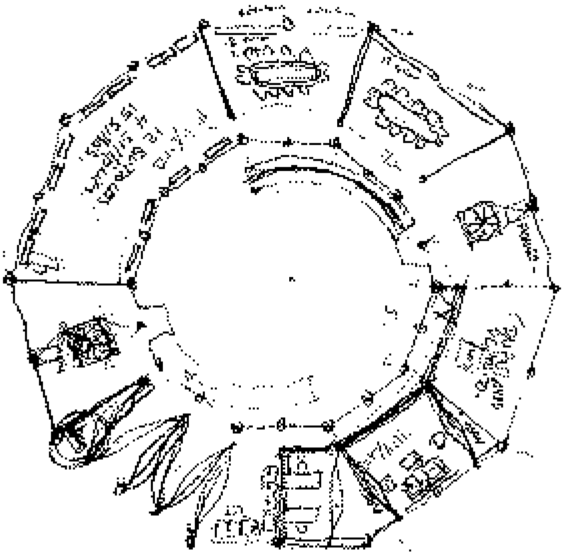
ZERI Pavillion on the EXPO 2000

Introduction

prototype of the ZERI pavilion



sketch of the architect

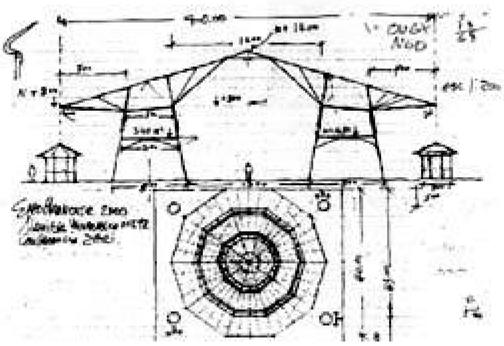
The ZERI organisation (Zero Emission Research Initiative) develops strategies for a lasting way how to deal with the natural resources of our planet in order to satisfy basic needs of all people.

The pavilion, which was build by I for the EXPO 2000 in Hannover, represents the principles of ZERI´s work. "The ZERI Pavilion is a circular construction, thus one without a beginning, without an end, open in design as to invite everyone to participate without obstacles. It is open and unobstructed. It symbolises a universally accessible organisation which embodies concepts and technologies which are applicable anywhere and accessible to everyone."(Marshall McLuhan)

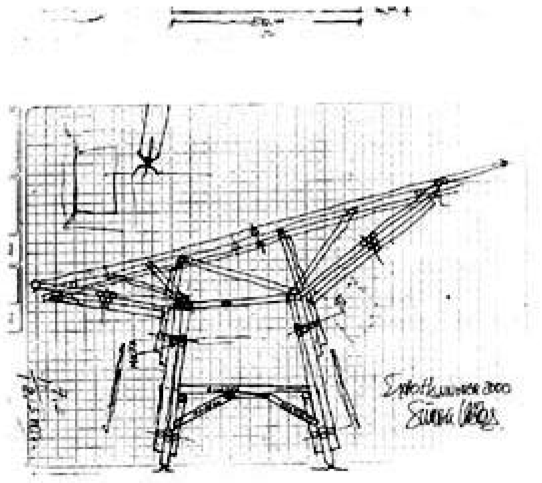
As it is one of ZERI´s purposes to establish bamboo as a construction material in South America, the organisation decided in 1997 to build the pavilion as a framework construction made of bamboo.

Simon Veléz , a Columbian architect from Bogota, has been working with bamboo for a longer while. He developed a new technology to connect the bamboo canes using thread rods and concrete/mortar injections. This new technology allows to realize impressive constructions and great spans.

Design



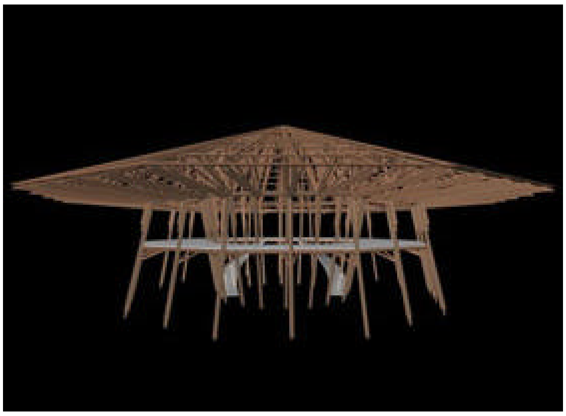
Simon Veléz´s project is a circular bamboo structure, or more precise a ten-sided polygon 40 meters in diameter with a peripheral overhang seven meters wide, so not only the interior of the open pavilion but also the construction is protected from rain. The building rests on two concentric courses of 20 supporting wooden pilars measuring 8 to 14 meters height. The pavilion provides 2,150m² floor-area on two levels (1,650m² at ground level and 500m² on first floor gallery).



sketch of the architect

The roof is typical the architecture of Simon Veléz', who calls himself a "roof architect". The roof overhang, which is much bigger than necessary for construction, is a special topic for Veléz. The pavilion with its wide roof looks like a mushroom. The organic form accentuates the materiality of the pavilion. In addition to this mushrooms play a important role in one of ZERI' s farming projects.

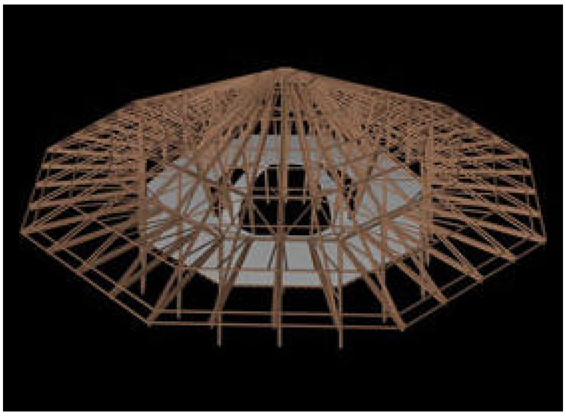
Static system



The ZERI pavilion is a circular building in skeleton construction, whose great number of rod-shaped construction elements may confuse at the first moment. At a closer look you perceive, that the main static system consist of a transom made of framework on two pillars with two cantilevers. Because of the radial arrangement there are always two supporting beams made of framework in one axis. On their highest point they form ridge ring. Ten pairs of framework-beams are arranged in a regular space. There are other framework beams in between in order to reduce the span. They don't give their load directly to the pillars, but they lead it over struts into the pillar of the next axis. To reduce the length of breaking of the pillars, a rotating gallery was inserted on half the height.

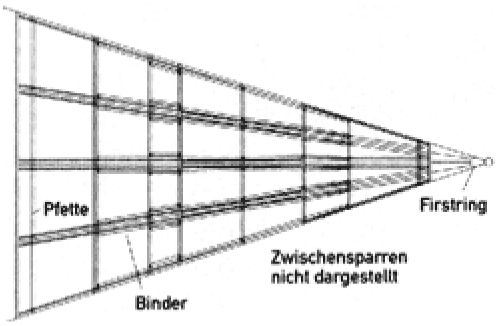
Elements of structure

Roof



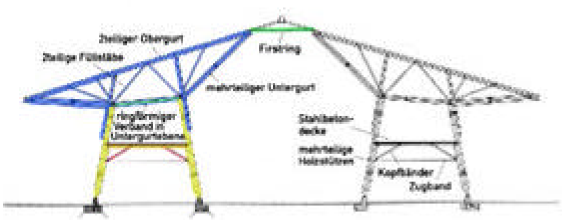
rendering roof

The roof of the pavilion is decagonal and juts out seven meters over the gallery level. The roof has got a diameter of 40m and is at the ridge 14,5m and at the gutter 7m high. The roofing is made of 9mm thick cement tile, which are strengthened with bamboo and lying in a 3cm thick mortar layer. This mortar layer gives together with an underneath arranged rolled metal layer the load of the roof to the spars. The spars are radial and concentrically arranged with small spaces in between. They give the load to ten ring-shapely round the whole roof running purlins.



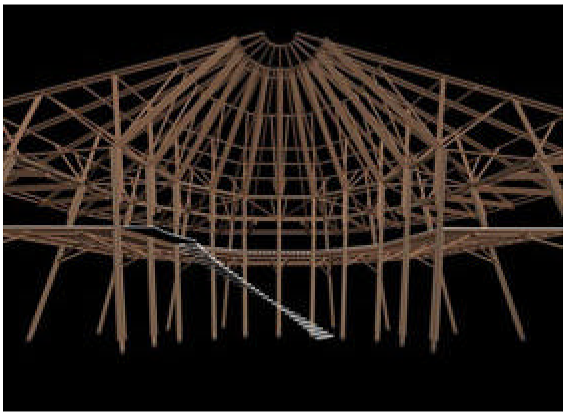
roof structure

Framework grider



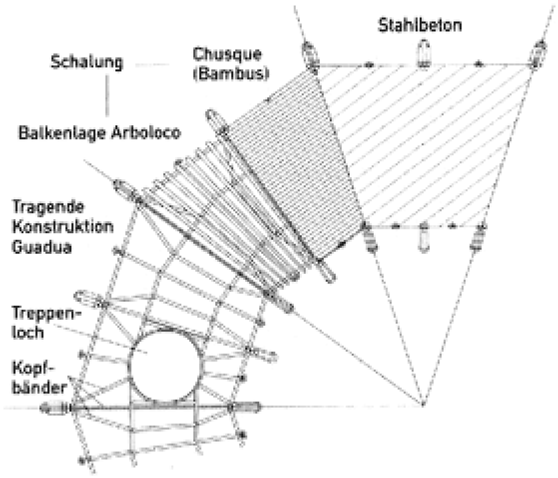
vertikal section

The purlins give their load to 40 radial arranged and in an angle of 9° standing towards each other framework griders. Every second grider is not supported directly, but gives his reactions to the pillar of the adjoining grider using diagonal rods and rings. There is a ring-shaped framework on the height of the pillar´s heads, that distributes the horizontal loads. The single elements of the griders are 'bundles' of up to 8 bamboo canes. Only at the connection points, where the loads are given to the pillars, single concerning internods (internodien?) are additionally filled with mortar. In all other areas of the girder the canes are only connected with steel rods.



section rendering

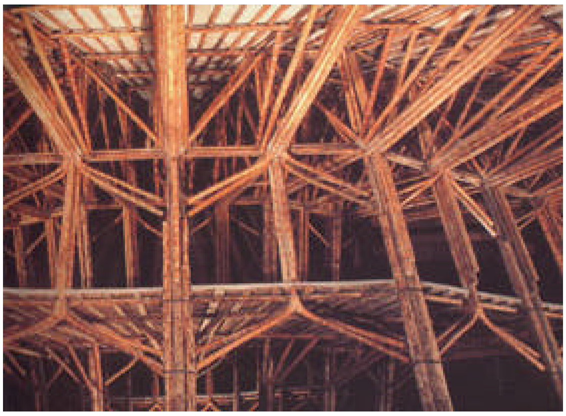
Gallery



gallery structure

The gallery consist of several layers. The lowest supporting layer is made of radial and ring-shaped arranged guadua bamboo canes, which are supported by struts in the knots. On these canes lies a layer of radial arranged arbocolo rods with half diameter. On this layer chusque bamboo canes with a diameter of 2 to 3 cm are lying really tight, they are a sacrificed shuttering for the reinforced concrete ceilling. The cast concrete ceilling is only 8cm thick and works load distributing for vertical and horizontal loads.

Pillars

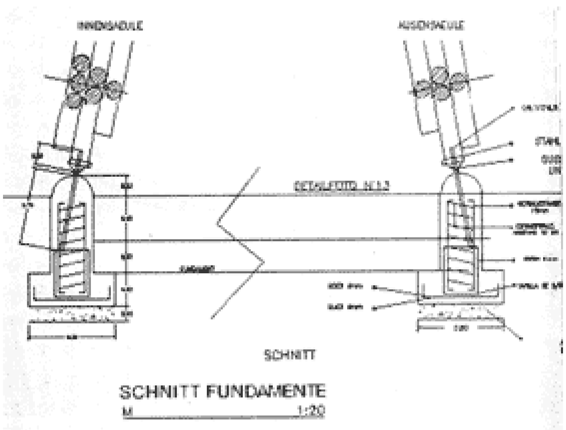


view underneath the roof

The outer pillars consist of 6, the inner pillars of 4 bundled aliso round timbers. They are connected by thread rods and flat steels. Only 2 of the 6 respectively 4 round timbers give the load to the foundations. The other round timbers increase the flexural rigidity. For bracing in peripheral direction there are struts. The lower very stable part of the bamboo plant was used for the struts.

Foundations

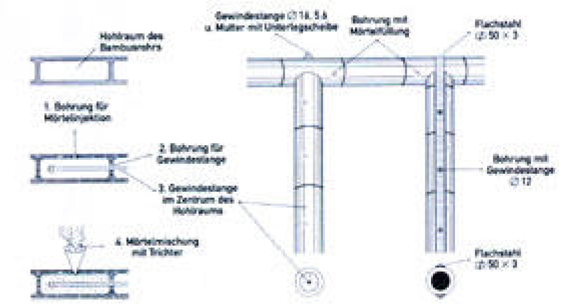
The inner pillars are standing on a foundation ring. The outer pillars are standing on single foundations, which are connected trough foundation beams.



detail section foundation

detail foot

Connections



connections of the bamboo canes


detail knot


detail struts

Two methods have been developed to connect two sticks orthogonal with each other. First of all this connections have to transfer tractive forces.

- Type A mortarted thread pole
- Type B lateral steel strap and mortar bolt

Type A mortarted thread pole
In order to connect a cane firmly with another, transferring tractive forces, you have to puncture two or three diaphragma (intermediate base), interlock a thread pole and fill the internodia (cavity) with mortar injections from the outside. Then the second bamboo stick has to be vertically punctured and put on the thread pole. At least a nut with an curved washer is screwed onto the thread pole, the punctured internodia is filled with mortar.

Type B lateral steel strap and mortar bolt
For this variant of connection two or three internodia at the end of the bamboo stick have to be punctured vertically. Thread poles were put through the holes, after that, the internodia were filled with mortar. The second bamboo stick is placed vertically at the end of the first stick. A steel strap is wraped round the bamboo and then screwed to the thread poles. So the steel strap presses the second bamboo at the other, like a belt or a loop. The bamboo´s internodia which is wraped had to be injected with mortar, because otherwise the stick would collabse.

Assessment of the connections
The experiments of the FMPA Stuttgart, an institute where materials are tested, resulted for type A in nearly no initial slip. Wedging the tube at the thread poles has caused the bamboo´s breakdown. The maximum load rose up to 70kN.
Type B had an initial slip of 1.5 mm, but was able to withstand 140kN. This connection had a maximum load twice as high as the other one. The breakdown was caused by flaring the holes of the steel strap or wedging the bamboo´s tube.

Materials


Bambus guadua angustifolia

The important materials for the primary supporting construction are the bamboo guadua angustifolia, the wood Aliso (alder wood), sturctural steel und concrete. The Arbolco wood and the Chusque bamboo were used for the interior works.

Bamboo guadua angustifolia
The Columbian bamboo guadua angustifolia reaches a height of 20 to 25 meters and can be cut at the earliest after three years. For the pavilion canes/tubes with a diameter of 10 to 14 cm and a wall thickness of 11 to 22mm were used. To protect the bamboo against insects and fungus diseases, it was smoked/fumed in its own resins like usually in Japan.


Aliso trunks

Wood Aliso (alnus acuminata)
The Aliso wood comes from a Columbian alder species. So it is a deciduous wood. The missing of annual rings can be explained as there are no real seasons of the year in Columbia. The wood is used for the pillars of the pavilion as 17 to 22cm big whole wood trunks. Because the growth of the wood is twisted, only with whole wood the necessary load capacity can be reached.

Floor and interior are also made of differnt bamboo types: bamboo from China for the parquet and bamboo from Bali and Columbia for the interior.

Building


pavilion during building

As only the materials steel and concrete have been admitted in germany, but most of the carrying material was bamboo (guadua angustifolia) and wood (aliso), a prototype has to be build in Columbia.. Also the new connection types with steel straps and poles and mortar injections had not been used or tested before. This prototype had to proove, that the pavillon could be build The prototype passed the experiments, so that a generall ability for building was prooved. After that a similar pavillon could be build at the EXPO in

working on the bamboo with a crowbar

Hannover, an "admission for an individual case" was requested. To get an approval following experiments were necessary:

a) first experiments, testing the prototype in Columbia, to estimate the security conditions

b) testing the single structural elements (bamboo guadua, wood aliso, connections), to ascertain the specific mechanical values

c) creating a static calculation

d) verifying maximum load and availability of the built pavillon in Hannover

e) quality assurance (first sorting in Columbia, supervision by a material testing institute, supervision by the building control authority)

This measures were taken before, while and after building the pavillon. 40 craftsmen from Columbia, which had been paticipating at the prototype in Columbia, put up pavillon in Hannover. The building-up of the pavilion started with the roof constructionin February. First the ridge ring, the eave ring and the purlin rings in the middle were made and stored on a scaffolding. The rings were connected by girder top boom bars. Next the inner and the outer ring at the head of the wood pillars were manufactured. Two wood trunks support the rings. After the aligning of the trunks the foot point of the pillars were made. The geometric angle were ready now. The bottom chord bars and the filling rods of the grider were completed. At the same time the struts in peripheral direction and the bamboo canes on first floor were build in. At the beginning of April the manufacturing of the under construction of the concrete ceiling made of arboloco bars and chusque started. In the middle of April the mortar on the roof the concrete for the gallery were put in.
The interior works followed in May. At the same time the tests were made. After the end of the EXPO the pavilion is taken down.

Static system's calculation


mass of water barrels


test of the foundations with chain draws


catilever test with paving-stones


test of the gallery

Static system's assessment and calculation

Structural elements' assessment
Two different ways were used to calculate the structural elements. First they applied strength values already known by literature, after that the new values resulted from experiments by the FMPA Stuttgart. The first calculation had to use wood's values (NH 10) which are only approximate values to calculate bamboo. The FMPA found out, that bamboo´s strength values are better then the values of wood, although flexuosity and shear were slightly worse. The connections were tested in two different ways, too. First they used results from experiments in Columbia, then they tested connections in Stuttgart.

Quality assurance
Quality had to be assured on-site while building up the pavilion. The Aliso wood was sorted like wood in DIN 4074 (Güteklasse 1 bis 3; Beschaffenheit: Risse, Verfärbungen, Schädlingsbefall). The trunks were tested and some of them were sent to the FMPA to compare these bamboo sticks with others formerly tested there. Although the bamboo should have been pre-sorted in Columbia, wall thickness and diameter differed extremely. So they were sorted in tree classes from carrying to non-carrying.

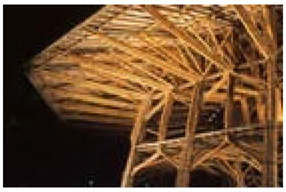
Calculating the structural elements
A high-grade indefinite system required a hybrid attachment where experiments could prove the security of single structural elements. The experiment's results pointed to congruence between first static calculations and load experiments in Columbia and Hannover.


frametest - oblique draw in the gallery plane

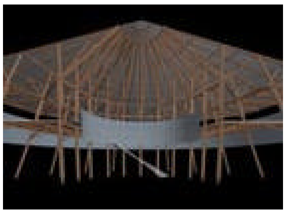
Gallery

To enlarge the picture, just click on it.

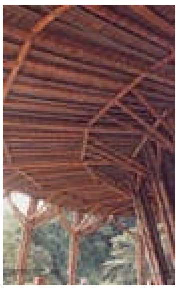

ZERI pavilion on the Expo

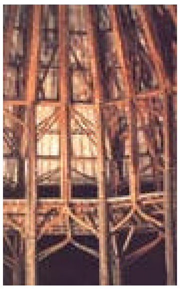

prototype of the pavilion


view underneath the gallery - rendering


section rendering


section


view under the gallery


view inside


ZERI pavilion during the building

List of literature

- Josef Lindemann / Klaus Steffens. Der Bambus-Pavillonzur EXPO 2000 in Hannover. Ein Schritt zurück in die Zukunft. In:Bautechnik. Nr. 7. 77 Jahrgang. Juli 2000. S. 484-491.
- Josef Lindemann / Klaus Steffens. Der Bambus-Pavillonzur EXPO 2000 in Hannover. Ein Schritt zurück in die Zukunft. In:Bautechnik. Nr. 6. 77 Jahrgang. Juni 2000. S. 385-392.

Links

- ✍ ZERI organisation

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