THE BAMBOO AS A SUSTAINABLE BUILDING MATERIAL AND EARTHQUAKE-RESISTANT

Carolina Salazar Ocampo – Architect
Professor at the Universidad Nacional de Colombia
Manizales

Facultad de Ingeniería y Arquitectura
Escuela de Arquitectura y Urbanismo
• ZERI Pavilion for EXPO 2000
• Design in a sustainable way
• Guadua as a construction material in Colombia
The pavilion was built with the best of nature, combined with the technology and creativity of the human being, applying concepts of sustainability and building techniques that led it to be one of the most prominent and admired in Hanover; therefore, it represented conclusively the theme of the EXPO: “Nature, humanity and technology”.

“The ZERI Pavilion is a rich symbol offering a message, which goes beyond the mere building itself. The ZERI Pavilion offers a number of symbols to the world”.
It includes a plant, a flower and two types of grasses, which come from the same Andean ecosystem, with natural coloring from insects and preservation agents extracted from the same bamboo, which preserves itself against insects and molds.
The best of nature is combined with the most creative forms of humanity, i.e. steel and cement. The performance of bamboo is dramatically enhanced with the technique of making joints with cement and iron.
There are one hundred million people without a home. ZERI uses waste (used bottles) and weeds (bamboo, aliso and arboloco are considered weeds) for cheap, functional and beautiful housing as summarized in the book "Grow Your Own House" which is based on the experience gained in this pavilion.
The present economy is good, but not good enough. The world needs a better production and consumption system, we need many more jobs. The ZERI Pavilion includes new building materials, grown and harvested sustainably, it demonstrates a preservation system eliminating toxic chemicals, and as such it creates new work and income.
The ZERI Pavilion does not have an entrance nor an exit, it symbolizes the open mind, where all paths are welcome, from wherever they come, but having the same desire, to do more and better to respond to people's needs around the world.
The ZERI Pavilion presents 7 new building techniques and 2 new construction materials approved by the German authorities, it offers a building method offering people a house which dances along with the movements of the Earth, and it is cheap.
The Pavilion was built without previous experience, without a clear budget, without a guarantee that the final permits would actually be obtained, though everyone who collaborated believed that it would be possible, and gathered all the energy needed to make it happen. And it did happen!
The ZERI Foundation proposed to build the pavilion twice, once in Colombia in order to undertake the stringent stability tests by German professors, which were passed, to then build it at the World Expo. Never in history has anyone built twice any construction to be able to be present at an Expo. The cost of tests and approvals is higher than the building costs.
This building sequestered as much carbon dioxide as was needed to make it.

Bamboo and arboloco used in ZERI housing, and fixed 40 times more carbon dioxide than timber; this building system could actually be financed with the CO2 emission rights that the rich are offering the poor.

Those who contaminate too much can now pay for social housing.
The first ever event held at the ZERI Pavilion was a congress gathering 2,000 young people from around the world who saw in this building an opportunity to contribute to a better world. At the ZERI Pavilion, over 100 volunteers welcomed everyone in nearly 40 different languages. It is an inspiration for all.
There is no better symbol for the work ZERI wants to achieve, “use all waste and weed to generate food and housing”. This pavilion demonstrates that it is possible, and that it is cheap, therefore becoming a symbol for the poorest of the poor who now can take pride in their natural building materials. It is the same for our programs “beer bakes bread”, “cement factory goes organic”, “water hyacinth fights AIDS”
The ZERI Pavilion is the only one considered a masterpiece by academics, which lead to the issuance of a diploma to all the workers. But more important, it is the only Pavilion, which introduces 7 new structural building systems, and 2 new building materials that were totally unknown to Germans. It is probably the best case of the theme “Nature-Humanity-Technology”
The pavilion was designed in a way that pushed the limits of materials and technologies.
• Form: Ten sided polygon inscribed in a circle (diameter=40m)
• Area: Site 2.150m² – Foundations 684 m² – Mezzanine 458 m² – Roof 1.306 m²
• Height: Total 14.40 m – Mezzanine 4.50 m
• Weight: Guadua, Aliso, Arboloco and Chusque 100 Ton – Steel and Iron 10 Ton – Concrete 290 Ton. Total 400 Ton
• Roof slope: 33.3% = 17°
• Columns: 40 aliso columns (20 interior – 20 exterior), 40 guadua columns on the second floor (20 interior – 20 exterior) Columns slope: 20% = 79°
• Access to the mezzanine: Two spiral staircases from steel and bamboo.
• Length overhang: 7.00 m
Guadua

- Family: Gramineae
- Species: Guadua angustifolia, Kunth
- Geographical distribution: Grows in the north of South America. Grows naturally in Colombia, Panama, Venezuela, Ecuador and Peru.
- Ecology: Grows in fertile, rich and humid grounds at altitudes between 400 and 2000 msnm.
- Maximum size of tree trunk: Height 25 m. Diameter: 10-15 cm.
- Environment: The compost of guadua leafs protect the earth and its extensive root system secures the existence of water.
- Utilization in the pavilion: Beams, structure of the double flooring, internal columns, "flutes" (extensions of the columns), support of the roof, crowns and rings.
**Aliso**

- **Family:** Betulaceae
- **Species:** Alnus acuminata, Humboldt, Bonpland and Kunth.
- **Geographical distribution:** Grows in South America in countries like Bolivia, Chile, Ecuador, Peru and Venezuela.
- **Ecology:** Grows at altitudes between 2100 and 3000 msnm. Prefers humid grounds.
- **Maximum size of tree trunk:** Height 35 m. Diameter: 75 cm.
- **Utilization in the pavilion:** Main columns
**Arboloco**

- **Family:** Asteraceae
- **Species:** Montanoa quadrangularis, Schultz Bip. In K.Koch
- **Geographical distribution:** The Andean Zone of Colombia and Venezuela.
- **Ecology:** Grows at altitudes between 1500 and 2500 msnm.
- **Maximum size of tree trunk:** Height 20 m. Diameter: 50 cm.
- **Utilization in the pavilion:** Beams in the double flooring.
Chusque

- **Family:** Poaceae Gramineae
- **Species:** Chusquea serrulata, Pilger
- **Geographical distribution:** Grows in high barren plateaus in the Central and Oriental mountain range of the Andes.
- **Environment:** Chusque secures riverbanks and protects rivers from evaporation, due to the shade it provides. Chusque also has an esthetical value in gardens.
- **Utilization in the pavilion:** Woven into the double flooring.
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Materials
SUPPORT FOR PILLARS

By inclining the columns added support is achieved, making the pavilion stable and adding to its indifference to earthquakes.
FIBER AND CEMENT

The combination of bamboo fiber and cement is an innovation that can replace the asbestos in cement with natural fibers. This technology is using in the making of the roof of the pavilion.

1420 slates - 50% cement 50% bamboo fiber

Product from Teiheiyo Cement (Japan)
Made in Indonesia
CEMENT AND GUADUA

Cement filled into the cañutos, the open chambers of the guadua, serve as reinforcement at the supportive points and also secures the iron fittings.
FILLING THE CAÑUTOS (internal chambers of bamboo) with a mix of cement, sand and water.
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FILLING THE CAÑUTOS
This supportive construction uses the solid guadua rhizomes to strengthen the structural system of the pavilion.
Pillars made out of concrete protect the wood from humidity coming from earth.
SMOKED GUADUA

Immunization through the smoking of the guadua is a productive and sustainable alternative to chemicals used today. Speed of immunization is radically decreased, as is pollution.

Every single guadua was immunized with smoke technique. The guadua used in the ZERI pavilion was immunized in two ovens, most of them in Armenia, by Antonio Giraldo and the others in Pereira by Gabriel German Londoño, both in Colombia.
OVERHANG

The length of the eaves protects the wood structure from water
Construction Techniques

FISH MOUTH

Handmade technique to fit a bamboo with another.
Experimental evaluation of the load bearing properties of the pavilion, by Prof. Dr.-Eng. Klaus Steffens from the Experimental Statics Institute at the University of Bremen, Germany

Professor Klaus Steffens (director since 1980 of the Institute of Experimental Statics of the University of Bremen) has realized experimental evaluations of load bearing and safety for the reconstruction of the Reichstag building in Berlin, among others.

1. Cantilever-roof
2. Ceiling of gallery
3. Frame
Experimental evaluation of the load bearing properties of the pavilion, by Prof. Dr.-Eng. Klaus Steffens from the Experimental Statics Institute at the University of Bremen, Germany

Cantilever-roof

Consisted of determining the load bearing capacity of the cantilevers (a 7.30 meters overhang).

This was done by hanging a weight of more than 650 kilograms in the middle of the third of their spans. A deformation of 7 millimeters was observed, which the structure recovered when it was freed of the burden.
To test the capacity of the upper floor, this structure as loaded down with 55 gallon barrels, which were uniformly spread over the surface and filled with water until they reached a load of 400 kilograms per square meter. When the deformation of the upper floor under this burden was measured, it came to 5 millimeters, which were recovered when the weight was removed. It is important to note that the estimated deformation for this test was expected to reach 25 millimeters, which means that the result was a fifth of the estimate.
The third test involved a simulation of wind stresses and consisted of pulling the structure in a horizontal direction. This was done by placing one cable in the middle part and another in the upper part of each one of the pediments of the pavilion and the subjecting each cable to a horizontal load of five tons. The result obtained was a horizontal displacement of one centimeter.
After carrying out these tests in Manizales, Professor Steffens issued a technical assessment that helped to support the application for the construction permit that was granted for the pavilion in the Hannover Expo-2000 Fair.

This study was complemented by a structural calculation carried out by Professor Joseph Lindemann, an estimate that was based, in part, on the results of traction, compression and flexion tests done by him in Germany.

Thus guadua passed all the tests and was officially authorized for architectural use in one of the countries with the strictest construction codes in the world.
Before the construction process, there were some stages developed in Colombia. The previous stages were very important in order to obtain the German permits.

Prototype – Manizales, Colombia
**Guadua**

Donated by Sr. Gabriel German Londoño Gutierrez from his farm “San Jorge” located in Pereira – Colombia. Cut in decreasing moon 3,500 pieces of guadua (9 m long) and 240 guadua roots.

**Aliso**

Donated by Aguas de Manizales S.A. E.S.P. from its farm “Rio Blanco” located in Manizales – Colombia. 200 also logs.

**Arboloco**

Some of the logs were donated by Aguas de Manizales S.A. E.S.P. from its farm “Rio Blanco”. The others were bought from Maderas y Celulosa S.A. in Manizales. 80 arboloco logs. 160 half pieces.

**Chusque**

Donated by the Comité de Cafeteros de Caldas from its farm “Pedro Uribe Mejía” located in Manizales – Colombia. 8000 pieces of chusque (3m long) carried by mules.
Quality Control

The German authorities request a quality control of aliso logs according to DIN 4074.

The guadua quality control was made according to a standard created by Colombian experts and German engineers, especially for this construction.

Quality control was not necessary for arboloco and chusque.
ALISO QUALITY CONTROL

Quality control was performed to every single log.

The diameters of the logs should be from 18 to 25 cm.

This form was filled for every single log with 4 different tests. The logs should be in Class I or II according to the DIN 4074 standard.
GUADUA QUALITY CONTROL

Class I
Top: cross-sectional area $A > 40 \text{ cm}^2$ and $\varnothing \geq 10 \text{ cm}$
(e.g. $\varnothing 10$, $t=15 \text{ mm}$)
Base: cross-sectional area $A \geq 55 \text{ cm}^2$ (e.g. $\varnothing 14$, $t=15 \text{ mm}$ or $\varnothing 12$, $t=20\text{ mm}$)
Middle: cross-sectional area $A \sim 47 \text{ cm}^2$ ($\varnothing 12$, $t=15 \text{ mm}$) and $\varnothing \geq 12 \text{ cm}$)

Class II
Top: cross-sectional area $A > 30 \text{ cm}^2$ and $\varnothing \geq 10 \text{ cm}$
(e.g. $\varnothing 10$, $t=11 \text{ mm}$)
Base: cross-sectional area $A \geq 40 \text{ cm}^2$ (e.g. $\varnothing 12$, $t=12 \text{ mm}$)
Middle: cross-sectional area $A \geq 35 \text{ cm}^2$ and $\varnothing \geq 11 \text{ cm}$ ($\varnothing 11$, $t=11 \text{ mm}$)

Class III
The guaduas that do not match Class I and II, are not good for construction.
LOAD AND UNLOAD MATERIALS

Manizales: Two containers with Alisos, and one with Arboloco and Chusque.

Pereira: Ten containers with Guadua, Guadua roots and Macanas.

Most of the containers departed from Cartagena Port (Atlantic Ocean) and the others from Buenaventura Port (Pacific Ocean) in Colombia. They all arrived in Hamburgo Port in Germany, and then the containers were transported by trucks to Hannover. The transportation between Colombian and German ports took approximately 24 days. Panalpina was the company in charge of the transportation.
Timeline

Colombia: eight months to build the pavilion

Germany: three months and two weeks
The prototype of ZERI pavilion in Manizales was made with the original sketches of Architect Simón Vélez.

To get the construction approval in Germany we had to make the complete drawings with all the structure details. Then the drawings were reformed and approved by, Dipl. Eng. Josef Lindemann and German authorities.
Simón Vélez Sketches
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Sketches & Drawings
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Sketches & Drawings
From idea to the construction, who has been involved?
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Idea

Gunter Pauli, Founder and director of ZERI foundation, Belgium
Simon Velez, Architect, Designer of the Pavilion, Colombia
Paolo Lugari, Founder and director of "Las Gaviotas", Colombia
Mario Calderon Rivera, President of Camara de Comercio de Manizales in 1999, Colombia
Carlos Bernal Quintero, Director of ZERI Latin America, Colombia
20 tradesmen and 20 laborers, Colombia
Photography & Cooks

Luis Guillermo Camargo, Colombia
Photography

Rosa Emilia Atehortua, Colombia
Cooks

Ruby Esperanza Franco, Colombia
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MINHOCA - Experimental Farm

Development of an experimental farm in the coffee zone. Implementation of various technologies, processes and systems, which can contribute to sustainable development of the coffee zone. These technologies meet the basic needs of the environment, such as water, food, health, housing, energy, labor and education.
Vereda la Trinidad, Manizales, Caldas, Colombia

Weather: warm and wet.
To start this project a first house of small dimensions was built (October 2003 - January 2004), which was designed taking into account the determinants of place and ecological principles: Dry sanitary – Natural Ventilation - Construction with smoked bamboo - Utilization of ZERI pavilion technologies

First level area: 43.63 m² - Warehouse and bathroom area: 34 m² - Total Area: 77.63 m² - Height: 5.90 m
Ceiling: At two waters - Foundation: Reinforced concrete - Warehouse and bathroom walls: Confined brick in concrete structure - First level walls: Bamboo, vein mesh and plaster with mortar - Covering structure: bamboo - Cover: Clay tile - Painting: Cal (white) and earth mixed with water and Acronal (terracotta)
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Concepts Applied

Anders Nyquist

DRY SANITARY
GRAY WATER TREATMENT
SELF SUFFICIENCY IN WATER
NATURAL VENTILATION SYSTEM
This project is based on a high quality housing, no frills, designed with ecological concepts and innovative technologies. All design meets the basic needs raised by the ZERI Foundation (Zero Emissions Research & Initiatives), applying concepts of conservation, adaptation and environmental friendliness.
Architectural Design Concept - Implementation of technologies

- Sun and warm protection in a natural way
- Use of natural resources
- Design with organic forms
- Guadua structure – Treated naturally
- Sun as an energy source
- Bahareque – traditional technique
- Wall inclination
Implementation of Technologies for Construction in Bamboo

Walls inclination for better stability.
In the case of Colombia in 1999 there was an earthquake in the coffee region where many structures were severely affected and the houses built with bamboo were the less damaged, besides these constructions are lightweight that minimize the impacts. In this sense we must recover the local materials and the typical construction systems of each region, and thus take advantage of our ancestors’ wisdom to overcome natural disasters, and also we must maintain the intention to innovate with new techniques.
The guadua is traditional material for construction in Colombia. Most of the rural houses are made of guadua with the "bahareque technique" and there are still a lot of construction in the historic center in Manizales. It has been used as a scaffolding system. Because we have a lot of bamboo and you find it everywhere, there are some people that don’t appreciate its value.
FROM A SYMBOL OF POVERTY TO A SYMBOL OF TECHNOLOGY...

Bamboo Houses at “El Nevado” Neighborhood, Manizales, Colombia.

Social Housing
Arq. Gilberto Florez
Manizales, Colombia
GUADUA ARCHITECTURE IN COLOMBIA

Gaudua Toll, Autopista del Café, Colombia.
Arq. Simón Hosie Samper
Bus stop, Autopista del Cafe, Colombia.
Bridge Jenny Garzón in Bogota, Simón Vélez.
Provisional Cathedral, Pereira, Colombia.
Simón Vélez
GUADUA ARCHITECTURE IN COLOMBIA

Biblioteca Pública, La casa del pueblo
Guanacas, Cauca, Colombia
Arq. Simón Hosie Samper
1er puesto Proyecto Arquitectónico
XIX Bienal de Arquitectura - Colombia
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