

Bamboo Building and Culture

Applications In The U.S.



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cover photo:

Dendrocalamus sinicus, from Yunnan province in southwest China,
grows to 15 inches in diameter at the base.

This species is not yet in cultivation in the U.S., and not much is known of its cold-hardiness
Photo by a member of the Southwest Forestry College in Kunming.

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Simon Velez designs buildings with either concrete or wood frame walls and bamboo roof structures with spans up to 60 feet (27 meters), and cantilevers close to 30 feet (9 meters) as seen in this clubhouse structure in Colombia.



This barrel-vault structure by Velez is built in a tropical area. With no end walls and using untreated bamboo, beetles immediately infested the interior of the poles but consumed only the starchy inner, non-structural core.



Ideas incorporated into smaller structures that could be built in the U.S.: Redundant members, triangulation, bolted connections and all poles held above ground.

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Bamboo Technologies in Hawaii has been importing bamboo poles and mats to build pre-fabricated structures with building permits in Hawaii



This structure was built under the direction of Simon Velez by unskilled Americans in a day

INTRO

Many Americans see bamboo as invasive and out of scale with our chosen landscapes. Whereas, from an Asian perspective, thousands of potential uses make bamboo not just desirable, but a required element in every house. Human culture in northwestern South America was feasible only because of the seemingly endless native bamboo. The Colombian earthquake in January of 1999 flattened 75% of the buildings in the region, but virtually all of the bamboo structures remained intact. This paper explores the progress in fine-tuning methods of using an easily replenished, locally grown material.

Bamboo tools, utensils, food and buildings strongly influence the lives of half the world's population. Bamboo housing has been traced to 3500 BC. The useful life of a pole ranges from 2 years – if buried underground (Hidalgo '92) – to several hundred years as seen in rafters of traditional Japanese farmhouses. Simple, quick joinery systems based on pegging and tying have given way to bolted joinery, which is both less labor-intensive and much stronger. Bamboo is the key element in designing large structures of minimal impact. The industrial infrastructure required for wood, concrete and steel production is not needed. Because of the speed and density of growth of bamboo, with a relatively small amount of land, a builder can be in full control of his or her source of material supply. So, one is able to think differently of bamboo buildings. In North America, we lack a bamboo culture, one that recognizes value in the use of this plant: gaining access to inexpensive land which is not valued for other purposes, choosing appropriate species, allowing the time for maturity, understanding the aesthetic of working with cylindrical materials in a predominately rectilinear society, learning to distinguish exceptional working stock, and developing a design approach which takes full advantage of both the strength and beauty of the timber bamboo, these are our challenges.

Bamboo is native to every continent except Europe, once covering millions of acres in the Southeastern U.S. Bamboo is an extremely strong fiber – up to twice the compressive strength of concrete and roughly the same strength to weight ratio of steel in tension. The hollow shape approximates the ideal shape of a beam. (Janssen '97). In the United States, now is an ideal time to draw upon the proven bamboo-working methods from Southeast Asia and South America as this is the first time in our history when a seemingly unlimited, highly subsidized source of structural-quality wood lumber does not exist in this country. While there are already thousands of timber bamboos growing in the western and southern U.S., many Americans have never seen one. Typical opinion of the plant is based on knowing only two small, running bamboos out of the 1500 species that exist. And the whole system of growing, processing and especially understanding bamboo does not yet exist in this country. Because of the relative scarcity of timber bamboo in the U.S., this discussion will concentrate on using the giant grass for its highest and best use: to take advantage of both the strength and the beauty.

Dutch researcher, Dr. Jules Janssen: "How much strength and stiffness can I buy with 1 kilogram?"

Strength:

Material	Stress	Mass per Volume	Ratio
Concrete	8 N/mm ²	2400	0.003
Steel	160 N/mm ²	7800	0.020
Wood	7.5 N/mm ²	600	0.013
Bamboo	10 N/mm ²	600	0.017

Stiffness:

Material	E-modulus	Mass/Volume	Ratio
Concrete	25000 MN/m ²	2400	10
Steel	210000	7800	27
Wood	11000	600	18
Bamboo	20000	600	33

"In the first table, bamboo ranks second," says Dr. Janssen. "In the second table, it ranks first."

E-modulus = Young's modulus Source: Dr. Jules Janssen, 11/29/96 Moso is quoted (Zou, 1981 & 1985) as having a "Tensile strength parallel to the grain" of 1,960.6 kg/sq cm. Its average density (Specific gravity) is quoted as 0.61. This converts to a tensile strength of 192 N/mm squared.¹

By comparison, Dendrocalamus asper is quoted (Surjokusumoa) as having a has a MOE of between 227 and 307.27 N/mm², between 16 and 57% stronger than Moso. D aspers average density (SG) is quoted at 0.7, which is 11.5% heavier than Moso.²

¹ Zou F in 1981 and Zou H M in 1985 translated from Chinese by Lou Yiping, an associate Prof working under Fu Maoyi at the Fuyang Research Institute.

² Surjokusumo of Bogor University, Subyakto Indonesian Institute of Sciences (LIPI), with further references by Widjaja and others.

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	Bamboo	Spruce	Concrete	Steel
Tensile strength	35-300 N/mm ²	90 kp/mm ² = 9N/mm ²	1/10 of compressive strength	250-350 N/mm ²
Compressive strength	64-110 N/mm ²	43 kp/mm ² = 4.3 N/mm ²	12.6 - 126 N/mm ²	250-350 N/mm ²
Shape characteristics	1.9 times stronger than a solid due to hollow cylindrical shape Efficient in compression and bending	Because it's solid, more weight to get same load-carrying capacity	best as composite with reinforcing in tension zone	Most efficient in tension, capable of most work in smallest cross section
Fire resistance (seconds until ignition, Dunkelberg '85)	Acts as firebreak when growing, (61.2 untreated)	(19.1)	Will not burn, but prone to spalling as steel expands	Loses elasticity, risk of quick failure
Embodied energy btu/cu.ft.	Minimal, unless imported	Transportation can be high	42 - 96,000 (ERG '97)	91,618 (ERG '97)
Regenerative capacity / year (Cooper '92) ³	80-300% (28,000 - 50,000 lb./acre)	3-6% (16,000 lb./acre - pine)	None	None
Time to maturity	7-9 years	60-80 years	--	--
Subsequent maturity after initial harvest	1 year	60-80 years	--	--
Conforms to Natural Step's 4 system conditions ⁴	Yes	Yes	No, fails first three	No, fails all four

Traditional Uses

Bamboo has been classified as having over 1500 different uses, including fences, gates, trellises, and every part of a building. In South America, structures of the native timber bamboo *Guadua* were popular for rich and poor until several catastrophic fires in Colombian cities at the turn of this century relegated the use of bamboo exclusively to the poor. (Vélez '96) And, unfortunately, most of those living in these structures consider them a temporary step on the way to a more "permanent" concrete house. The current work of a few – especially Simon Vélez and Marcelo Villegas in South America and Bobby Mañoso in the Philippines – are making bamboo structures acceptable among the wealthy once again, which is critical for ultimate acceptance by all. It is estimated that over 800,000 people live in bamboo structures just in Guayaquil, Ecuador today. Similar statistics can be found for much of Latin America. Our

collective efforts at building cities could be considered more sustainable if many of these average people could be convinced to use mature bamboo, inexpensively and benignly treated, to make beautiful cities rather than considering their houses temporary steppingstones on their way to much more energy-intensive structures.



House for former Ms. Colombia, by Simon Velez

In Andean Colombia, timber bamboo is commonly used as structural posts, split open and

³ Though this is the only U.S. study which compared yields of bamboo and pine, W.H. Hodge of the USDA estimated that bamboo annually produces 6 times as much cellulosic material per acre as does southern pine.

⁴ 1. Substances from the Earth's crust must not systematically increase in the biosphere
2. Substances produced by society must not systematically increase in the biosphere.
3. The physical basis for the productivity and diversity of nature must not be systematically deteriorated.
4. There must be fair and efficient use of resources with respect to meeting human needs.

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flattened to be used as lath, finish wall surface, ceiling surface and flooring. Flattened poles are actually cheaper than round ones. Very rarely is bamboo separated by grade, age, thickness or any criteria generally accepted for materials like wood. In Colombia, only 5-10% of the poles for sale in the “lumber yards” selling exclusively bamboo are mature enough to be considered structural. Most of the poles sold are used for scaffolding and concrete formwork.

Traditionally, one can usually find bamboo, whether left over from a construction project or growing nearby. In recent years, population pressures have significantly reduced the supply accessible to the public.

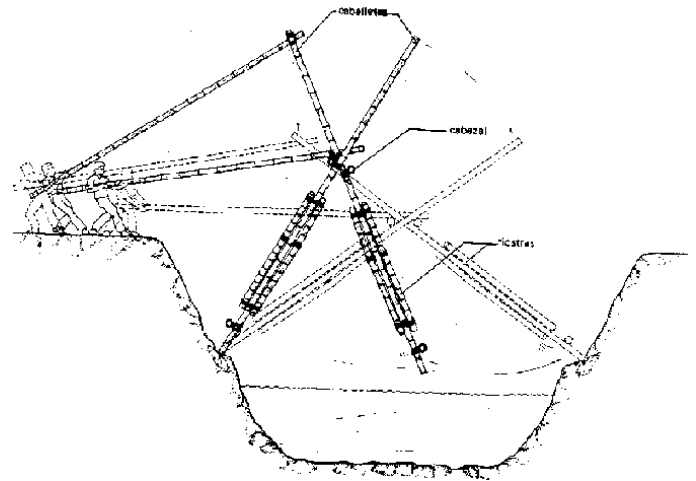


The National Bamboo Project has planted 2000 hectares in the last several years in hopes of bringing back the plant that once blanketed the region and was so critical to the establishment of human settlement.

In rural Thailand, parts of Indonesia, and many Pacific islands, bamboo is used for every aspect of life. In most of the rest of Asia – especially Japan – bamboo is used less structurally and more decoratively for walls, flooring and the occasional roof frame. (See later discussion on Japanese Traditional Curing Methods) Much of the way a region makes use of bamboo is rooted in a tradition of isolation. In some areas, truly inventive ideas used for centuries would be rejected in other places as entirely impractical. For example, bamboo roof shingles work well in the humidity of Bali but tend to split under more intense sun. Traditions of uniquely detailed doors have been developed to keep livestock out of houses, window lattice is the strongest available material to give both ventilation and personal expression, an entire house full of furniture can be built for a materials cost of less than a day’s wage. Where bamboo grows, it allows.

Because bamboo systems require relatively little space, the same small number of people can be involved all the way from planting through

utilization. These few can be in full control of their bamboo supply and be flexible enough to shift production into whichever of bamboo’s 1500 uses is most in demand. There is minimal need for infrastructure or equipment. Every part of the plant has a use and the appropriate timing of that use not only doesn’t hurt the plant, but encourages future vigor. The groves can be located to take advantage of the plant’s unusual ability to quickly process nutrients and water left over from livestock farms, sewage treatment plants and industrial processes. In contrast to most plants, when bamboo receives excess fertilizer, it does not become “leggy” and out of control. Instead, the quality of the poles remains steady, as there is a time lag while the energy is stored in the rhizome for later release as next year’s culms. (Liese '92) The structure of those rhizomes is meanwhile very useful for holding topsoil and for erosion control. Even though bamboo is a heavy feeder, there is evidence that mycorrhizal relationships with soil and rhizome are developed to make the soil in a mature grove more fertile. The plants create their own microclimate with transpiration to cool a grove as much as 10 to 15 degrees F. The branches and leaves are useful as animal fodder with a protein content equal to alfalfa several times a year.



Few bridge structures are this easily portable. Few building materials can be used to span a long distance, then be carried away on one’s shoulders. The strength to weight ratio is thought-provoking.

Composites

From our orientation toward wood as the most common building material, bamboo is an awkward shape without the forgiveness of wood which allows nailing or gluing on another piece to solve problems. Our tendency is to try to make

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bamboo into wood. Flooring milled from thin strips of bamboo and woven matting are two very simple substitutions for commonly used materials. These changes require no training or shift in mindset. The problems will have more to do with the inherent difficulties of industrialization: demand outstripping sustainable supply, local producer economies destroyed by outside owners and cash economy demands, and short-sighted use of cheap materials, etc. Bamboo is more capable than any other plant material of keeping up with the demand, if it is well managed. With the big flooring companies now gearing up to be the major producers of bamboo flooring, it will be interesting.

The species available currently include the temperate specie, Moso, which is the most consistent, nearly white color. Most suppliers also offer a fumed (not stained, so the color goes pretty deep) darker color. Other tropical clumping species from Asia and recently, South America, are what allow the color variations. For the established companies, look at www.4specs.com

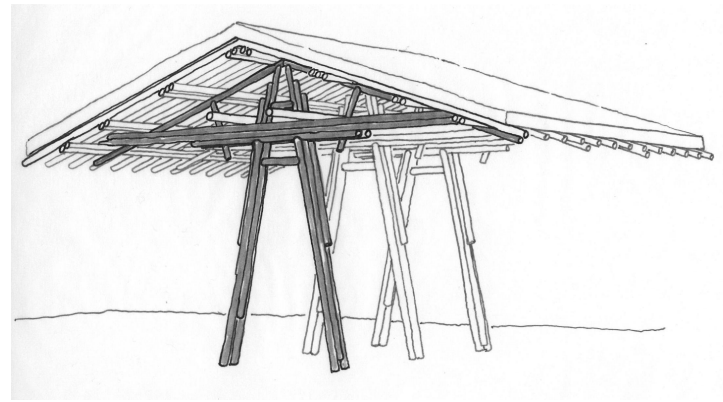
By far the most common glue used in composites is urea formaldehyde, which is highly sensitizing, generally accepted as carcinogenic and should be avoided. Significantly better are the polyurethane, isocyanate and aliphatic "carpenter" glues, which are non-reactive after a day. A more sustainable future is quickly arriving with the recent release of soy-based glues, which can allow building materials to permanently stay out of the toxic category. Assuming we keep in mind the social implications of our materials decisions, and encourage local control of locally appropriate materials for local use, many of the problems can be solved.

Checklist for well-designed bamboo truss structure

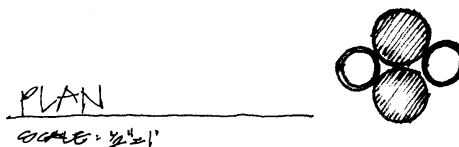
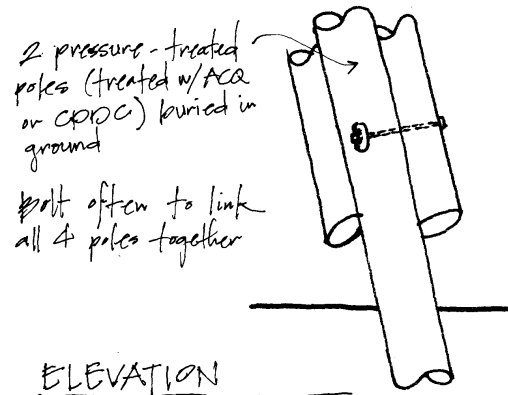
- Good solid static analysis to distribute loads more evenly among the joints and axially along the pole
- Slenderness ratio of less than 50 (Arce '93)
- Bolted joints with solid-filled internodes
- Dry poles that are still easily workable – about 6 weeks after harvest is ideal
- "Good hat and pair of boots" for your building – keep the poles out of the sun and dry
- Find a way to obtain lateral strength – either through creating a shear panel consisting of

a mortar-bed over lath or avoid mortar altogether and rely upon redundant triangulation within trusses to distribute the forces

- Refer to the engineering formulas and testing criteria developed by Jules Janssen (Janssen '97)



In this structure designed by Simon Velez, redundancy and visual richness is found in using multiple poles along the same line, the overhang is wide, and the only parts touching the ground are pressure-treated wood. An alternative connection to the ground would be to bolt the bamboo to a steel angle iron set into a concrete footing.



There are only 2 kinds of joints (see 'Joinery Design,' for illustrations of both), along with strategic locating of steel straps where tensile forces are greatest.

Building Code Approval

Through most of the world, there are no provisions in the codes for bamboo construction. A model non-prescriptive code written by Jules Janssen for the International Network on Bamboo and Rattan (INBAR) is intended for inclusion in the year 2000 International Building Code and could have a lasting impact on widespread acceptance. This code helps the user to analyze beams, trusses, columns, joints and composite mats. Dr. Janssen has also written, for INBAR, the *Standards for Testing Bamboo*, an important work because of the many species and the current difficulty of comparing test results by different people. Relying heavily on Dr. Janssen's work, the International Conference of Building Officials (the people responsible for the Uniform Building Code) have written the "Acceptance Criteria For Structural Bamboo," effective in the U.S. since April 2000. For a copy, call 562-699-0543, and ask for Subject AC162-R2-0300. Contained in this document are rough formulas and known performance characteristics. Unfortunately, missing are the design values for individual species. Currently seeking funding for the needed testing are Jeffrey Trudeau and David Sands of Bamboo Technologies in Maui, Hawaii. Trying to find \$20,000 to generate information that would then be in the public domain, makes securing private sponsorship difficult. In the past, a strategy of theirs was to use ferro cement (a thin shell of concrete trowelled over wire mesh and rebar) to build a house with stay-in-place formwork (that just happened to be bamboo). Ferro cement has full code approval, and was considered the system supporting the building.

- **Just ask** – Building Departments are given the power to approve any alternate building system (1997 UBC Section 104.2.8), provided that "sufficient evidence or proof be submitted to substantiate any claims made regarding its use." Ask your local official to interpret that one.

- **Put a designers neck in the noose** – Another approach is to put the design and inspection responsibility in the hands of the designer. For example, the County of Kauai Building Official wrote an open letter, which asks for the signature and stamp of a structural engineer or architect, along with special inspection (1997 UBC Section 106.3.5) during construction. They also suggested that a prescriptive code be developed by the local design community to "provide uniformity in submittals." As the U.S. is

expected to adopt the International Building Code, Janssen's model code will likely be able to apply here, but a step-by-step prescriptive code will be very useful to allow approvals in jurisdictions with little experience in structural bamboo. The first all-bamboo structures have been approved in conformity with the current code.

- **No permit required** – For places in the U.S. with unenthusiastic building officials, there is 1997 UBC section 106.2, exempting from permits "*One story detached accessory buildings used as tool and storage sheds, playhouses and similar uses, provided the floor area does not exceed 120 square feet (11.15 m²).*" This provides the opportunity for anyone to get something built which can help convince the building officials of the viability of larger structures.

Earthquakes and Wind

There are two different strategies for overcoming lateral forces. One – represented by the recent, engineered Latin American structures – relies on the shear provided by mortar on both the bamboo-lathed walls and roof. In April 1991, 20 houses constructed with the cooperation of Dr. Jules Janssen in Costa Rica survived a 7.5 earthquake near the epicenter. The relatively lightweight bamboo structures attracted far smaller lateral forces than the surrounding masonry buildings, which sustained significant damage. The other approach uses the forgiveness of the traditional lashed, pinned or bolted joints of both Asia and the Americas. In both locations, much anecdotal evidence shows them surviving unscathed when the much more rigid adjacent concrete structures routinely fail. Even the structures with intuitive engineering and non-optimized joinery take great advantage of the broad elastic range of bamboo in allowing it to be pushed out of shape and return once the load is removed. It is very difficult to cause failure in pure compression or tension, and bending can be quite dramatic and still not fail. "Failure is not failure." (Janssen '97) The joints are most critical.

In overcoming lateral forces in roof structures, Simon Velez and Marcello Villegas have created the redundant second roof. They feel it is important to design structures with redundant systems, capable of both tension and compression. A joint purely in compression under gravity loading might be pulled apart in

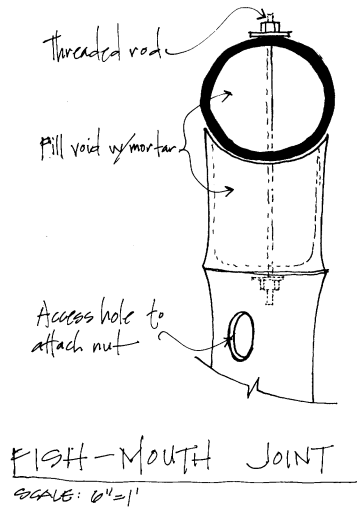
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tension in the event of high winds or earthquake. So, a second set of rafters that triangulates with the first, can carry those temporarily opposing forces when needed. As an added bonus, this sophisticated structure is quite beautiful.

Joinery Design

Lashed and pegged joinery has been used successfully for millennia. It allows for movement, and if natural fibers like jute, hemp, rattan or split bamboo are used while still green, they will have a tendency to tighten around the joint. Unfortunately, in most of the U.S., the seasonal moisture changes will cause the bamboo to expand and contract by as much as 6% across the diameter (Dunkelberg '85), causing a slackening of the joint, and not all joints remain accessible for tightening. It is also important to distinguish between tension and compression joints, a joint designed purely in compression under gravity loading might be pulled apart in tension in the event of high winds or earthquake.

The joint of preference has become the bolted connection developed by Simon Velez in Colombia. The first of two types is where the two poles are meeting in the same plane to form



a “T.”

Because the end of one pole must be carved to meet the curve of the other, it is called a “fish-mouth.” The bolt is critical if the joint ever needs to resist a tensile force, and filling both poles with mortar at the incident of the joint is what makes the whole system work. The complex fitting is usually done with only a machete, a method universally considered too difficult for gringos. I have also used the curving end of a stationary belt sander or a forstner drill bit the same size as the pole.

The second variation – much easier than the first – is where two or more poles are crossing to form an “X.” A hole is drilled for the bolt to go through the two poles and another about 3/4” dia. is drilled nearby to pour in the mortar. To place this hole, think about how gravity will cause the mortar to flow downhill, and imagine how the hole will be seen in the finished truss. There may be a side hidden from view.



In avoiding the “fish-mouth” condition where perpendicular poles are in the same plane, the X joint encourages us to design trusses multiple pieces thick, creating great opportunities as in this roof structure, designed by the author.

When loads are well distributed throughout the structure, bolts can be used without mortar. An example of this is the traditional layout of a house in Japan. A gable roof consisting of rafters spaced closely together is topped by purlins running perpendicular to the rafters. Many joints are created with relatively small loads at each.

A simple vault design can consist of pieces coped to fit together purely in compression. Because gravity holds them together, no bolts are needed under gravity loading. But, if this vault is placed on top of vertical walls, a horizontal collar tie member must be added to prevent splaying. This piece must be bolted and mortared. If there is an additional lateral load,

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like wind, the design needs more triangulation to hold the compression-fit pieces together.

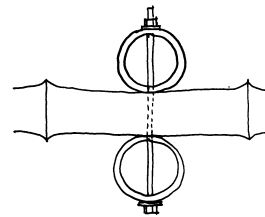
Where members of the truss come together at angles, and tension forces are anticipated, a steel strap is placed to bridge the pieces, and the joints filled. Especially for center-bearing trusses, tensile loads on this strap can be quite large. For all of the dozens of structures built by Velez, he says, "I have never seen the bamboo fail, only the steel straps have failed under load testing."



Tools

The appropriate use of tools is difficult to teach in a book, best is to learn from craftspeople like Doug Lingen – 530-292-9449 or Nicanor Non – 218-668-2545. But a few general principles can be discussed. Because of the lack of reinforcing for the very long fibers in bamboo, one needs to cut, not tear or pull those fibers. In drilling, this principle translates to the use of brad-point bits for smaller holes and Forstner bits for larger holes. In cutting, this principle forces us to rotate the pole during the cut so fibers are pushed toward the pole not pulled out to tear down the length of the pole.

AVOID ECCENTRIC LOADS



BALANCE LOADING WITH SYMMETRY

Design opportunities

Experiments to gain the spans achieved by Simon Velez have taken place far from any inspection. Now that these 66 foot spans and 30' cantilevers exist, they stand as proof of what works and as a model which might enable us to attempt only one quarter the span and still find it adequate for most of our needs.

Make Use of Smaller poles

In this country, by far the most common variety is *Phyllostachys aurea*, or Golden Bamboo. Next is *Phyllostachys nigra*, or Black Bamboo. These two are readily available, but rarely longer than 15 feet or over one inch in diameter. The fibers are strong, though somewhat prone to splitting. A great challenge is to find use for these common varieties. One solution is to make structural members out of split bamboo. This allows the further advantage of being able to form curves, as in this trellis

designed by the author. (Photograph by Jacqueline Lytle)



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Build Structures Exempt From Permits

Detached accessory buildings less than 120 square feet are exempt from permits, according to the 1997 Uniform Building Code, section 106.2. The following is an ad hoc bus shelter we built in a day as part of a workshop in Seattle.



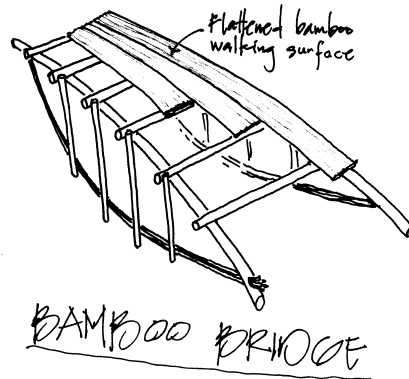
At the University of Oregon, this structure we built would have been small enough to qualify under the “accessory” provision, but the students did obtain permits and historical board review to build it on campus.



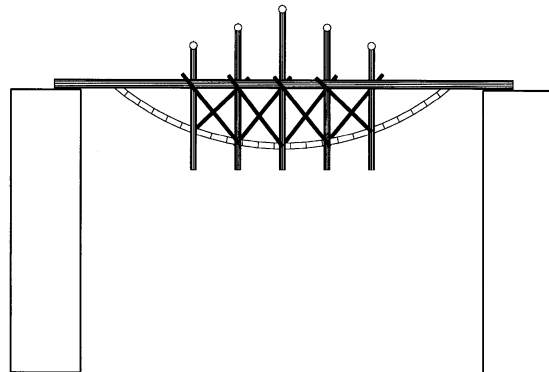
Use curving poles

In contrast with Asian groves, a characteristic of many of our available timber bamboo groves is that they were never thinned to maximize pole production. In the new shoot’s search for light, the pole can become quite curved. This truss designed by the author uses the “camber” in that large pole as the top of a bridge. There

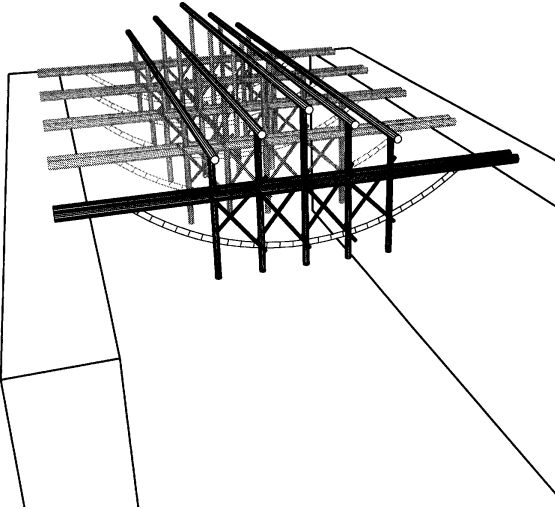
will be two of these trusses with joists to connect them and a mat of split-open bamboo as the walking surface. (photograph by Kevin Falkerson)



The same idea can be applied to a roof structure:

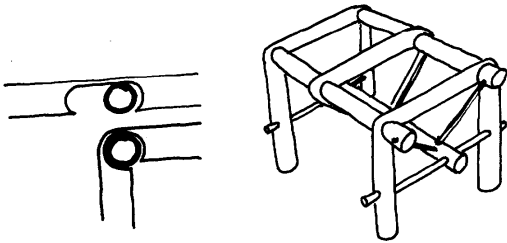


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Use as both tension and compression members

As in this stool, the same member can act both as a compressive post as well as a flexible fiber, capable of bending into tight radii.



Use custom cross sections

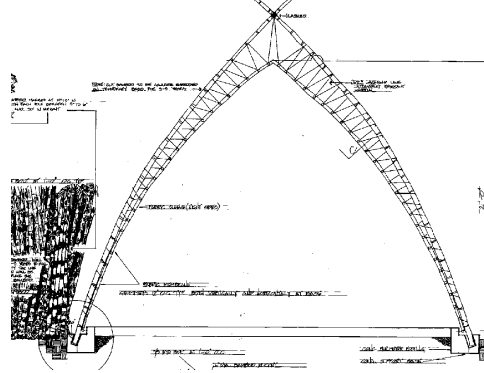
As the new shoot is forming, it can be molded simply into, for example, a square cross section. This ability can bring bamboo at least occasionally closer to our rectangular mindset. (photo by Woody Woodworth)



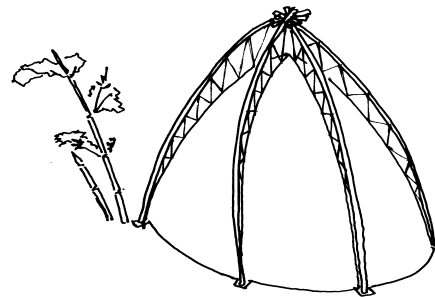
Living structures

Because of the speed of renewal and durability of the living plant, once a master plan for a site is created, future buildings –

and especially trellises – can be anchored to the ground. In this case, a structure is planned and temporary poles carry



the tensile fabric roof while the bamboo is given a half dozen years to mature. Once the culms are large enough, they will be bent and tied together at the center of the circle. Bob Mandich, designer.



Or, if a design calls for a strong edge, plant a fence or trellis:

LIVING FENCE/TRELLIS

Fill trench with well drained, high nitrogen soil, manure compost

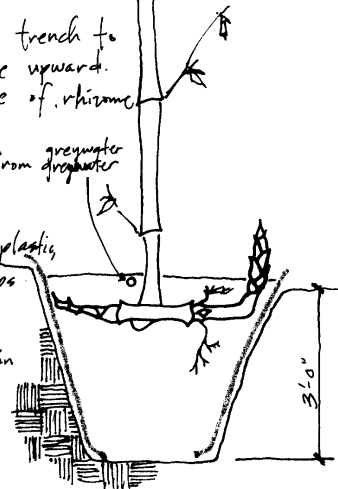
Slope sides of trench to deflect rhizome upward. Don't bury edge of rhizome barrier.

Drip/soaker hose from dripper

Barrier: 40 mil plastic, use stainless clamps at joints

Allow base to drain

Lay rhizomes along length of trench

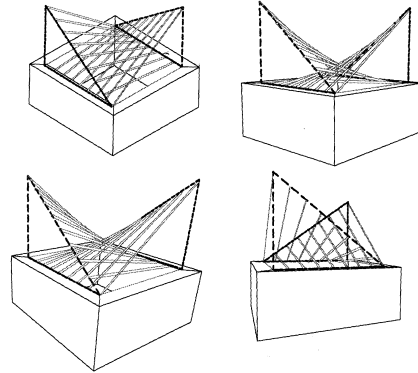


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Strawbale composite



The "all-grass" solution: bamboo, straw bales and thatch (not shown). It begins with a bamboo substructure formwork upon which the bales are laid and pinned together with bamboo or rebar. Another superstructure of bamboo over the top is tied through the bales to the substructure creating a composite beam to make the whole structure integral. [architects Dan Smith and Bob Theis 510-526-1935; Kelly Lerner 510-528-3765, see articles in *The Last Straw* # 12, 14, 17 (520-882-3848)]



The structure below was created at the Bamboo Hardwoods factory in Vietnam by a French architect



Use straight poles to define curves

Curved roof and wall surfaces can be described with a series of straight lines, as in this design by the author:



Urban Landscapes

Few plants are capable of such a sizeable presence in a small footprint. Bamboo can lend texture to a façade and soften while still

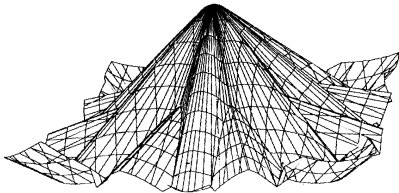
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allowing transparency.

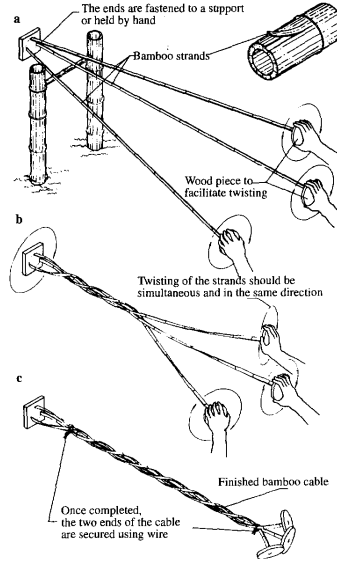


Building as Basket

Imagine being able to weave an entire building the same way as the integrally strong baskets are made. This is a design by architect Shoji Yoh. The bamboo was woven and supported by temporary posts as it was lifted into position. A very thin concrete shell was cast on top of the bamboo framework.



Rebar / Cable



Oscar Hidalgo has achieved success in turning culm splits into something of a braid, increasing the surface area for adhesion (Bali '96 v.3, p. 76). Janssen has mixed feelings but thinks the technique is sometimes appropriate (Janssen '95, p. 49). For our use, research focus should be on using bamboo for carrying distributed loads like footing reinforcing and slabs rather than for concrete beams where loads are too concentrated.

Composites

Bamboo flooring and plywood are making inroads because they are easily substituted for standard hardwoods. Most are glued together with the less preferable glue, urea formaldehyde as that is what is most commonly available in Asia (and dramatically cheaper than the preferable polyurethane or aliphatic glue, also known as "carpenter" or yellow glue. The flooring installs exactly like other tongue-and-groove floorings, so the installer doesn't even have to know it's bamboo. Some versions of the plywood consist of long, laminated strips, making the board quite stable. Voids are few, gluing and finishing are the same as most hardwoods, though the lack of crossgrain keeps stains from soaking in, so most coloring is done with smoke or chemical reaction. The bench below was designed and built by the author from vertical grain plywood made distributed in the U.S. by Smith and Fong, 650-??? (show how it's glued??) .

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This gluing pattern gives the designer the same straight lines and predictability as the sinful vertical grain douglas fir which can only be made from huge, old-growth trees. In an industry where designers can only specify standardized materials (i.e. 2x4, #2 grade), this material could make quite an impact on slowing the use of scarce resources. My only reservation is the glue, and the solution there is to use a good sealer, like AFM's Safecoat? or at least a water-based varathane.

Split mat – esterilla

The versatility of this plant is seen when making a flat mat from a round pole. These mats are used for flooring (spanning as much as 6 feet), as a plywood substitute, as lathing under plaster, and siding where ventilation is desired. The trick to making “esterilla” is to split the bamboo many times without having more than one of the splits run the full length of the pole. The first step is to split it many times at each node with an axe. To break the nodes all the way through, it may still need to be hit with a hammer. Then, open one split the full length and open it up.



In Colombia, we saw the better quality poles sell for about a dollar, while the crooked or blemished poles were made into esterilla and sold for seventy five cents – even after all the “value-added” work. Unfortunately, in both Colombia and Ecuador, the

practice is to have no grading system and the vast majority of poles and esterilla for sale was less than a year old. It's easier to tell the age of tropical bamboos as the moss and lichen count is linear with age. Always choose the worst looking poles as they are the most mature.

Flooring using Esterilla

Through much of the bamboo world, esterilla is used as flooring. Desirable features include ventilation of the space, soft feel on the feet due to the convex shape, ability to span long distances meaning less supports are needed. The allowable spans are culturally dependent. In China, spans are up to 5 feet.



In Ecuador, spans are half that and large splits of bamboo are placed under the esterilla for extra stiffness. In the U.S., acceptance of this floor structure is doubtful due to our desire for stiff floors. Nonetheless, when this simple, strong system is used, some form of treatment is necessary because so much of the sugary interior of the pole is exposed.

Social Housing

As a solution to social problems, especially in places with huge numbers of people with absolutely nothing, bamboo finds a niche. In Guayaquil, Ecuador, several hundred thousand people are estimated to earn less than \$50 per month. A housing program called Hogar de Cristo, run by Jesuits, finds a way to provide housing – often unsubsidized – for all the women who need it. By using locally available materials: the vertical aerial mangrove roots that can be harvested sustainably (though not always done so in practice) for the frames, with split-open guadua esterilla “plywood” as siding, people can have a secure, ventilated, solidly-built structure that can be erected in a day. In such a desperate situation, land is obtained by a sort of institutionalized squatting system. For electricity, there is only illegal (but widespread) access. And, there is no plumbing but yet it remains a viable solution due to the local availability and ease of working with this plant. It occurred to me that for the price I paid for a mediocre

hotel room for a few weeks, I could have bought several houses. If similar thoughts run through your mind, Hogar de Cristo can be reached through their

website at ??? and they accept bank deposits through their account:???

Bamboo growth strategies

The plant

Think of bamboo differently. The strength of the plant is underground awaiting next year's shooting season. One can dig up a 60 foot tall culm and keep it alive in a 24 inch pot. It's future has less to do with the visible portion above ground, and much more to do with how well the rhizome below ground has been storing energy throughout the year. You are only rewarded next Spring for how well the plant has been cared for the entire previous year. Choose plants that are literally bursting out of their pot. A plant that appears the same size above ground can have a year's head start once planted out.

The new shoot emerges from the ground as large as it will *ever* get. As the plant becomes established, subsequent year's shoots are larger than the "parent" culms. Don't succumb to the temptation to take the largest, nicest looking culms as they are always the youngest and probably aren't ready yet. Temperature is a key factor in the production of new shoots in running bamboo. Studies by the USDA determined that the years with the most days under 40 degrees F corresponded with increases in the following year's number of shoots. Bamboo, because it is shallow rooted, has evolved a complex relationship with certain soil microbes. A photosensitive algae is used by root tips to determine optimum sunlight conditions for new shoots. Studies have begun to uncover some mysteries of bamboo nutrient uptake by close analysis of microscopic nutrient transfers. Scientists in Asia have begun to identify the role that mycorrhizae fungi have in allowing bamboo to break down and absorb complex minerals as well as bring nutrients and moisture from lower strata. In the U.S. climate, with different fungi and different relationships with other more deep-rooted plants, some success has been had in injecting spores of some of our fungi, and in considering mushrooms one of the major crops of the grove. Rhizomes have low survival rates when detached from the mother plant at times other than spring when new shoots occur. But, rhizomes with even the smallest plants attached will have a much higher survival rate, leading to suggestions that the amount of shooting is regulated by substances produced in the culms or leaves, according to

USDA research⁵ in the early '60's. It has been established that the culm itself is capable of photosynthesis.⁶

The fiber lengths vary across the culm wall: shorter in the interior and exterior than in the center of the wall. The shortest fibers are near the nodes where cracking is likely to first appear. (Liese '92) Fiber strength is significantly greater at the exterior. One aspect that has yet to be fully explored is the sharp contrast between the way wood is formed in trees – from the cambium layer outward to form bark and inward to form annular rings – and bamboo which, as a grass, forms by stretching. The structural and design implications have yet to be explored.

Original forest "types" for the *Phyllostachys* genus show a close associative affinity to deciduous hardwood forests of subtropic and mild temperate zones surrounding China. In a twenty-year forest analysis in Hunan Province, supplemental mulch of bamboo leaves and pine needles proved the most effective at inducing nutrient absorption. Both of these unrelated plant families have evolved symbiotic mycorrhizae. Bamboo's ability to occupy a shallow soil zone and absorb nutrients from surface litter which contain toxic alkaloids is due to the quick fungal breakdown of the elemental nutrients before the toxins kill the delicate feeder roots. A mulch of rice hulls was found to be the most effective at both providing minerals and raising soil temperature to induce much earlier shooting (when prices are higher) and dramatically increasing the number of shoots. (Bali, '96 – Qungen et al)

Control

One reason the running bamboos have attracted the ire of neighbors is that the rhizomes can travel as much as 30 feet horizontally in a year with no visible signs of growth. Those intending to use the culms intensively welcome this aggressive search for nitrogen and water as the edges of the grove can be easily contained with plastic rhizome barriers, two foot deep ditches or using mulch as a growth medium, allowing the rhizomes to be easily dug.

⁵ anonymous

⁶ Dr. Hau-Po Mok, personal correspondence

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If an existing grove has overstepped its bounds, remember that the straight rhizome is the lifeline back to the mother plant. Follow the line of shoots back to the acceptable spot and sever the rhizome there. Then find a member of the American Bamboo Society to remove any traces of your timber bamboo, or cut the poles near the ground and break off with your foot any new shoots you see emerging over the next few months. Soon there will be nothing to sustain the rhizome and it will give up.

Running bamboos produce a limited number of viable rhizome buds, sometimes spaced a foot apart. If a plant is divided leaving no buds, the plant will not spread.

In places where bamboo naturalizes, it is almost never cultivated. This means that it is only available in the forest which is owned by all, yet when population pressures come to bear, it is those places with unclear ownership that are overharvested first. Because bamboo is such a valued resource, there is never a question of bamboo taking over. The problem is much more often the opposite. With edible bamboo shoots selling for \$4 per pound retail and a 24" pot of mature timber bamboo selling for \$1500, 5 gallon plants routinely retailing for \$50, there is a much greater fear of bamboo poachers than of the plants taking over. Conversely, there is a threat from gophers, deer and neighboring goats when the plants are small.

Species selection related to climate

For structural use, several species stand out and lend themselves to specific climatic selection. While wind should be avoided and water ever-present, the most significant factor in site and species selection is temperature. Several large, strong temperate *Phyllostachys* running bamboos can withstand 0 degrees F., and appreciate hot, humid summers: *P. bambusoides*, *P. heterocycla pubescens* (*moso*), *P. nigra henon*. One clumping timber spans the range between the temperate

runners and the tropical clumping types: *Bambusa oldhamii*, hardy to 15 degrees F. (although its new shoots happen in November and December, so even though the plant may not be killed, it can be set back a year with a hard freeze) The tropical clumping varieties like the other *Bambusas*, *Guadua* and the strong *Dendrocalamus* species (*D. brandesii* and *D. asper*) will barely tolerate freezing, although extensive research with interplanting among trees, avoiding frost pockets and using mineral-salt fertilizers is being carried out in Australia (Cusack '97) which has found success in resisting temperatures 9 degrees F. colder than the species was previously seen to tolerate. But, again, for those of us in the northern hemisphere, the vulnerable shooting season is the coldest time of year here.

Daphne Lewis details species selection for growers in the U.S. Pacific Northwest, covering the *Phyllostachys* varieties related to size, hardiness, quality of poles & edible shoots, forage quality and flowering dates. (Lewis '98)

Water sources

Through most of the West, the rains happen in the dormant season for running bamboo. The time of most intensive water need, in late Spring when the new shoots occur and late Summer when the rhizome growth occurs, is the dry season. So, especially here, bamboo is inextricably tied to care given by people and well meshed with urban systems. Eighty million gallons of sewage and stormwater are processed each day in the city of San Francisco, the amount can double on a rainy day. All of the treated freshwater is eventually dumped into the ocean. In fact, the waste created by people is often ideal for bamboo: the phosphates in soap, the nitrogen in food waste can make greywater a very consistent source of sustenance. The secret to growing giant *moso* seems to be to water it every day, so a constant source of industrial greywater can solve several problems. In places where septic systems won't percolate the soil, the EPA now encourages sand filter evapotranspiration systems (<http://www.nsfv.wvu.edu>), where a plastic liner keeps any effluent from reaching the ground. All water must exit through evaporation or transpiration. In this system, bamboo with shallow roots, great height and large surface area of transpiration can accelerate the transpiration system. It is easier to grasp the potential when one enters a large grove as the new shoots are emerging. Water droplets are pushed ahead of every tip of new growth and it literally rains there. [Diagram of Watson Wick]

Checklist for obtaining construction-quality poles

- Age – 3-5 year old culms best, depending upon species
- Starch content – harvest at right time of year to minimize beetle/fungus attack (see chart)
- Appropriate species for the intended use (Lewis, '98)
- Sufficiently adapted to local humidity – especially for interior use
- Stored out of direct sun, preferably vertically

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- In the running bamboos, use the bottom 5 feet or so for other purposes as it is usually crooked, has nodes too close together and density characteristics different than the rest of the pole
- Treated for insects and fungus if used outside (think wood)

Cautions

Giant timber bamboo is the wrong scale for our most commonly created American landscape: the suburban single family lot. The rule-of-thumb is that a mature grove wants to be in radius the same as the height. So, a sixty foot high *Phyllostachys henon* grove will expand to a 120' diameter and find stasis and comfort in the micro-climate created for itself. There are, however, many useful smaller species, especially mountain clumping bamboos hardy enough for many colder areas. Consult the ABS species list.

It takes longer to achieve a mature grove (4-10 years) than most people are willing to stay in one place.

New plantings of bamboo are extremely fragile, as the rhizomes may have just been cut – somewhat like an umbilical cord – from a single organism that may have covered thousands of square feet. Until the canopy grows high enough to shade the ground – usually several years – the new plants are subject to quickly drying out, neighboring hungry horses, gophers, or an ill-timed frost. One quick mistake can be fatal to a new grove.

• **Bamboo supply**

Currently available timber bamboo poles in the United States consist primarily of culled, older, ungraded, highly blemished and fumigated (upon import) material from China. What we have to work with does not at all resemble the Kyoto system (see the harvesting and curing section), which we might hope to emulate.

• **Longevity**

Some species have a higher starch content and leave themselves open to earlier attack from fungus and insects, so much of the information on longevity has to do with local conditions: with more rain, humidity, and tropical climate, the quicker bamboo will return to compost. If buried underground, in most places, bamboo will survive a couple of years at most. In tropical rainforests with no preservative treatment, houses are expected to last from 3-5 years intact, rarely will they last longer than 15 years. The whole structure is rebuilt in a matter of days as part of an accepted rhythm.

In the U.S., thoughts are long-term because of mortgages and the fact that we expect perfection when hiring someone to do our work. In the Colombian Andes, one of the stronger, longer-lasting species, *Guadua angustifolia* has traditionally been used untreated for posts, beams, flooring, roof structure and lathing for plaster walls in houses now over 90 years old. This thick-walled species can withstand some beetle damage and still stand. But, it is only possible using culms that are at least 3 years old when cut and the plaster on the ceiling and walls protects from beetle damage. (Hidalgo '92) In Japan, temperate, running bamboos have been seen to last hundreds of years when used as ceiling structures receiving the smoke from unvented cooking fires. (see the section on curing)

Cracking can be the first step toward breakdown as insects are then allowed access and the strength of the tube is lessened. Exposure to the sun and dramatic changes in humidity combine to increase the frequency of cracking. Both the interior and exterior shell of the pole are watertight and the appearance of cracks on a hot, dry summer day is accompanied by a loud popping sound as the pressure finally equalizes in the pole. Some timber species, like *p.n.bory* seem predisposed to cracking more often than others, but the splits can be minimized by both evading the sun and keeping the humidity high, or at least constant. And, for fence or gate structures which are not attempting to span, the common technique is to punch out the nodes with a steel rebar or by making an incision along an unseen side to encourage splitting to happen there. In designing structures, it is very important to keep the forces axial within the length of the bamboo, and not place any imbalanced or eccentric loads.

Bamboo Harvesting and Curing Techniques

There is a huge compendium of stored knowledge in traditional bamboo cultures-- a living tradition kept by craftsmen following methods that have proven effective over generations. In one of the most rigorous systems, still kept alive today in Kyoto, each specie of bamboo required a slightly different harvest and curing procedure with key seasonal factors dictating once-yearly maintenance to clean up groves and produce useful byproducts.

Methods traditionally used to preserve bamboo culms for light construction fall into two categories:

The first principle is a clear grasp on local growing conditions that can be manipulated to give best results. Bamboo needs a moist well-aerated soil to spread rapidly and produce high quality poles.

The second principle of culm preservation is the method of drying. Because there are no radial fibers in bamboo, the hard outer layer won't transpire and, if dried too quickly, will split due to its watertight quality and shrinkage around the solid node. In regions where bamboo thrives, winter temperatures seldom stay below freezing long enough to

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create the super-drying effect found in Europe and the Eastern United States. Three to four months of air drying is sufficient to slow-cure the poles. These months of curing should be cool, the area well ventilated and free of organic material that could harbor pests. Most importantly, the culms should be stored horizontally out of direct sunlight to prevent uneven curing.

Harvests and Grove Maintenance

Propagation of small plants is labor-intensive and slow, especially for the running bamboos. So, the price of plants in the U.S. will probably remain at a premium. Planting a grove of timber bamboo in loose soil like sand and mulch allows for easier propagation and digging of rhizome. Groves can be a high value use for wet soil especially. The major work season should fall during the plants' dormant months, and the work in a mature grove

involves harvesting very young edible shoots and mature poles. In China, the proportion of harvest is to take 80% of the shoots as food to thin the grove and leave 20% to mature into well-spaced (2-3 feet apart) poles. These will be marked with the year of their shooting and taken after 3-5 years. Ideally, poles should be harvested about 6 weeks before use, as they will have shrunk to their expected size, while still maintaining the working characteristics of green bamboo. In early spring, walking in the grove should be avoided once the shoots are expected. Several varieties, notably *Moso*, push moisture ahead of the new shoot, so a very clear wet spot can be seen on the ground just before the arrival of the new culm. Those with tough feet will walk through the grove barefoot to feel the arrival of new shoots so that soil and mulch can be mounded over the new arrival postponing by several days the contact with air, which causes the shoot to become inedibly fibrous.

Bamboo harvest seasons in Western U.S.

	Running bamboos	Clumping bamboos
Edible shoots	March - June	October – December
Rhizome divisions	Just before shoots begin	January – February
Plant divisions	Avoid heat of summer	January – February
Leaves as animal feed	Anytime, esp. after pole harvest	Anytime, esp. after pole harvest
3-5 yr. old poles	April - June	January – February

Once the grove is mature, culms selected for strength and durability should be in their third to fifth season of growth, and harvested when sugar levels are at their lowest. In the tropics of South America and Asia, this corresponds to the dry season. On the west coast of the U.S., the best time may be late Spring once shooting has ended for the running species.

Sidebar

Wet season harvests have three immediate problems:

1. fungal contamination from the humid conditions
2. insects are active during the same wet season,
3. excess pole moisture makes them difficult to fully cure -- traditional harvesting techniques apply to regions where bamboo evolved within the forest.

Bamboo Aesthetics and History of Preservation

Before exploring the process of curing bamboo for interior uses, it is worthwhile acknowledging that the cultures of Japan and China are attracted to bamboo's natural green color and understand the

value of perfectly unblemished poles. The effort of harvesting bamboo on the day of use to make, for example, cups and a sake dispenser, demonstrates respect for the guest, generating frequent comments on the beauty of the freshly harvested culms. For this type of "instant" construction there is of course no preservation method – the materials are selected fresh and used immediately. The "new" green color reflects an esthetic of renewal. While the older waxy green color, short-lived, expresses strength and special awareness of a season or annual festival. Structures of green bamboo can be rather large-scale and always exude functionality--common booth displays for bonsai plants or a shed stall with a canvas cover. The roof material is also of a temporary nature; the most traditional covering, (seldom used since the advent of blue polyethylene tarps), would be a *Sasa palmata* bamboo leaf thatching – woven onto a light bamboo frame over *Phyllostachys nigra f. henon* rafters. Larger structures can also incorporate *P. bambusoides* posts and beams with simple lash and mortise joinery. This temporary structure is light and easy to assemble and disassemble with easily replenished local ingredients.

Permanent structures in Japan usually rely on heavier structural materials such as wood posts and

pine log beams, with bamboo incorporated as rafters and purlins for the ceiling, over which some form of thatch is applied. The model for this type of framework comes from the thatched roofs of farmhouses which, until this century, was the most common rural roofing material. Thatch was easily available, and the periodic re-thatching was a chance to replace bamboo weak rafters. What allowed this type of roof to last more than ten years or so were the flue-less fireplaces of the traditional farmhouses. The smoke wafting up through the bamboo and thatch coated the entire surface with an acidic film similar in composition to creosote which slowly dried and preserved the bamboo framing and *Miscanthus japonica* thatch. The resulting bamboo ceiling frame can last several hundred years and be highly resistant to insects. Traditional untreated and uncured bamboo structures without the benefit of this smoke curing, are said to only last for ten years before the bamboo is infested by powder post beetles. Selecting bamboo as an interior ceiling frame wisely keeps bamboo well away from destructive moisture, which is invariably, the problem in using bamboo as a foundation.

The bamboo ceiling prototype of the country farmhouse has metamorphosed into the elegant bamboo elements used in the Japanese Tea Ceremony. The refined utensils and architectural elements all derive from the "rustic" esthetics, often called 'wabi sabi'. These mood-evoking terms refer to the simplicity sought in the understated designs reserved for the tea room architecture. As the actual tea room is never large enough to accommodate a fire, the preservation techniques for the bamboo curtains and window frames and ceiling are somewhat unique.

Traditional Japanese Curing Method

The winter harvest and curing previously noted is followed by a short secondary curing. This second curing lasts only one or two weeks. First the bamboo poles are selected to match one another in size and evenness of internodal spacing, determined by the culm's location within the grove. Near the center of a mature grove the culms have fewer branches and must stretch to reach the available sunlight; this characteristic also creates very evenly spaced nodes without branches for several meters from the ground, and these poles have somewhat thinner walls which makes them dry uniformly from bottom to top. After careful selective grading the bamboo is transported to a special curing yard set up with peeled *Cryptomeria japonica* drying racks. At this point the partially aged poles are pale green in

color. Apprentices are set to work leaning the poles vertically in the sun-- the season is usually dry but without intense sunlight or high winds. During the secondary curing the poles are turned constantly-- each pole must be turned two or three times a day to keep sunlight from splitting the culm. After having been spun approximately twenty times they are ready for the final process of smoking the poles quickly to preserve them with the creosote naturally in the smoke. The charcoal pits are constructed at ground level two to three feet wide by the length of the pole -- twelve to fifteen feet long. Each pole is suspended over the pit by two workers standing at either end of the pit and slowly spinning the culm between them until the light green color begins to vanish. This final process takes less than five minutes. It is important that the pole has received enough time in the yard prior to this final processing. If the culm has been dried too quickly the baking cure will result in a blotchy "finish". The Japanese expression for the final curing is 'rokettsu-dosu', which refers to removal of the exterior culm wax, which naturally occurs on the outer surface of bamboo. The wax is quickly wiped off while the pole is still piping hot, leaving a highly polished surface. While still warm, the poles are flexible and can be straightened. As soon as the poles have been wiped and cooled in a well-ventilated rack they are stored upright in tidy storage barns, ready for use. At this point the color is an even tan shade which will very slowly patina over time.

Recently, a method of boiling bamboo culms in caustic ash solution has been used in Japan. The method employed is to follow the curing process for three months and then to boil the culms for twenty-five minutes. This method is less time consuming and expensive, but does not leave a satisfactory polish on the culms and brings a lower price for the finished product. In Costa Rica, culms are boiled in caustic soda to remove the wax so their dark flame-finish will apply evenly.

The insects are most interested in the starchy fibers closest to the interior of the culm. But neither the smoke nor the boiling methods effectively reach those fibers. Holes can be drilled into each internode to allow some penetration, but since there are no radial fibers in bamboo, full treatment is not always possible, depending upon species. In tropical regions especially, it is most advisable to treat with a pressure-injection system, like the Boucherie.

Preservation with Borate Solution

The "Boucherie" method was pioneered by Dr. Walter Liese, of Hamburg University. This

technique replaces the starchy sap of the just-harvested bamboo with a borate/borax salt solution to make the cellulose and lignin fibers indigestible to insects and microbes. The culms selected must be of mature age and the machinery close enough to be processed in the first day after harvest while the sap remains fluid and capable of capillary action. The dye-marked solution is pressure-fed until it is seen at the far end of the pole. Borates are used as fire preventative in various insulations, but no testing has been done to our knowledge on the fire-resistance of the bamboo poles treated with borates. More information on this method has been disseminated through the INBAR bamboo research network in India, and the borate is a less toxic (to humans) method to preserve bamboo culms — although it appears to be difficult to incorporate in industrial-scale production methods

Finishing the surfaces

Careful handling keeps bruises and imperfections from spoiling the clearest possible finish. Again, if the culms are not thinned and are allowed to grow

too close together, they will cause a great deal of surface damage to one another.

With the natural waxy coating of bamboo — especially the older culms — there is no strict requirement for applying a finish. If a stained or torched finish is desired, the wax must be removed first, usually by boiling or by abrading with wet sand.

Regardless of color or striping when alive, almost all bamboos dry and turn a consistent light brown. One exception is *P. nigra*, which can maintain the black color, especially if kept out of the sun. Another exception is *P. nigra bory*, also known as Leopard bamboo because of the spots that remain even after drying. The Japanese have refined an artificial method of obtaining a similar coloring using sulphuric acid mixed with mud.

A dark brown patina is obtained with the smoke curing method described above under “Japanese Curing Method.”

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Overview

This paper is intentionally sketchy about specifics because of the many variables involved for someone to try to replicate the work here: bamboo species, age, curing method, wall thickness, bolt size & material, mortar type, and especially design variables. This work is very buildable and that by knowing some of the details of the way Velez works, we might begin applying some of his methods in the U.S., especially with smaller structures for which permissions can more easily be received. Larger structures should involve Mr. Velez – there is no substitute for experience.



Velez is a graduate architect, from the University of Colombia in Bogota. He has completed over 60 projects using a controlled palette of concrete, bamboo, mangrove wood, woven palm mat lathing (or expanded metal lath) and clay roof tile.



This view is up at a ceiling through the palm mat lath.

Simon Velez works from Bogota, Colombia, South America. As much of his work has been in very rural areas for ranchers, he has been allowed to experiment with the locally available materials due to a lack of a regulating authority and the relative difficulty of importing the standard building materials of brick and mortar.



The two critical breakthroughs Velez is able to teach us relate to the bolt joinery with filled internodes and the approach which uses no sheet goods (such as plywood) to achieve extraordinary shear strength in high wind and earthquake areas.



In Velez' designs, roofs framed only with bamboo are capable of cantilevers as long as 28' (above). Especially intriguing when considering how much weight is in his standard roofing of clay tile set in a full mortarbed – he feels the heavy roof is needed to combat the high winds, exactly the opposite of conventional wisdom in the U.S. Clearly, we have much to learn.



In the image above from the book, *Tropical Bamboo*, one can see a rare simulation of what Europeans saw when they first came to this part of the Andes: a continuous, feathery guadua forest. While the botanists have classified several sub-species of *Guadua*, Velez feels that many of the plants are the same species, and it is the different climate and soil

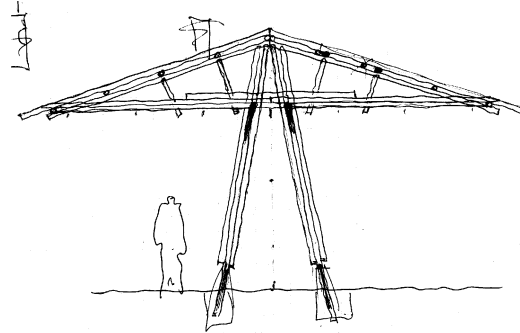
type, which have great effect on plant characteristics and pole quality. For example, Bogota is too cold: a little too high in elevation (2600 meters) for *Guadua* to grow. His source of poles is in the lower elevations outside the city, but there is a significant structural difference between the 8-inch (20 cm.) diameter coastal *Guadua* and the preferred 4-inch (10 cm.) which grows in poorer soil and slightly cooler temperatures. When Velez works in neighboring regions and countries, he brings a supply of the favored bamboo with him. Learning the appropriate microclimate for each strain of each specie is one of our most arduous tasks in the U.S.



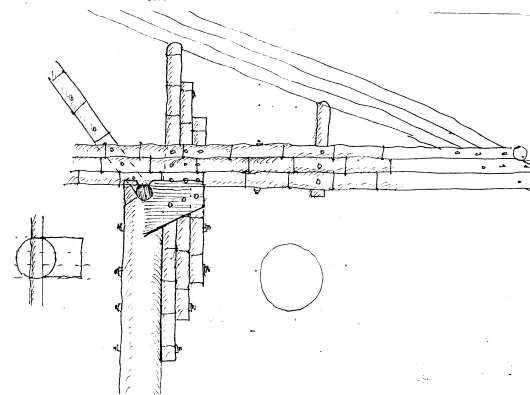
The species of timber bamboo preferred by Velez, *Guadua Angustifolia*, achieves full height (100 feet +) in 2 months, adding only strength for the next 3 years at which time it is harvested. It is reputed to be the only species of bamboo capable of having nails driven into the culms without splitting. However, it doesn't tolerate frost well and will only grow in the far southern U.S. states. He was impressed with the strength of our *Phyllostachys* varieties, though nobody has tried these kinds of spans here.



In the trusses at the base, the wooden poles are joined in the same manner as the roof bamboos.

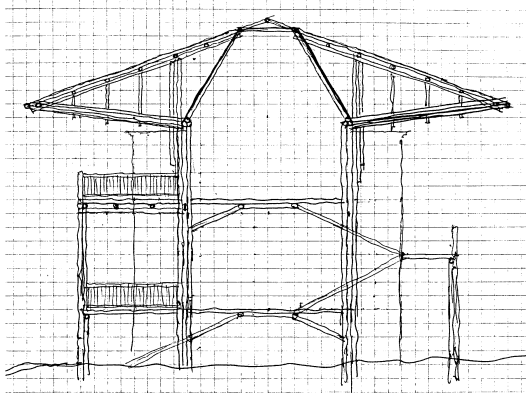


Velez has developed a very interesting model for building experimental structures. He builds only with his own well-trained crew of workers, so he is able to constantly draw upon past successes and failures in detailing. He intentionally keeps drawings simple, usually freehand on single sheets of 8x11 graph paper. Full-sized details are mocked up on-site or are referenced from the memories of past jobs.

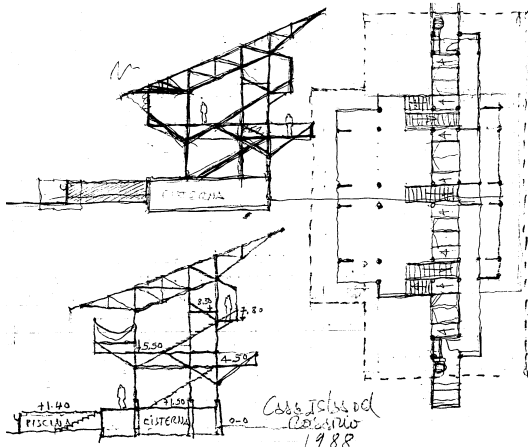


In traveling with Velez, I saw numerous original drawings sprinkled over the jobsites. Because he is free of the contentious architect/contractor relationship, his drawings are done completely to serve the building.

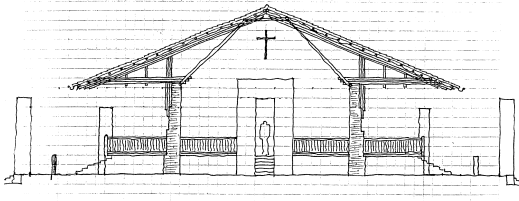
To Velez, the building is all that matters. If absolutely required, the client must obtain Building Permits, but he won't help. Velez views every moment's delay as an impediment to the most important task of building. Detailed drawings are seen as another delay. The client is shown very few drawings. What is important is that the client maintains absolute faith in his ability to execute the work.



He keeps that by making drawings that embody the intent of the structure.



Most useful are the section views which are usually repeated through the whole building.



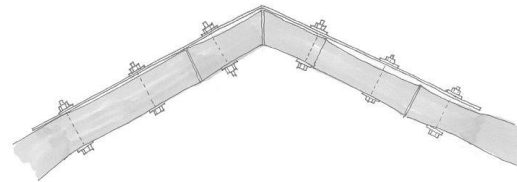
The clearest concept to be seen in his drawings is the necessity for balance. These cantilevers are very large, but maintain an obvious center of gravity over the support.



All joinery is done with bolts, he never uses tying because the bamboo shrinks and the joints become slack. Sometimes the bolts are reinforced with straps where the forces are the greatest.



His experiments have made his buildings exercises in statics - keeping most of the members in tension, but where compression and shear exist at the bolted joints, he fills the internode with mortar to keep the bolts from crushing the walls of the bamboo.



With many of his center-bearing trusses (posts close to the middle of the truss), the point of great strain is the very ridge. Across the ridge Velez puts a steel strap which is bolted through the bamboo on either side. In stress tests, it is this strap or the bolts which fail. He has yet to see the bamboo fail.

The only substantial publication of his work is a book published by Rizzoli call *Tropical Bamboo*, now out of print. If you can find a copy at a library, it is the best source for giving a context to Velez' work. In it, Velez wrote, "At the beginning of this century, two successive fires in Manizales razed only the upper-class houses. The rebuilding of the city center and cathedral saw the first use of concrete and marked the demise of the use of bamboo or any kind of wood. Ever since, in Colombia, bamboo and wood have been synonymous for slums and misery."



When he does a structure that he considers experimental, he charges little and tests at full scale. Clients don't let him test those structures to failure like he wants, they live in them.



These images show that bamboo used as bamboo, taking advantage of its unique qualities is capable of so much more than solid wood. We can begin to transition to the use of structural bamboo in this country by building structures half as big as these and still feel confident in the integrity of the material.



It is important to note that in Colombia, the wealthy are now accepting a material that is inexpensive and associated with poor people.



Pound for pound, the *Guadua* has a better tensile strength than steel. The structural strategy is to design trusses which take advantage of the tensile strength of bamboo, then, where the inevitable shear and compression loads exist, the internodes, through which bolts are placed, are filled with concrete.



A passive solar, bamboo-framed house where the mortar and plaster is put to good use as thermal storage.



Velez believes traditional joints are unreliable. If structures are to be plastered, organic ropes can't be cinched up in 3 months when the bamboo shrinks or in 2 years when the humidity rots the rope. *Guadua* is so strong and will definitely continue to shrink and

swell that it will overwhelm any other binding material.



He advocates a rigorous approach to structural engineering where the stresses are spread out more evenly throughout the structure. That way, in theory, many of the bolts could actually be removed because the structure is in static equilibrium. Just the key joints are reinforced with concrete.



One of his first structures, with no preservatives. The beetles which immediately attacked, ate the soft, starchy interior of the bamboo and then exited, having done no structural damage because all the strength is derived from the bamboo's hard outer shell. (Powder-post beetle infestations in temperate, thinner-walled species like *Phyllostachys* can be much more devastating) His early designs shared the characteristic of this barrel-vault truss, which put components primarily in compression.



The future

Photos of Velez' design of the Colombian Pavilion built for the year 2000 Hanover Exposition can be found at <http://www.zeri.org/> Imagine, a 9000 square foot public building of bamboo. German tests showed that ten ton loads at the end of the trusses deflected 5 cm. The expo runs through October. (photo by Luis Camargo of ZERI)



Lessons learned

Velez' methods of work are, in many ways, different than those in use here. Some of the key components we can come away with include the strong scientific basis of the design – he considers bamboo a “high-tech” material, deserving of very rigorous detailing. His intuitive ideas come from long experience with the qualities of the material.



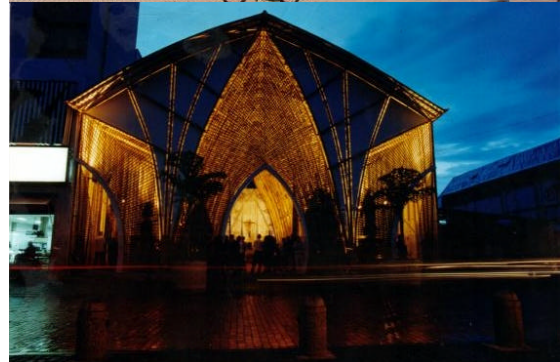
Above all, bamboo structures which employ these long spans are still quite new and I urge extreme caution. Because just one flawed, uninformed design can cripple future building possibilities, we should all err on the side of being too conservative and overbuild redundant systems guaranteed to be the last to collapse in catastrophic events.



Velez' new office under construction



Art nouveau detailing with rebar



The cathedral, rebuilt in 7 weeks after the earthquake. There was some discussion that masonry takes longer, and tends to fall on people in earthquakes.



An art gallery with a bed made of guadua.



Not all of the truss needs to be visible in the final ceiling.



“Fish-mouth” joints on both ends of a line of poles make precision a necessity.



Even the bathrooms can have a simple, primal quality

Marcelo Villegas and Simón Vélez

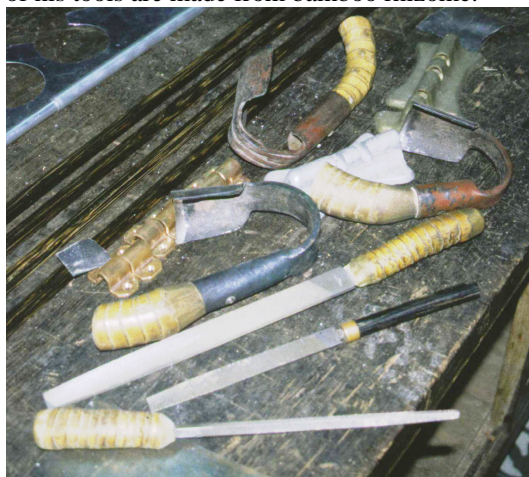
I went to Colombia with the express purpose of seeing some of the bamboo buildings of Simon Velez. What I found was significantly more. In the region of Caldas, where the giant timber bamboo *Guadua angustifolia* is native and still quite abundant, there is also the work of Velez' best friend, Marcelo Villegas, author of the book, *Tropical Bamboo*, builder of about 8 houses,



and furniture craftsman with a 3-story workshop



and his own foundry. He makes all the tools he needs, including a modified planer to cut the ubiquitous “fish-mouth” joints used so often in Colombian bamboo construction. Even the handles of his tools are made from bamboo rhizome.



In every corner of every room is a prototype, an idea partially born. We could have spent a week in that one building.

Though others thought he was crazy, he felt that he requires enough bamboo that he planted *Guadua* throughout his 5 hectares of coffee, phasing out the “traditional” cash crop in the next half dozen years. Being near the equator and at nearly 7000' in elevation, every day is a pleasant temperature, very similar to Colombia's National Bamboo Center's recommended daily high temperature of between 68 and 78 degrees F for *Guadua*. Imagine being able to plant small slips of bamboo, needing to do nothing for them for 2 ½ years, just returning in time to see 4" diameter shoots. This is the plant that once covered the landscape and informed the farmers where the most fertile soil was. Now relegated to non-tillable areas adjacent to waterways, drainages and steep slopes, *some* *Guadua* is still visible from any vista.



Villegas is convinced that this is the species he must work with, he had no interest in importing others which might give different size poles, edible shoots or be resistant to Santa Fe disease, the little-understood blight that did a great deal of damage during the last year. (A bacterium or virus may have caused the disease, and the unusual El Nino drought simply made visible what had been present for years.)

The culture of bamboo creates unexpected sights. The local “lumberyard” sells no lumber from trees. Only bamboo is found – at a cost of USD\$0.80 per pole – and used mostly as scaffolding or shoring, with the flattened poles made into sheets for concrete formwork, flooring, siding or ceiling finish. After a standard construction project finishes with the poles, the workers take them home and build their houses with them. I was surprised that almost all of the poles for sale were harvested too early, a condition that is very easy to see there because of the lack of lichens and mold on the poles younger than 2 years. So there are two problems, the *guaduales* are not rejuvenated and the available poles are weak, contributing to their reputation as a lesser building material among the poor who seek an eventual house of concrete. Interestingly, wood frame walls simply don't exist there. Brick is regarded as much quicker, while bamboo lath and plaster is faster still. 180,000 of 220,000 people in the city of Armenia, near the epicenter of the Colombian quake, were made homeless in January of 1999 because their houses were built of concrete and brick. The recent bamboo

Marcelo Villegas and Simón Vélez

buildings survived well while some of the much older, untreated bamboo structures known to be unsafe, collapsed. There are plans to rebuild relying much more on bamboo. A question I have is whether a grading system will be implemented in time.

While it's still unclear whether first designed by Velez or him, Villegas now makes several variations on a chair that makes interesting use of the nearly ninety degree connection of the rhizome to the culm.



When he needs a smaller angle, he harvests the bamboo on a steeper slope. But with the sub-roots (feeder roots?) coming off the rhizome averaging over an inch in diameter, digging these guys is no small task. With this species, the rhizome neck is consistently around 2 feet long horizontally, and it swells to make for a very animal-like body. (see the photograph of his lamp on page 107 of *Tropical Bamboo*, it gets a reaction from everyone) Another design is a couch with suspended cushions.



The sophistication of the roof designs by both Velez and Villegas is worthy of a book-length discussion. The interplay of complete and separate systems of tension and compression within a single roof makes quite a beautiful experience, and a particularly difficult challenge to represent in photographs that can only show a small percentage at once.



One of the most spectacular structures is also a good study in the methods of work.



This tower was built to give an overview of what is virtually the only tourist attraction in the region: a coffee plantation with a cable car. Almost precisely on the epicenter of the earthquake, it was undamaged. Designed by Velez and built by Villegas with the details worked out in frequent site conferences, there were minimal drawings and no engineering calculations. As an architect, it is refreshing to see a process with so few people looking over one's shoulder. Both men have little faith in the ability of engineers to appropriately analyze their buildings because so few really understand the capabilities of bamboo. During the Costa Rica Congress, I observed the many academics present spending most of the week focusing on the perceived limitations of bamboo. It was quite enjoyable to watch Velez calmly nod his head in respect and diplomacy, then to take the stage at the end of the week, and show building after building that spoke eloquently of how little patience he has for the naysayers.

World's Fair Bamboo – 20,000 square feet

By Darrel DeBoer, photographs by the author unless noted. This article speaks to code, seismic and structural issues around one of the largest bamboo structures ever attempted.



The theme of **Expo2000 in Hannover**, Germany allowed each country to show off their ecological vision for the 21st century. The “Hannover Principles,” drafted almost a decade ago after great deliberation among the best thinkers in the field of sustainability, were almost universally ignored. All the vision in the world could only generate the usual lifeless steel and glass 3D travel brochures instead of truly thoughtful design. The U.S. pavilion was conspicuously absent while virtually every other country in the world participated.

Several traditional earthen structures from Ethiopia, Yemen and Bhutan, focused well on the past. But, the only two buildings in the entire fair offering intriguing new solutions were Shigeru Ban’s Japanese pavilion, made entirely of paper and the bamboo pavilion from the **Zero Emissions Research Institute** (www.ZERI.org) designed by Simon Velez from Colombia.



Japan pavilion made entirely of several-hundred-foot long cardboard tubes and resin-coated paper

ZERI's mission is to put together industries and processes where the leftover from one becomes the fuel for the next, with no waste at the end. Bamboo met their criteria well as they state that the giant grass sequesters 40 times more CO₂ per square meter

World's Fair Bamboo

per year than pine trees, and the preservative method was to smolder bamboo sawdust to smoke-cure the culms. In effect, the bamboo treated itself against insects and fungus using the naturally occurring

pyrolitic acids. The spectacular CD, available on the ZERI website explains the details through drawings, and many photos.



In a structure 14 meters (47 ft.) high, 40 meters (139 ft.) in diameter, using 4,000 Colombian *Guadua angustifolia* culms, some small diameter “Chusquea” culms (used as the ceiling under the mezzanine level) and Arboloco (Montanoa quadrangularis), or “crazy tree” wood columns; 39 Colombian carpenters built the whole building in 13½ weeks. The result is one of the few buildings that meets the modernist promise of beauty resulting from a stripping down to the bare essentials of structure. The natural curvature where the root becomes the pole is used with striking results visually and structurally. The ZERI pavilion was one of the few places in the fair where one didn’t have to pay to occupy space, the huge overhangs were immediately packed when the daily rains began. In such a respite, many only then took notice of the truly natural beauty surrounding them.



Almost nobody noticed the deft use of recycled coke bottles that keep the mortar from coming out the ends of the handrails. Filled with mortar, the clear plastic looks like stone.

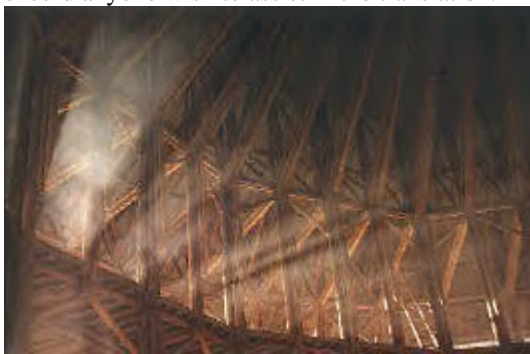


Scale is hard to feel in 2d images. These are 4 photos, taken with a 28 mm lens, digitally stitched together.

World's Fair Bamboo



In a move that will now enable bamboo building through most of the world, the extremely thorough German engineers and fair organizers subjected the design to extreme structural testing. The authorities stated they would only accept either hundreds of pages of calculations (the criteria and formulas for which, are too conservative to approve such a structure), or full-scale testing. So, the 19,700 square foot building was built in Colombia first and passed. The high strength-to-weight ratio of the hollow bamboo kept the structure very light while still allowing much redundancy. The whole project was only possible because of the joinery system. (see the Bamboo chapter of *Alternative Construction*, edited by Lynne Elizabeth and Cassandra Adams (ISBN # 0471249513). Ten ton loads placed at the edge of the 7.5 meter (26 ft.) cantilevered roof caused a movement of just 5 centimeters (2 inches), almost all of which came back after the load was removed. It was enough to allow an identical structure for Hannover. A building permit was received the day before the fair began. The author has a copy of the original German test results should anyone wish to assist in the translation.



This image, taken by a ZERI photographer, captures the piercing quality of light



In Colombia, a 'guaduale' planted at the when this Velez building was built from the plant's predecessors

The idea for the pavilion was being formed at about the time of the earthquake in January 1999, in the coffee/bamboo-growing heart of Colombia. Nearly all of the several thousand people who died, were killed by falling concrete and brick. Throughout the region, 75% of the buildings collapsed. All of the recent bamboo work was unscathed. The town of Pijao, built almost entirely of bamboo, lost only one person - and he lived in a concrete house. Further from the epicenter, Barcelona, a town of 7,000, built of concrete, suffered tremendous damage and lost 48 inhabitants. Bear in mind that some of the older lashed bamboo structures were close to 100 years old, obviously never engineered or treated with preservatives. There was no grading or sorting to use only culms 5-7 years old - yet, still, they survived. Optimized bamboo structures could literally have saved every life in a place where bamboo poles are by far the cheapest building material.



The surprising innovation of a bamboo-cement composite roof board (www.taiheiyu-cement.co.jp)

World's Fair Bamboo



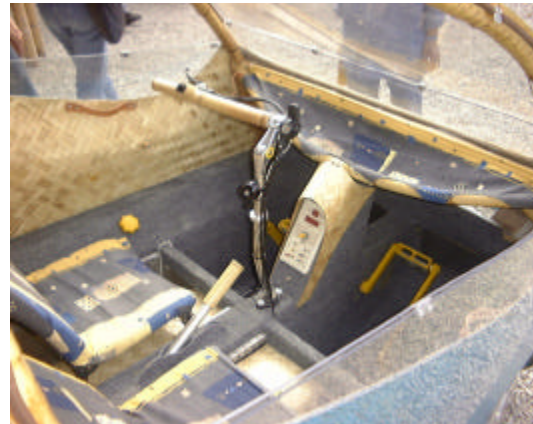
In the author's opinion, to succeed against earthquakes, structures need an appropriate combination of flexibility and resistance. The U.S. building codes are designed in a linear way to relate rigidity to strength. The Northridge quake showed that extremely rigid steel connections fail dangerously in relatively mild temblors. We think of horrible quake damage as only possible in faraway places with inadequately reinforced, "inferior" formulations of concrete, responsible for the deaths of tens of thousands of people. The problem is, we've only just recently agreed that rigidity only works up to a point. After that, resistance is futile – so to speak. Research into improving the performance of bamboo and other high strength / flexible natural materials is not just useful, it is imperative.

A 500m² bamboo floor was also included in the pavilion, supplied by Elephant Parkett GmbH (www.elephantparkett.de),



Bamboo table by Linda Garland, Will Hooker, Pintor Sirait, Alicia Romero on mezzanine floor of bamboo

Unlike all other participating pavilions, there was no country bankrolling this project, the budget was truly meager. The cost of testing was equal to building a third pavilion. Having built it in Colombia, then in Germany, non-profit ZERI paid over 2 million dollars for these "three" structures.



The electric bamboo car – using woven mat for the body, and poles for the frame – allowed easier transit around the fair.

The volunteer tour guides were the people who really made it work. To save money, several lived together in a shipping container several hours away from Hannover. They just simply believed in the project and seemed to be having a great time of it. It's almost enough to give one hope.

It was known from the beginning that the structure would not be able to be dismantled because of the mortar poured into the joints. Despite great lobbying efforts to find an alternate use on the original site, the pavilion was destroyed in early 2001 to make way for a parking lot. An inglorious end to a building that spoke so eloquently of our potential future.