The results of the load tests showed that a corresponding grid shell with secondary diagonal grid can support a load of  $250-330 N/m^2$  and a wind pressure of  $500 N/m^2$ .

Conclusions

1. Split bamboo is a very suitable material for the grid shell construction technique.

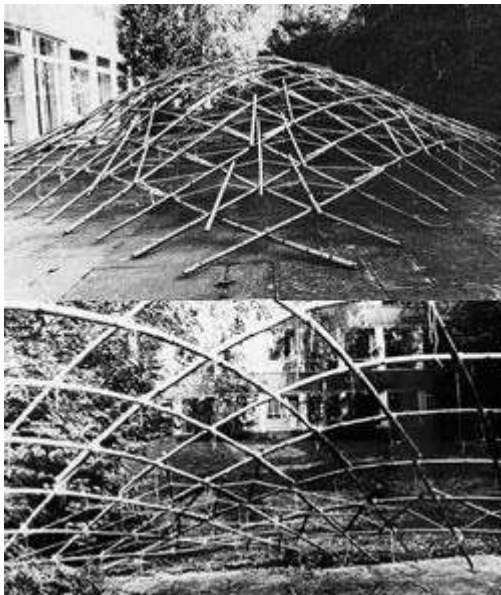




Modell in scale

2. The cross-sectional irregularities of the grid bars, which are inherent in the material, pose no serious problems.
3. The shape or dimensional tolerances caused by the irregularities could be reduced by an appropriate selection and arrangement of the grid bars within the grid.
4. The jointing of the structural elements developed from the traditional tying techniques have basically proven successful.
5. The harmonious curvature of the grid bars is not distributed by the rope tie joints.
6. With large grid shells the grid has to be suitably prepared in order to facilitate its assembly and final forming.
7. The limit of the maximum spans of grid shells made from split bamboo is around 10m. This span limit is probably also dependent on the species of bamboo used.

## Detail studies



Grid shell

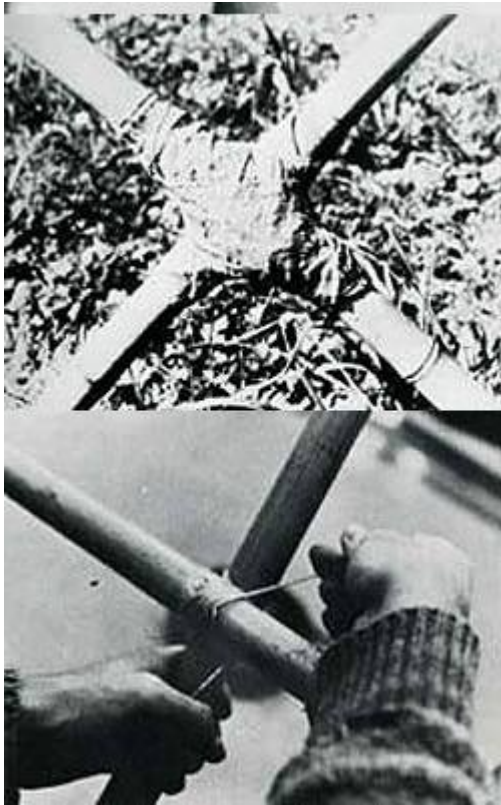
### Detail studies of a bamboo grid shell

A study carried out by the Fachhochschule Aachen had the objective of developing earthquake-resistant and cheap structures for developing countries, which should be made from local materials and erected by the users themselves. Under certain conditions bamboo is preferable to timber, e.g. Because it grows more quickly, helps to prevent ecological damage and can be transported and worked without the use of expensive machinery.



Two node details were examined which were secured against sliding movements in different ways. In addition one of these nodes was secured against rotation by a cement-impregnated jute bandage. The so-called "rubber knot" consisted of two bamboo rods separated by a layer of rubber and tied tightly together. Its resistance against sliding movements was 0.6kN as measured in several tests. At higher loads the cross bar could be shifted to the next node, at which point one of the bars failed at 2.5kN as a result of excessive transversal compressive stresses.

With the second so-called "pinned knot" the two



Verschiedene Knotenpunkte

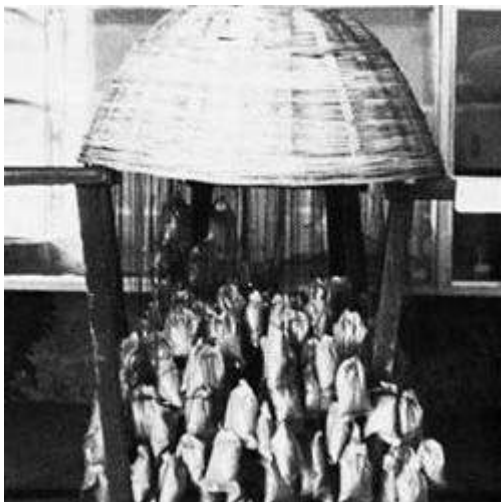
bamboo canes were linked by a bamboo pin. In version 1 the resistance against sliding movements was 0.5kN; at this loading the hole edge stress was exceeded and the pin tilted in the hole. For version 2 a resistance against sliding movement of 2.5kN was measured. Failure occurred at the load point through excessive transversal compressive stresses in the bar. This type of joint was used for the construction of the grid shells.

After erection the grid shell can only maintain its shape and transmit the loads in the desired way, if a change in the angle formed by the grid bars in the node, is prevented.

#### Summary:

In the form shown a bamboo grid shell having a covering of local materials can therefore offer a cheap and relatively earthquake-resistant alternative to the traditional roof structures used in developing countries, which can also be erected by the users themselves under suitable supervision.

## Basket Shell

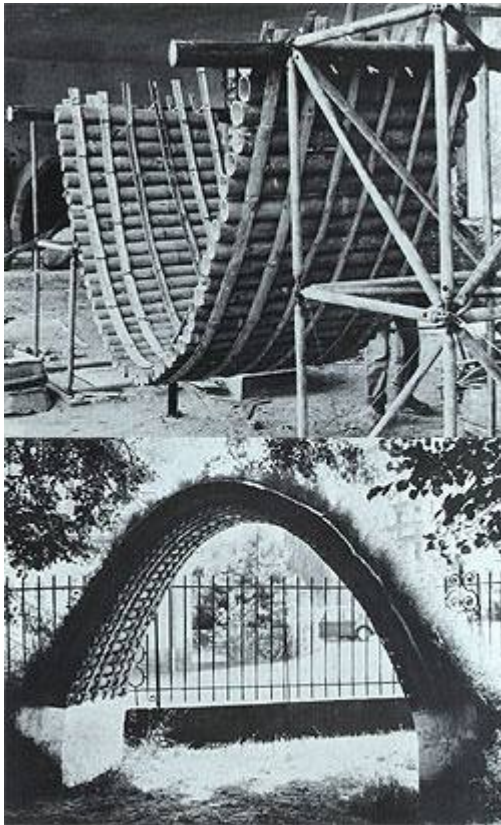


Basket Shell under load

### Basket shell made from split bamboo

For this experiment an Indian craftsman was instructed to weave a small dome from very thin and narrow strips of bamboo using the conventional radial weaving technique. The shape of the model was largely identical to that of suspended form (diameter: 56cm, height: 25cm, weight: 865p). With two thirds of the edge resting on a surface, the model was loaded with suspended weights. Under an evenly distributed load of 1000 N/m<sup>2</sup> of a base area, no measurable deformation of the surface was recorded.

## Bamboo arched structures and barrel vaults.

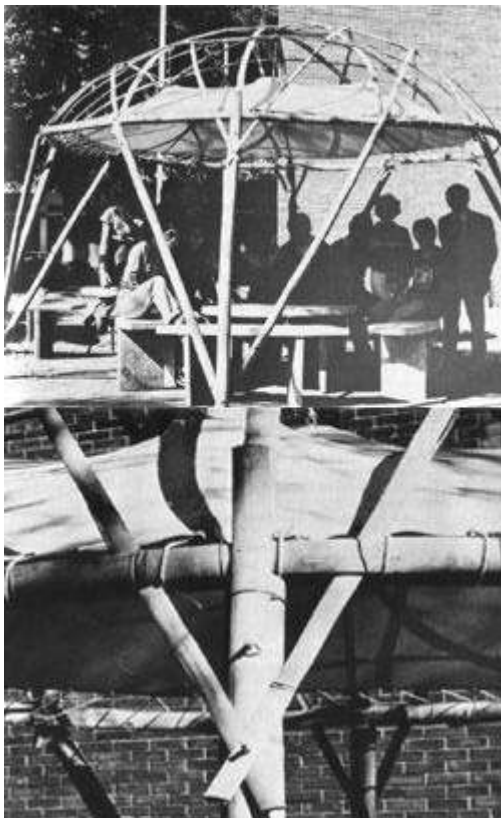


Bamboo arched structures and barrel vaults.

### Bamboo arched structures and barrel vaults.

Within the research project "Building constructions using bamboo" the Research Laboratory for Experimental Constructions of the University of Kassel carried out studies in 1981 and 1982 on simple joining techniques for bamboo canes and the application of bamboo for the construction of dome or barrel-shaped roof structures. As a test material bamboo canes of 10-15 cm diameter and 6m length of the species *Guaduaangustifolia* were used.

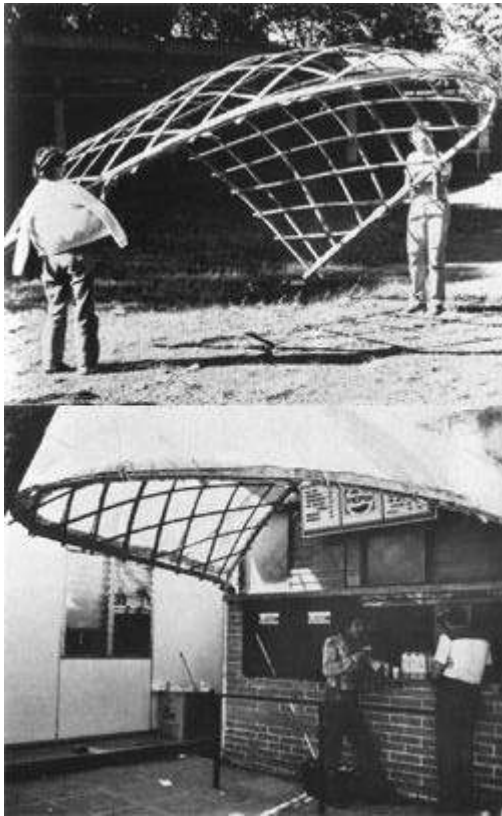
### Several Projects



Double curved grid shell

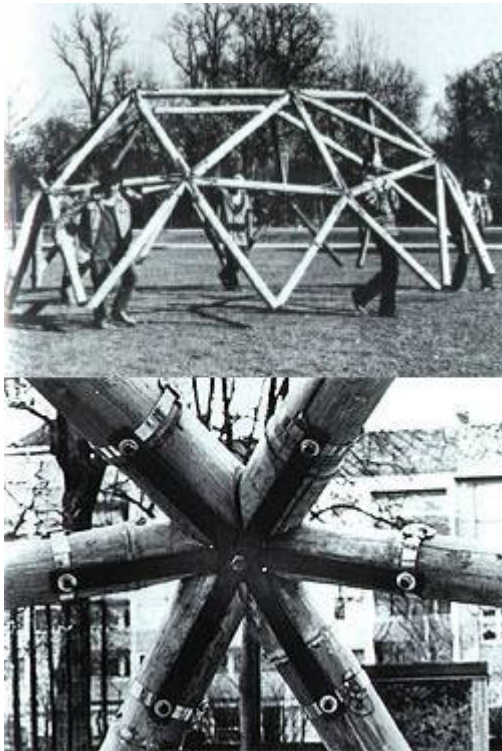
### Several Projects

1. Double curved grid shell, developed at the University Francisco Marroquin, Guatemala



shop roof

Close-mesh grid made from split bamboo canes which serves as a cover for stalls. It is covered with a PVC-coated cotton fabric.



Very strong structure

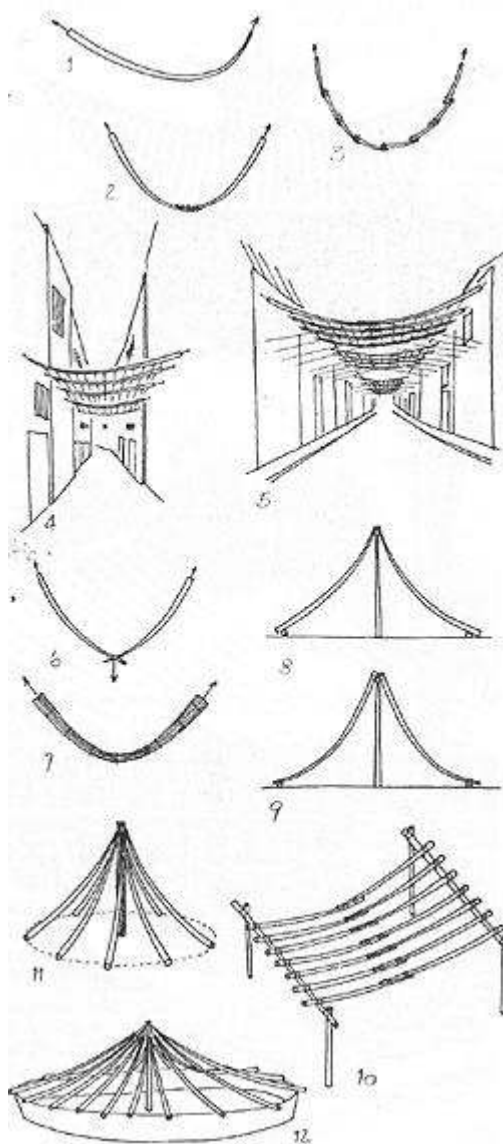
Grid-shell construction weighing 2kN. It spans more than 6m and is capable of supporting an earth and grass layer of app. 20cm thickness as well as additional snow and wind loads amounting to a total load of 200kN.

## Curved Tension Rods

## Introduction

As a supplement to the comments made in [curved compression rods](#), the following chapter presents constructions which were developed using the "curved tension rods". These structures all belong to the form family of the suspended roofs curvature resembles but because of the flexural rigidity of the free-hangig chain.

## Structural Systems



### Hanging Curves

Vegetal rods which, as a result of their low flexural rigidity but high tensile strength, are suitable for structures subjected to tensile strength produce a characteristic, asymmetric hanging / bending curve when hung between two bearings.

This form becomes more obvious the greater the load is.

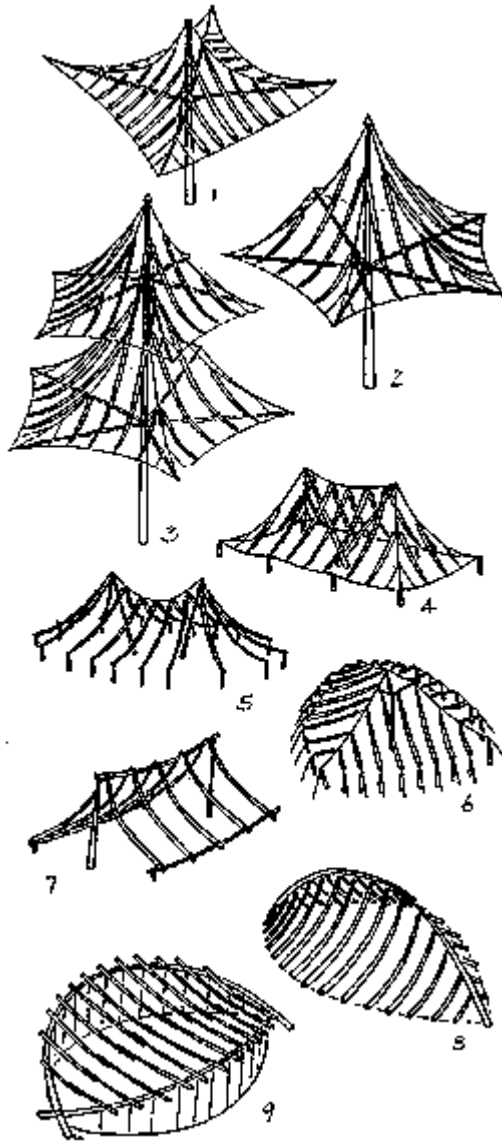
For larger spans and symmetrical roof forms, two or even several rods are combined. Normally suspended roofs must be established by under spanning.

A number of different arch forms are necessary depending on the load situation. Arches, which must bear for example an additional spot load in the centre, are built as suspended pointed arches.

The addition of several hanging / bending curves forms characteristic structures in particular tent-like suspended roofs.

Hanging Curves

### Tent-like structures



Tent-like structures

As the traditional structure in Asia, the umbrella-like tent roof with groins and horizontal compression struts has probably been developed to become the classic form. In addition to being able to form groins and edge supports as ropes, these elements can also be replaced by flexible rods.

In order to cover large floor plans, it is possible to fan out into a two branch tent with suspended ridge. These structures are formed by combinations of compression and tension elements.

### Tensile Cable Structures



#### Example: The An-Lan suspended bridge

The best known bamboo rope suspension bridge is the An-Lan bridge of Kuanhsien spanning the river Min. Probably this bridge was erected in the 3rd century A.D. and since then frequently changed and repaired. It is reported that not a single piece of metal has been used in the entire construction of the An-Lan bridge. The photos taken in 1958 show that the bridge has eight spans. The longest being 61 m and the total length of the bridge is 320 m. The bridge hangs from seven piers. Six out of hardwood, the centre pier out of granite.

For the production of rope the bamboo canes are split



The An-Lan suspended bridge

into fine strips. Because of their lower tensile strength the strips from the inside of the cane were used for the cable core. This core was covered with a densely plaited layer consisting of the very strong bamboo taken from the outer layer of the cane. It is reported that the tensile strength of such ropes increases by 20 % if the rope is soaked in water.

The anchoring of the bridge cable in the bridgeheads is effected by large wooden winches. The winches are held by huge baskets which are filled with stones and by that the bridge cables are re-tensionable.

## Literatur

Alle Projekte und Bilder sind entnommen aus:

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