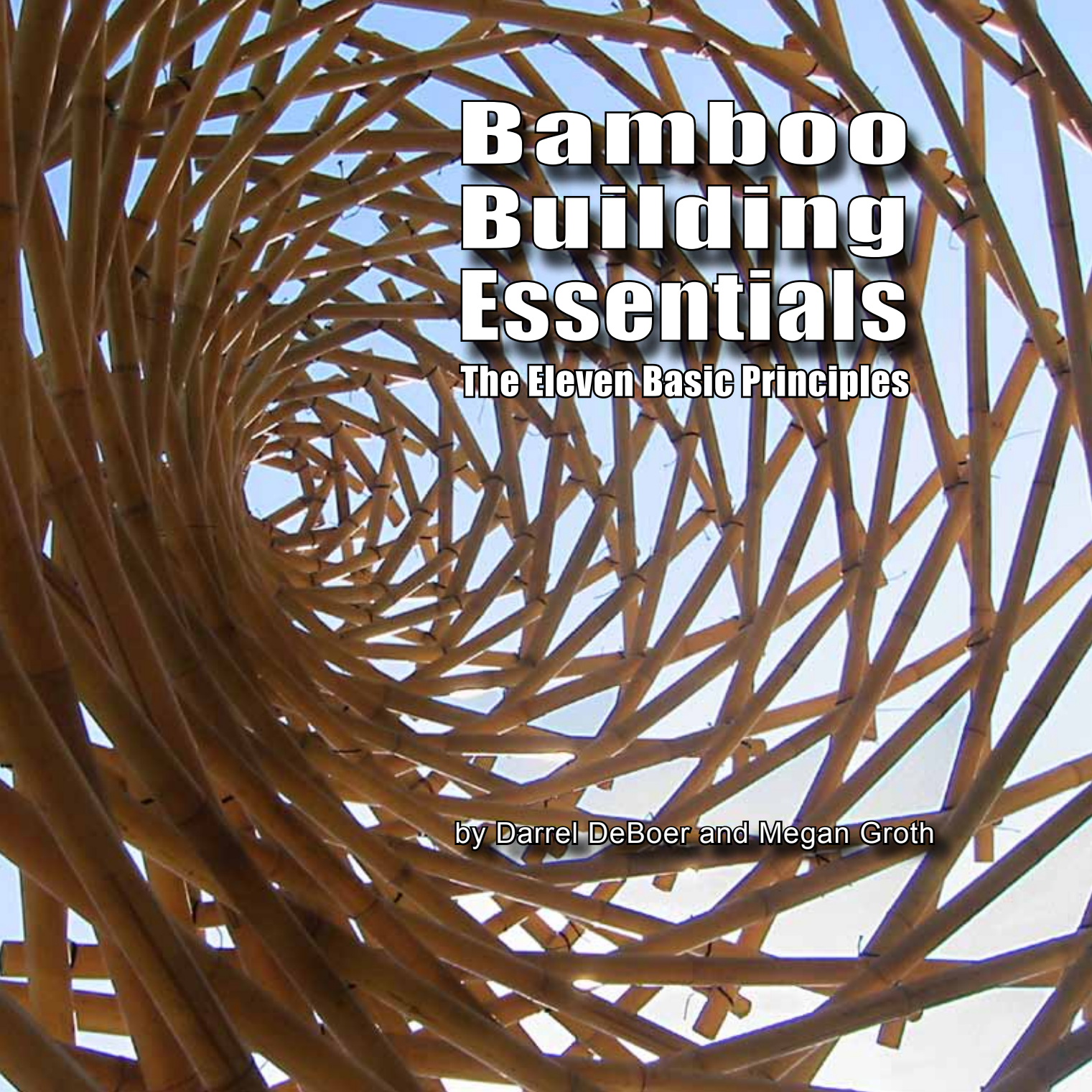

Bamboo Building Essentials

The Eleven Basic Principles

by Darrel DeBoer and Megan Groth

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Note from the authors

What if there was a plant that could grow 4 feet in a day, with an ultimate tensile strength equal to steel, stronger than concrete in compression, requiring a land area for growth no larger than the building you want to build and replenished with that much building material each year; treated with laundry soap and eyewash, then put together with joinery so strong that the steel bolts are the weakest link? What if, as the builder, you could completely control your source of building material, so economic meltdowns and price fluctuations wouldn't affect you? Not found only in Asia, in fact, the best bamboo building practices are found in South America where native bamboos have provided the basis for many thousands of years of civilization.

In the push toward more sustainable building practices, our culture tends to first look at technology for answers before considering what has been there all along. In the case of bamboo, whether you just appreciate its aesthetic quality or you need a plant to offset carbon emissions, or you predict high oil prices will soon force materials to be locally sourced, we hope to convince you that bamboo is the fastest growing, strongest plant fiber that can be most effectively used unprocessed - just as it grew. The goal of this book is to transform the way people think

think about and use bamboo. We would like people to take a deeper look at natural materials generally and see how they can be slightly augmented by simple technologies (bolts, mortar, treatment for longevity) and design (good layout, efficient joinery that doesn't put too much load on single pieces) in order to make something that is hundreds of times better than either the traditional method or conventional building techniques.

And what better time to change. For one, bamboo is readily available, simple to use, and if it used correctly, super strong, durable, and as "green" as it gets. Though humans have been building with bamboo forever, changes in the field over the last 20-30 years have made obsolete the image of the tiki hut. Today, engineered, thoughtful structures are within the reach of everyone. Oddly, the largest challenge in most of the world is exactly that inexpensive, accesible-to-all quality. The middle class moves away from bamboo to escape their association with poverty. It will be the lavish developments for the wealthy by people like Simon Velez of Colombia that will inspire those of all income levels to live in something locally produced, strong, durable and affordable.

Why Bamboo?

It is stronger than any other common building material when used in pure tension or compression and more sustainable due to its speed of growth and rate of carbon sequestration. Bamboo provides habitat and cooler temperatures when growing along with being one of the most accessible building systems ever invented. The question of bamboo is not "why" as much as "how" - how to implement it in countries (such as the United States) unfamiliar with the properties of the material, of the plant? To understand "how" is to fully understand the nature of the plant and how to put a "round peg" in our square way of thinking.

How Bamboo?

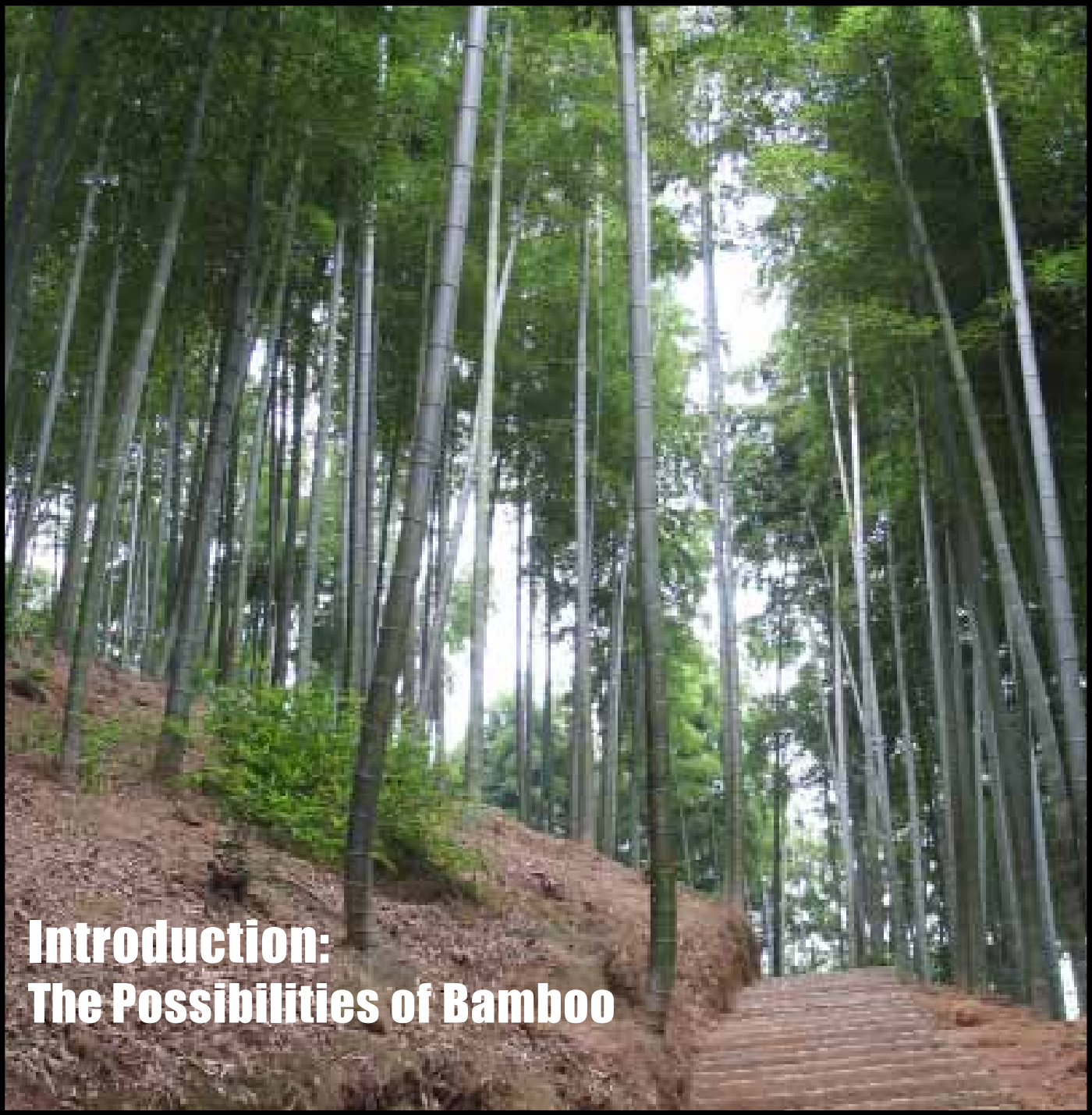
Well behaved plants are those that don't expand from where they were planted. Their job is just to be beautiful. Not since a hundred years ago when 90% of us were farmers have we seriously positioned plants as necessities in our landscapes. As the global reliance on oil becomes increasingly problematic, it is important to once again think of our landscapes as productive, as able to produce raw building materials. Tame, clumping bamboos can provide many of the bamboo needs, but there are many more species that are more cold-hardy and have different working characteristics – as a group. They are the running bamboos that can emerge 4 meters from the parent plant in a year. North America and parts of Europe are the only places in the world where running bamboos are considered a problem. Everywhere else, they are eaten or used. The key to success is to know how to properly care for and manage running bamboo, as well as to accept its natural properties. Think of the positives - a well-thinned, beautiful grove of bamboo is a bonus in addition to the edible shoots and leaves that are more nutritious than alfalfa for livestock. All of the thousands of uses for bamboo are, and will soon be even more relevant. Now is the time to use bamboo where it is plentiful and plant where it will naturalize.

The purpose of this book is to help an inexperienced designer/builder avoid the common mistakes and start to think of buildings that are uniquely suited to this material. A good design can make a building several times easier to build.

The **Heart of the book** will be the 11 principles coming up in bold, maroon type. Once those have been thought through, the examples that follow will be possible beginning points in the journey to make even better bamboo buildings.

And in order to keep the book size to a minimum, we put lots more information on the website that we encourage you to use alongside the book:

www.BambooBuildingEssentials.com



Introduction:
The Possibilities of Bamboo

Ways to Use Bamboo -

- pole, esterilla ("equivalent to plywood for the rest of the world"), lata (one stick split), laminate

Building with bamboo is about the manipulation of a line and there are many ways that it can be used:

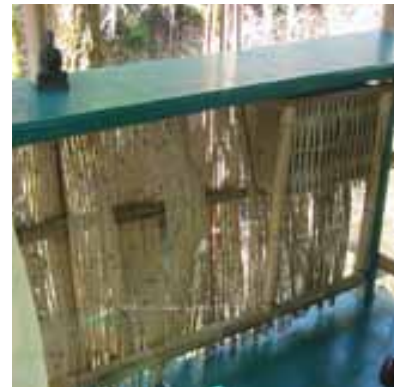
(1) as a whole pole,

(2) as individual split pieces or latas.

(3) "Esterilla" in Colombia, or "caña picada" in Ecuador, considered to be the plywood of the southern hemisphere. (this photo is in Yunnan, China) In this case, the splits are not allowed to be continuous the length of the pole. The opened pole stays together like an accordion and used as lathing or for floors.

(4) A pole can be heated - by steam, a blowtorch or campfire – and either straightened or bent into a variety of shapes. Fill the culm with sand for tighter curves.

(5) Similar to wood, it can be glued together as flooring. (courtesy of Smith and Fong) Already, composites like this are appearing as structural beams and the future may bring much more of this approach as a timber replacement. Since there are no knots or flaws that run through it, it can be given very high theoretical strengths so beams can be smaller in required cross section than sawn lumber.

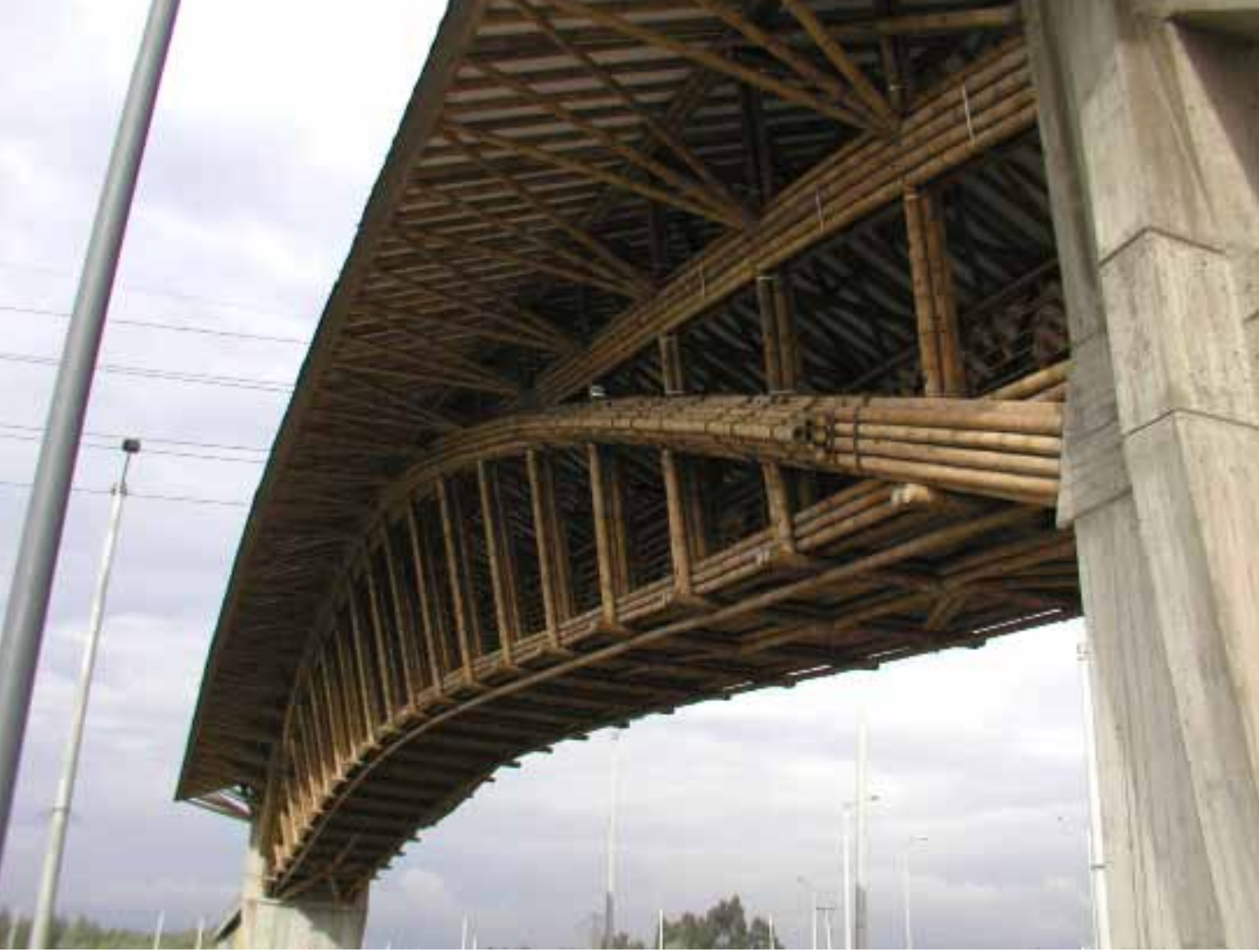


There are a variety of different forms that bamboo comes in naturally and ways that it can be manipulated. One can choose poles that (1) are of a species that grows into interesting shapes (e.g. Bambusa tuldoides) or (2) have been manipulated - sometimes accidentally - to take on a new shape or (3) as new shoots were purposefully grown through forms that force them to take on a specific shape because all of the growth happens at the tip of the plant. Break off the tip and it's done. Understanding the natural and manipulated forms of bamboo is important because – in the views of the authors – bamboo is best used "as-is". Working with bamboo requires a fundamentally different way of thinking than wood, which is endlessly manipulated, glued up or planed down to size. Mature bamboo grows in groves of uniform size. Plant the desired size or find another endless source. It will come back when harvesting mature poles, so revel in it.

key to photos

1 2
1 1
3 1

Today, bamboo is most often seen in housing and relatively temporary structures, such as food stands and animal corrals, in equatorial developing nations. Because bamboo grows in a range of elevations and temperatures, the design and construction of bamboo walls changes with the climate. For example, in Guayaquil, Ecuador, the warm tropical climate makes insulation unnecessary, and bamboo houses need little more than the split bamboo walls for privacy and ventilation. This is where the non-profit Catholic organization Viviendas Hogar de Cristo manufactures 40 bamboo houses per day for the poorest of the poor in the coastal provinces in and around Guayaquil (see photo on this and the following page). Each house consists of 4 bamboo panel walls, an elevated wood plank floor and corrugated metal roof, all of which are put together by the family based on directions from one sheet of paper. The houses cost US$800 each (which the family can pay over several years) and are often the only way that these families can put a roof over their heads. As you travel up to the Andes, bamboo is used in waddle-and-daub or "bahareque" (Colombia) or "quincha" (Peru) techniques (bamboo frame covered with packed earth) for more insulation for the cooler climate.



Little by little, public opinion is changing and coming around to the idea of bamboo in modern structures. Changes in the field over the last 20-30 years have made bigger and better structures more realistic, thus propelling bamboo as a building material with real potential and application. People around the world are beginning to better understand how to use the material to its fullest capabilities. Extraordinary bamboo structures by architects and designers such as Colombians Simón Vélez and Marcelo Villegas, German Joerg Stamm, Celina Llerena of Brazil, Bobby Manosa from the Phillipines and Jorge Moran in Ecuador are demonstrating to the local communities and world that bamboo is a beautiful material that even the wealthy are choosing for their houses and buildings. In this book we will cover eleven design principles that, if used properly, will make best use of the highly engineered properties already in bamboo.

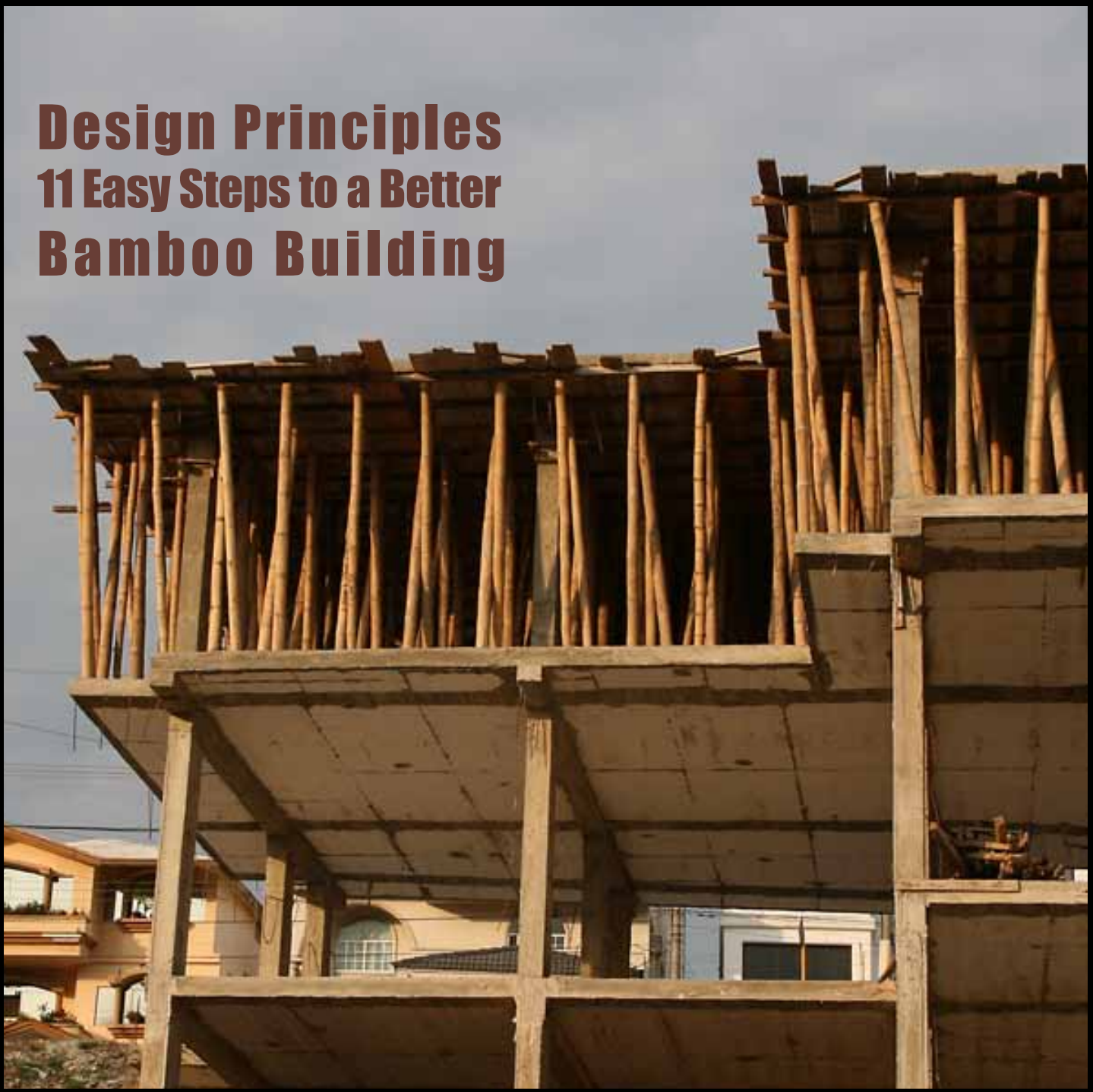
Brick, concrete block and bamboo house.

bamboo lath.

In many places where there is a long tradition of bamboo buildings, today there is a cultural resistance to the material. Bamboo carries the stigma of being the "poor man's wood" for many of the reasons modern designers think that it is so wonderful - it grows quickly, is found everywhere, is cheap and easy to use. Yet, in places such as Ecuador and Colombia, as soon as a family can afford it, they will trade in their bamboo house for a concrete block one – even if they have to pay and build it in installments. As a result, many coastal neighborhoods are composed of a combination of bamboo, cement block, brick – whatever material the family could afford at the time. It's not uncommon to see a bamboo house covered in plaster to look like concrete, sometimes bamboo houses are painted with grout lines! As Simón Vélez wrote in his book Grow Your Own House, "Social climbers from the lower rungs of society, as with many drug lords in Colombia, still want nothing to do with bamboo. In their eyes it represents the poverty that they have fled…"

Much of this reputation has to do with how the material has been used. Bamboo poles found in lumber yards in Colombia are often cut too young and used for concrete formwork. They are not suitable for permanent construction, but are still used anyway. In many countries, bamboo forests are on unmanaged land not "owned" by anyone, increasing these cases of misuse and overharvest. These unpreserved, exposed young bamboos will only last a few years at most – and walking around the barrios, a person is struck by how many families are living in rotting bamboo houses. People blame the material. We blame the techniques of building. Working with mature, well cured poles can make a great marriage with the simplest of free earthen plasters (since the clay always wicks moisture away from the cellulose, usually protecting it from rot unless the water volume is akin to a waterfall) or last many years under a generous overhang.

Design Principles
11 Easy Steps to a Better
Bamboo Building



Principle 1: Plant the Strongest Species

When you have complete control over the entire growing process, the first step is to plant the strongest species of bamboo for your use. This will depend on your climate and environment. In the United States, for example, it means planting bamboo species that can grow in USDA Zone 7 and higher. This includes the western parts of Oregon and Washington, most of California, the Southeast and Southwest of the country, and Hawaii. In colder zones, smaller species such as *Phyllostachys nuda* can be grown to an inch in diameter and survive temperatures as low as -30 degrees Fahrenheit.

When growing bamboo species for building, choose varieties with thicker walls, as well as a cold tolerance that relates to your area - the key is to plant a species that is capable of withstanding your coldest temperature. Refrain from using fertilizer on the bamboo, in particular nitrogen, which leads to rapid growth and weaker poles.

The current International Building Code states that the strength of a species of bamboo can be determined from samples from a single place and time. These results are considered applicable for the entire species, regardless of growing conditions. Several builders have put forth the "unproven" idea that the density of the wood is a better measure of how soil, rainfall, care and age have all had their effect - regardless of species.

soil, rainfall, care and age have all had their effect - regardless of species. A one year old pole is extremely light, and even three year old poles can characteristically crack at the nodes after the drying process, but it is only experience that teaches these things. Unfortunately, there are currently no grading or quality standards for bamboo poles. This means that the purchase of poles involves a great deal of faith and relationship-building between buyer and grower.

While the discussion here will be confined to choosing the best species, for the serious study of growing this plant look at Farming Bamboo, by Daphne Lewis and Dr. Carol Miles. For the choices in cultivation in the U.S., with information on the diameter, height, shade tolerance and the traditional use of each species, look at the tremendous resource updated annually by the American Bamboo Society (http://www.americanbamboo.org/SpeciesSourceList.html). Consider joining their efforts to continue documenting traditional uses and expand the database of local names for various species.

Different species are chosen for import into the U.S. because of a unique visual characteristic, such as striped leaves or colored culms. For builders, the most intriguing species are seen by others as "just another green bamboo" by horticulturists. But imagine what we consider the Holy Grail of bamboos: in the tropical latitudes of the Himalayas, over the course of thousands of years, tropical plants have been forced to adapt to the rise of the mountains to very high, colder elevations. If this unique combination of a clumping, cold-tolerant, large diameter with strong fiber and tremendous pole production when grown in a more favorable climate exists, many of the issues that we have with growing and building with bamboo in temperate regions might be resolved. For now, the gene pool of Himalayan bamboos enables hybridization that might produce ideal building materials. Until then, there are a few bamboo species to choose from when starting a grove for use as building material.

Chimonobambusa tumidissinoda

A large lawn allows P. vivax to have a huge number of rhizomes yet produce only a few very strong, thick poles - errant shoots are mowed

Bambusa oldhamii 'hirose', very vertical = straight poles. Tolerant of 15 degrees F.

The distorted nodes of rare P. edulis 'Heterocycla' can often be found in the common P. aurea, aka golden bamboo.

Very productive chusqueas, borindas, and fargesias, clumping bamboos that will define the new identity of bamboo in the landscape.

The spots on P. nigra 'bory', or Leopard bamboo, will remain even after it dries.

Variations:

Within the limited definition of bamboo, there are over 1500 variations. And within species, there are huge variations depending upon climate. Most members of the genus Phyllostachys perform poorly in the tropics while many tropicals do well in temperate places until the temperature drops suddenly. To qualify as a bamboo, a grass (graminae) must have woody branches and a few other characteristics seen only in their rare flowers. The differences between species include the sizes, shapes and colors of the nodes, leaves, sheaths that support the new shoots, rhizomes, and the rarely seen flowers and seeds. For building, we care about wall thickness and fiber strength. Many of the species below are smaller, but come in already decorative shapes that can work for accents or furniture. Do a Google search under "Images" to see many examples of each.

Species that will dry **interesting**ly for furniture and ornament:
Chimonobambusa quadrangularis (square cross section)
Chimonobambusa marmorea (reddish)
Chusquea pitteri (decorative spikes at nodes)
Bambusa ventricosa (bellies if you're lucky)
Bambusa vulgaris 'wamin' (compressed, bulbous internodes)
Phyllostachys aurea
Phyllostachys aureausulcata
Phyllostachys nigra 'bory'
Qiongzhua tumidissinoda
Thamnocalamus crassinoda 'Mendocino'

Black (color remains even after drying; from smallest to largest)
Borinda fungosa – small diameter
Phyllostachys nigra
Bambusa lako
Gigantichloa atroviolacea
Dendrocalamus asper 'hitam'

Useful, cold tolerant species that can take 0 degrees Fahrenheit:
Chimonobambusa pallens (prolific, small poles)
Chusquea gigantea
Fargesia robusta
Phyllostachys bambusoides (madake in Japan)
Phyllostachys edulis (moso)
Phyllostachys nuda (the most cold tolerant of all)
Phyllostachys viridis 'Robert Young' (very thick walled)

Particularly **beautiful** plants that you can probably talk someone else into growing for you
Bambusa textilis 'gracilis' (suburban landscape sized version of textilis)
Chusquea uliginosa
Otatea acuminata 'aztecorum'
Phyllostachys dulcis (great edible shoots)

Strong species used for building (as a guideline, species with smaller leaves are stronger)
tropical: most *Dendrocalamus, esp.*
D. strictus (solid culms)
D. asper (the Indonesian strain is great for both shoots and building. Thai asper is much thinner walled)
D. jianshuiensis (survives 25 degrees F)
Guadua aculeata (smaller, but thick walled)
Guadua chacoensis
Guadua angustifolia
Bambusa beecheyana (is thick, plants get big quickly but shoots in the autumn so many are killed)
B. oldhamii (is thinner walled but survives colder temps)
B. stenostachya (BambooTechnologies.com did the crucial structural testing)
B. textilis (best for splitting and weaving)
Phyllostachys bambusoides (best of the temperate runners)
P. edulis 'Moso' (most bamboo flooring is made from this)
P. nidularia (small but strong)
P. nigra 'Henon'

Phyllostachys aureosulcata. A few culms will zig-zag at the base. The stripe disappears when dry.

Phyllostachys nigra. The canes are green until gradually darkening in the third year. Other variations include *P.n. bory, known as* leopard bamboo

For places that don't freeze, an even more compelling black: *Gigantochloa atroviolacea.* Thick walls, good structure.

Bambusa ventricosa known as 'buddha's belly'. There are many opinions but few conclusions about sure ways to get the species to belly.

Chimonobambusa marmorea is a great example of a bright colored live plant that tempers to brown when dry.

Mexican weeping bamboo, *Otatea acuminata aztecorum* has a solid culm and is great for furniture-making.

Guadua *angustifolia 'kunth'* is the king of the building world, with its thick walls and strong fibers. The plant is protected by its porcupine-like spines that are disguised as innocuous hairs on the new shoots and emerge as the branched thorns on the adult culms that are as effective as barbed wire. The new shoots emerge 3 feet from the mother culm, making *Guadua* forests easily habitable for a variety of animal species, which encourages more plant and animal diversity than other bamboo groves which can become impenetrably dense (a good tbing for birds evading predators tbough). The one weakness is the plant's intolerance to freezing. Within the U.S., only Hawai'i, San Diego and south Florida are relatively safe from frost. (A system to consider might be to grow it in a part of Mexico to encourage a local economy to grow with it.)

A mixed Guadua forest at the Maquipucuna Reserve in northern Ecuador. Due to rapid deforestation to make way for farmland, there are very few natural stands of Guadua that survive today.

2) Growing

Bamboo requires plenty of water year round, as well as an abundance of sunshine. For this reason, bamboo is seen growing wild in ravines and along the banks of rivers and in places with a Monsoon hot-season climate: tropical Southeast Asia, the temperate foothills of the Himalayas, and the tropical northern half of South America primarily.

In places where there is less rain and naturalization is unlikely (i.e. southern California), wastewater is a good water source. The dense feeder roots make great filters to clean water and bamboo is capable - more than most plants – of using even uncomposted manures. (though don't apply it directly on newly planted feeder roots) Early morning is the best time to see the quantity of water pumped through bamboo plants - there will be droplets of water on every leaf. Moso (*Phyllostachys edulis*), the huge timber bamboo from which almost all bamboo flooring is made, seems not to thrive unless watered every day.

When growing bamboo in places without monsoon rains, a liberal use of mulch and cardboard will both hold in the moisture and allow the plant to use less energy otherwise needed to force its roots through the heavy clay soil. Nutrients, especially nitrogen, will need to be added as the mulch breaks down. Additionally, oxygen enters through the rhizomes of the bamboo, therefore it is important that the plant is able to drain well. Mulch will allow this process to happen.

In the example above, cardboard is sandwiched between layers of mulch to trap in moisture. The next year, a mat of rhizome will have developed directly under the cardboard for easy propagation - or the new shoots can simply grow through the cardboard as it breaks down.

Sun

The amount of sun required varies by species. Over 25 years of experience in plant introductions in the U.S. is cataloged at http://www.americanbamboo.org/SpeciesSourceList.html.

Some bamboo species are native understory plants and need to be established in partial to full shade. In general, though, growth rates are significantly faster in full sun. The bamboo looks natural around traditional villages, like this one in southern Yunnan Province, China, but there is usually a strict hierarchy related to use and microclimates formed by the plants. This configuration is most easily manipulated during the rare flowering periods as seedlings are much easier to move compared to the 16" diameter culms. (depending upon species, "gregarious flowering" occurs every 40 to 120 years, when every member of the species will flower in the same year and either die or be so weakened that it will only come back slowly - like the new seedlings)

3) Harvest mature poles

Bamboo reaches maturity 3-6 years after the shoot first emerges. At this point the fibers are strongest and there is less moisture in the culm. The beauty of planting your own bamboo is that you can stamp the age of the culms, and therefore when it is time to harvest. If not, there are a few tell-tale signs to look for in order to determine whether or not a culm is ready to be harvested. In tropical climates, the oldest culms are the ones with the most lichen and mosses (upper left photo on following page). Clean, smooth poles (upper right photo) should be avoided as they are probably new shoots and are lacking the strong structural qualities needed for building. If used, young culms will very quickly look like the bottom two photos on the next page. Some species (i.e. Genus *Phyllostachys*) have a characteristic white wax ring below the nodes that will gradually darken over the years. Once it is no longer "white," the pole is in its third year. Look up as the white is often more pronounced higher on the culm. Other species acquire color slowly over time, for example *Phyllostachys nigra* and *P. nigra* "bory" acquire their dark spots over several years. Also many in the Phyllostachys genus grow another sub-branch on the same lateral branch each year - therefore the age of the culm can be found by counting the branchlets.




Harvesting Guadua for sale
near Puerto Quito, Ecuador.

4) Harvest when the sugar content is lowest

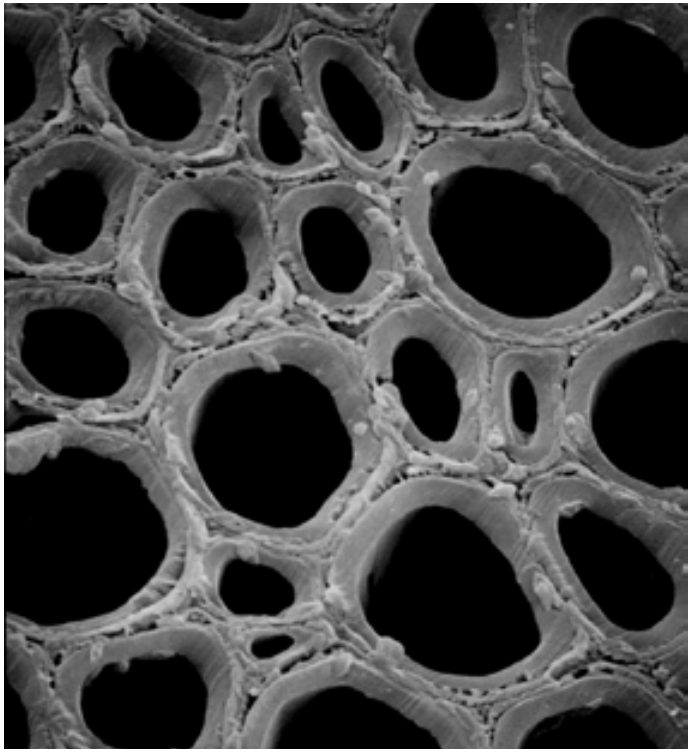
It is best to harvest bamboo after either of the two annual growth spurts when the starch content of the plant is lower and therefore less susceptible to attacks by insects (though some argue that this is due to seasonal changes in insect populations and not the starch content of the plant). There is rich regional folk lore and traditions that describe the optimal bamboo harvesting day and time. In Colombia, for example, it is widely believed that bamboo needs to be felled during the waning moon, just before sunrise. In parts of India, bamboo that is cut during the bright, new moon is believed to be less susceptible to insect attacks. The important point is to harvest when sugar is at a minimum: after the spring and fall growth spurts, and following the rainy season can make a difference.

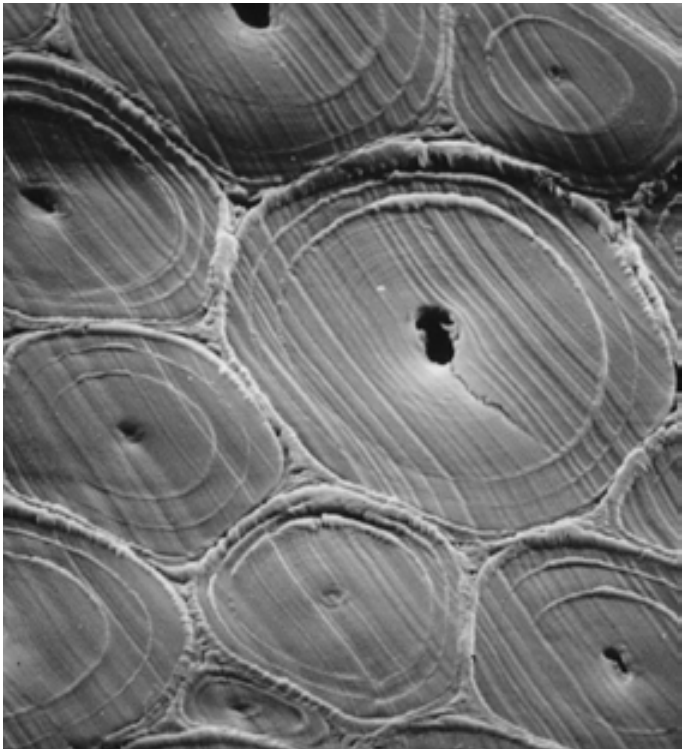
When felling the culms, cut at the base, "over the first node located above the ground", using as narrow a cutting tool as possible to reach between culms. A battery-powered Sawzall, chain saw, machete, pointed handsaw or a hatchet are all effective. Make sure that a bowl isn't formed by the node that will collect rain water to encourage mosquitoes and rot the rhizome.

photo of cross section of a thin-walled bamboo eaten by beetles

While bamboo is relatively resistant to pests, the reason for the concern about sugars is related to attacks by powder post beetles, Dinoderus minutus. Termites are generally uninterested (except in very tropical places) and other insects see the bamboo more as a home than food. The beetles, on the other hand, will drill their 1/8" diameter holes and eat until very little structure remains. The damage might not be obvious since the beetles tunnel back and forth within the fibers and only visibly emerge when they are done - at which point the thin walled poles can be crushed with your bare hand. The advantage of choosing the thicker walled poles is that the edible portion is the pithy interior fiber, not the structural exterior material. In this case, the pole will retain its structural qualities after an insect attack.

There are many physical and chemical treatments that will prolong the life of bamboo culms. Physical treatments such as submerging a pole in fresh or salt water for several weeks, and heating or smoking the culm will decrease the amount of starch in the culm, and thus its susceptibility to certain insect attacks. However, these treatments compromise the strength of the pole and usually do not completely protect the bamboo from beetles or fungus. According to bamboo expert Marcelo Villegas, there are hundred year old structures in Colombia that have finally just been attacked by beetles. Another consideration is the way bamboo matures, seen below in electron microscope photos by Walter Liese of *Phyllostachys viridiglaucescens*. The voids and nodules of sugar seen on the one year old specimen on the left are replaced by stronger fibers at age twelve on the right. One can guess the difficulty of pushing through treatment fluid. Ideally, culms half this age will be treated so the challenge is not as stark.





5) Use less-toxic treatment methods

There are two main ways that treating bamboo extends the life of the pole: 1) by making it distasteful to insects and 2) by altering the pH and keeping moisture levels low to keep away fungus. When thinking about treatment methods, consider how framing lumber is treated in local construction, and do the same. Think of bamboo as you would structural lumber. For example, Douglas fir is not used exposed to weather, therefore keep bamboo inside or under cover for maximum longevity. In particular, make sure not to expose the interior of bamboo to the outdoors. If bamboo is split open to reveal the interior, the sugar will cause little black dots of mildew to appear as soon as the rain starts. In general, untreated bamboo poles last the same as softwoods: 1-2 years when exposed to the elements, 3-5 years when sheltered from rain, and up to hundreds of years when dry and used indoors.

The next best idea is to get water soluble salts to the interior fibers. This, in theory, allows the pole to be exposed to the rain for awhile – though it is not considered great practice. Surprisingly, one of the most effective treatments combines the ingredients found in eyewash and laundry soap. Boric acid -- found in Visine eye-drops, and most inexpensively sold as a fertilizer or mouse poison -- has little ill effect on mammals. Combine in equal parts with borax (sold as "Twenty Mule Team" laundry detergent). This mixture is too concentrated for disposal on plants, but at about a 5% concentration , it is effective against both fungi and powder post beetles. The photo above shows the vertical soak diffusion method in Bali where the borax mixture is poured into the pole which has had the nodes punched out, leaving only the last one. The mixture is left in the pole for nearly a week and it diffuses through the pithier interior cell walls.

Bamboo Building Essentials

Another treatment method is the Boucherie system: a form of pressure injection that must be done within 24 hours of harvest or the capillaries will close and not conduct the chemicals all the way through the poles. This method is not convenient in places where the groves are not near the treatment facility, unless the equipment is made portable. But when it works, a pole can be treated in a few hours instead of the week that is required for the vertical soak diffusion method.

Various experiments have been done using smoke, but with mixed reviews. Japanese companies have perfected the method but the specific details have not reached other countries.

At the moment, there are good things to say about hydrogen peroxide (except that it is relatively expensive), and various plant-based traditional treatments practiced regionally worthy of intense study. Possibly the most encouraging preservation method on the horizon involves displacing the sugars with liquefied sand, called “Water Glass”. The wood treatment is commercialized under the name of TimberSIL. From personal experience, cedar oil treatments that work on wood are not effective for bamboo.

Dendrocalamus sinicus grows up to 16 inches in diameter, photo by Jiarong Xue

6) Cure the Bamboo

It is possible to work with fresh, green bamboo if adjustable joinery (a system that can be tightened over time as the poles shrink) is used, but it is recommended to work with dry bamboo. After harvesting the bamboo, leave the culm in the grove - upright, propped up off the ground and with the branches and leaves still attached - for a few weeks. It will continue to photosynthesize and use up the remaining sugar in the culm until the plant runs out of water. The powder-post beetles are unlikely to enter the culm during this time because they enter through the cuts (i.e. where the branch is cut off). Keeping the culm off of the ground prevents rot at the base from moisture seeping in. The moisture content varies greatly between culms (as well as between sections of the same culm) and as the bamboo dries it will shrink about 6-10% in diameter, but almost not at all along the length. A general indicator is that once the green color is gone - between 6 weeks and 6 months - it may be checked to see if it has the desired 10-15% moisture content. (or use it so shrinkage doesn't affect the project. For example, leave bolts accessible for tightening after a few months) Air-dry the bamboo by storing it in a covered area, out of the sun, preferably vertical for good air circulation and to keep it from becoming more curved as it conforms to an uneven surface.

Drying bamboo should be stored upright and rotated often if in the sun, which is useful in the humid tropics, but patience and shade are suggested elsewhere.

Racing bike by Craig Calfee with what are likely the strongest joints made - also discourage splitting. photo by Morgan Meredith

7) Plan on splitting

Outside of the nodal region, the fiber structure of bamboo runs in one direction, the length of the pole. At the node, the fibers turn and run perpendicular to the exterior to fill in the middle of the pole. Unfortunately, when the pole dries, the shrinkage of about 6-10% is entirely across the grain and the node shrinks less than the rest of the pole, causing the pole to split. This is especially true when a heat source, like the sun, hits the pole on just one side. Fence builders in Japan have learned that completely punching out the nodes can often prevent splitting. The stress can also be relieved by making a pre-emptive cut on the bandsaw the length of the pole, then glue it back together (just as with a curly piece of wood). Joinery that wraps all of the way around the pole can also contribute to holding the pole together. Using banding or fiber binding at crucial joints will keep the fibers together, even if it never splits (Band-It tool, above left; Racing bike by Craig Calfee with what are likely the strongest joints made - epoxy and bamboo fiber, which, as they dry, tighten around the joint. A simpler version for less intensive use would be wetting natural fiber string with watered down aliphatic wood glue). With hollow bamboos, using something as simple as a radiator hose clamp can hold the fibers together. Joints can also be wrapped with twine for a different aesthetic but not nearly as much strength.

Choosing the right bamboo specie for the job is important. Some of the solid bamboos are much less prone to splitting: *Phyllostachys heteroclada* 'solid stem,' *Dendrocalamus strictus, Otatea acuminata 'aztecorum'*, and most in the Chusquea genus. Of the hollow bamboos, those of the Guadua genus are generally thicker walled and less prone to splitting. The lower portion of the culms, for example, will usually accept a nail or screw without drilling a pilot hole or splitting.

Even if the bamboo does spit, the effects can be minimized. To keep the bamboo fibers together, find a way to surround the bamboo with lashing or with something industrial but widely available like these stainless steel hose clamps. (which are first interlocked in a figure 8 pattern to form the joint)

8) Keep bamboo away from moist surfaces like the ground or concrete

In the photo above, best practice puts a moisture stop of galvanized sheet metal or plastic between the bamboo and the concrete.

Regardless of climate, a main objective of bamboo design is to prevent the wicking of the moisture that is always present in the ground up into the bamboo. Building codes generally require eight inches between wood and soil, and at least several inches between wood and exterior concrete. This is a good rule to use when constructing the foundations and base connections for a bamboo structure. The other requirement for a post is to prevent it from pulling out of the ground. A good joint has a metal plate between the bamboo and the foundation, while still connecting well to the foundation. That connection can be made with rebar, threaded rod or a strap – preferably galvanized – mortared several nodes into the bamboo to prevent withdrawal.

The great advantage of bamboo over timber frames is that bamboo is not as precise (or heavy!), to the point that foundations can be poured AFTER the frame is up. In the top row of photos, rebar was cast into the base with the mortar formed by the soda bottle - this provides the separation between bamboo and earth. Those poles were then integrated into trusses and the foundation was cast last *(middle left)*

The photos on the middle right and below show different cast metal fasteners that provide the same function of protecting the bamboo from moisture. The part that's not visible is the rod that continues both up into the bamboo as well as down into the foundation - connecting the two pieces and holding them in place.

The auditorium of Las Amantes de Sumpa in Santa Elena, Ecuador by Architect Daniela Loayza has simple cast metal joinery that separates the bamboo from moisture. Other great aspects to note about the building is that the borax treatment on the poles also functions as afire suppressor, and the design of the auditorium pulls hot, humid air up and out through the ridge naturally.

In contrast, the short-sighted design of this bar first does not acknowledge the winds that tried – and will continue to try - to lift off the roof. That problem was then not fixed by setting poles right on the soil. In some ways, this is a good example because it points out the flexibility of bamboo to inexpensively solve problems. It also, though, makes obvious the need to design joints which work both in compression (from the gravity load 99.99% of the time) as well as in tension for those catastrophic winds, earthquakes, hurricanes or whatever nature has in store. It is often the force reversal from compression to tension that cause the unexpectedly catastrophic failures in structures.

9) Give the building a good hat and boots

This is undoubtedly the most important lesson and one that is most often overlooked. The first choice is to use all of the bamboo *inside of the structures*. This will keep the sun and rain from negatively impacting your building. Even small rafter tails peeking out beyond the overhang will certainly split in a couple of years and provide insect habitat inside of the culm.

The photograph on the next page is a bamboo bathroom at the 1999 World Expo Garden in Kunming, Yunnan Province, China. The photograph was taken seven years after the structure was built with no protection from the elements. In the U.S., millions of board feet of our favorite framing lumber - Douglas fir - are used, but almost none outside where it would meet an identical fate as this structure. When bamboo is exposed to the elements in this way, the first thing that happens is the sun and rain dissolve the protective wax on the exterior of the pole. The surface bleaches to silver and the heat from the sun on only one side of the pole causes it to expand unevenly then split as the fibers become brittle and easily broken.

An excellent overall example of contemporary bamboo housing is bamboo designer Martin Coto's home in San Jose, Costa Rica. The simplicity and elegance of his design demonstrates the feasibility of a low-energy future. Here, earthen tiles cover the roof and an earth and lime plaster covers the wall and frame, both of which are made entirely of bamboo. In another project, Coto uses bamboo for the structure of a cupola at the Cuna de Angel Resort in Dominical, Costa Rica. The beauty and strength of the bamboo is on display, while still being protected from the elements by the sheathing on the roof.

With a little planning, a simple and elegant structure, such as the one above found in Ecuador, can be quickly designed and built. Both the raised footings for the bamboo and the wide overhang of the roof minimize rot and prolong the life of the building.

The Modern Era

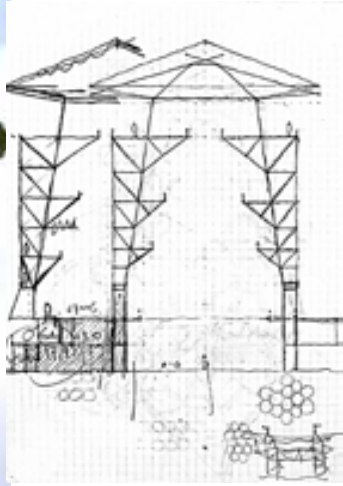
Colombians Simón Vélez and Marcelo Villegas developed the mortar-filled joint a quarter century ago. Combine that with better treatment methods and the modern era of bamboo architecture begins. Suddenly, structures with 25 foot cantilevers and 60 foot spans are routine - and with some of the heaviest roofs possible, clay roof tile set into a full bed of mortar. Engineers in the U.S. would hesitate to try this in steel, but these buildings have survived high winds and earthquakes larger than California has seen in 150 years. The work of Vélez and Villegas prove that structures of this size can be grown where they will be built by those who grew them.

10) Achieve shear strength with triangles in your truss design or with shear walls

The key is to use poles in pure tension and compression, not bending (avoid the flexing of a fishing pole). The distinction is clearest when triangles are made to put all of the force along the axis of the bamboo. In general, the design principles are the same as in any other building system: for longer spans, design trusses. Trusses will keep the poles from acting in bending.

Make sure that the design does not require the same curve in multiple poles, as that rarely happens. Tight curves in particular will be more of a fight than the project usually necessitates. Meanwhile, it is important to recognize the ever-present natural curvature of the pole. Most bamboos naturally curve in two dimensions not three, and along the same plane as the branches.

When using multiple poles in the same plane (in framing a roof, for example) the poles can be turned until the flat side is found.



Another way to get lateral resistance is seen in traditional pole barns which bury the bottom of the column in the ground and don't allow the corners to lift. Close to the epicenter of a large earthquake in Colombia, this tower for a tourist park by Vélez and Villegas survived unharmed. The posts are wood and the roof - which must have received the worst of the whipping effect of the quake - is bamboo.

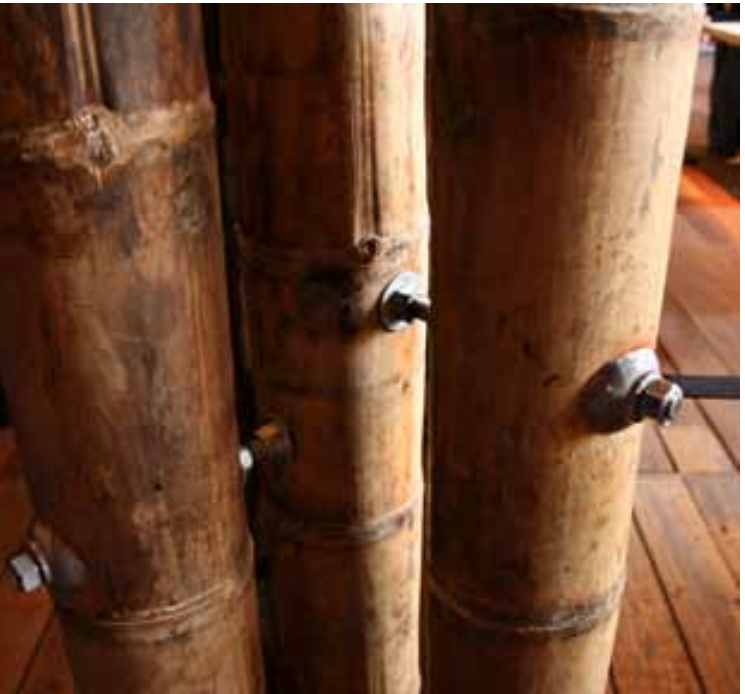
The photo shows an example of repeatable, well thought-out trusses at the FERTISA plant in Guayaquil, Ecuador, designed by Architect Jorge Moran. Moran is one of the most tireless advocates for the rights of the poor and for the promotion of bamboo in Ecuador, as well as the world. The clarity of his thinking comes out in his buildings. Note that the longer spans have two or three bamboos stacked - this acts as the structural equivalent of a glue-laminated wood beam. It is also a very good example of how triangulation provides stability by making the entire structure rigid. In this case, there are no shear walls to carry the horizontal forces down to the ground. To safely rely on the strength of the joinery to this degree, requires the joints to be optimized as much as possible.

Joerg Stamm has built some very successful 'fish' trusses, which take advantage of the strength gained from pre-tensioning the poles. Though the poles are clamped together at the ends while held apart in the middle by the strut, the forces they carry are along the axis in tension and compression.

11) Use approriate joinery systems

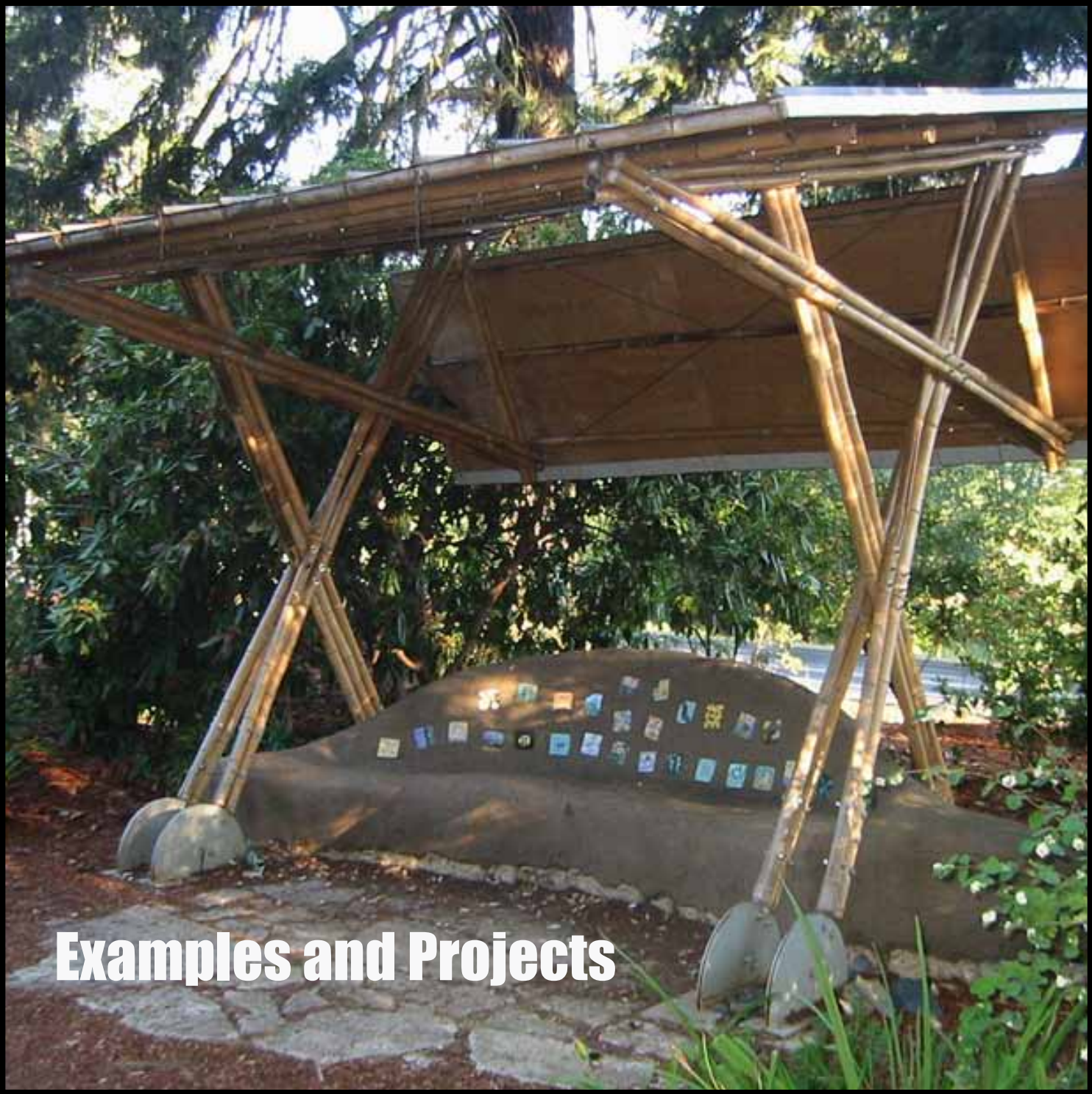
This is the principle where planning ahead helps the most. If the structure is designed to be quick to assemble and relies on simple joinery that is hundreds of times stronger than traditional lashed or pinned connections, then a relatively small investment in hardware makes perfect sense. In western cultures, we think of our favorite building materials, especially wood, as subtractive. We start with a large piece and keep making it smaller until it becomes a module that can then be built back up again into a laminated object or even a house full of standard shapes. With bamboo, the thinking is more akin to masonry, with the shape predetermined and not easily changed. Celebrate the difference and use bamboo where the shape is an asset, such as very visible finished surfaces. Design the structure in order to avoid time-consuming joinery, especially where materials must be coped and curved in order to meet the bamboo. Put the effort into smart design rather than laborious repetition.

Conceived by Simón Vélez and Marcelo Villegas, the mortar-filled joint is a recent development in the history of bamboo buildings. It is the most important recent advance in making bamboo a modern material capable of making the same structural claims any industrialized material.



Specially designed joints are designed to overcome the not quite round, irregular characteristics of bamboo by reaming it out and inserting various sizes of dowels into the pole. It's one way to bring bamboo into an industrialized mode of production, though still often very labor intensive..

Make "X" joints, where the bamboos pass by one another. It makes us think in 3D and avoid coped joints which are labor intensive, and therefore commonly used in countries where labor is cheaper than materials. Any unfilled joints under heavy loads will crack, as seen in the above example.



Examples and Projects

Bamboo and Building Codes

Code approval for building with bamboo in the U.S. has happened due to the efforts of one company: www.BambooLiving.com. A prefabricated building company located in Maui, Hawai'i. The international standard that has now been incorporated into the building code calls for testing of each species according to a specific protocol, then putting the resultant numbers into approved formulas. The testing is expensive and approves the entire species for use by anyone. The reports are available at www.icc-es.org. We will have the standard which was incorporated into the building code on our website. www.BambooBuildingEssentials.com

Meanwhile, a bamboo house is now much easier to imagine here, especially after the same people sponsored www.bamboocompetition.com and encouraged the next generation of talented designers to weigh in on what bamboo could be used for.

There is still a need to do the testing for several key species, including *Guadua angustifolia* (the tests have been done in Colombia, but need to be done here), *Phyllostachys nigra 'henon'* and *Phyllostachys bambusoides*, thicker walled runners capable of being grown through most of the U.S.

As a result, most of the following projects were done in places outside of the United States, where building codes are different and there is a readily available supply of high quality bamboo poles.

Dining room at La Hosteria Alandaluz, Puerto Rico, Ecuador by leading architect and bamboo evangelist, Rafael Rojas

Use bamboo to span long distances. (Above) This bridge by Joerg Stamm is one big reinforced arch but still, every piece forms part of a triangle for stability.

The Acceptance Criteria for Structural Bamboo that has been accepted in the U.S. and other countries in various forms was written originally by a committee of international experts led by Professor Jules Janssen from Eindhoven University in the Netherlands. The challenge was to take a material most building officials were unfamiliar with and remove the fears of liability. Primarily this was done by encouraging structural engineers to review and sign off on projects. In Europe, the path began with the ZERI pavilion built for the Expo 2000 in Hanover, Germany. The effort of building this 20,000 square foot pavilion led to the incorporation of bamboo into the European building code because of the testing that was required, and entirely supervised by German structural engineers.

When we look at bamboo, we see a 4 inch diameter log and tend to design something appropriate for that much mass. But for a post of bamboo, only 10% of fibers are being asked to distribute and carry the entire load, instead of all of the fibers if it were a solid pole.

Make a balanced design – with no eccentric loads. Loads should all run along the axis of the bamboo. Bamboo has two great qualities: it looks good and it spans long distances well. It is best to use it for roof structure and the overall frame, not to fill large areas (like a "log cabin" wall). The infill of walls is usually better with earth and straw: plentiful, inexpensive materials already used by half the world's population.

Bamboo Building Essentials

Sometimes small demonstration structures like this one by Celina Llerena are the best way to inspire people to think differently about a familiar material.

Bamboo Fencing as ornamentation, a way to quickly and beautifully transform a space

Living Fence:

The tallest plant with the smallest footprint and the lightest weight when dragging pots around - great for blocking out that ugly neighbor. In this case, this clumping bamboo requires no root barrier, but running bamboos will need a three foot (one meter) deep trench lined with a thick plastic known as a rhizome barrier.

www.bambooheadquarters.com
www.bamboosourcery.com

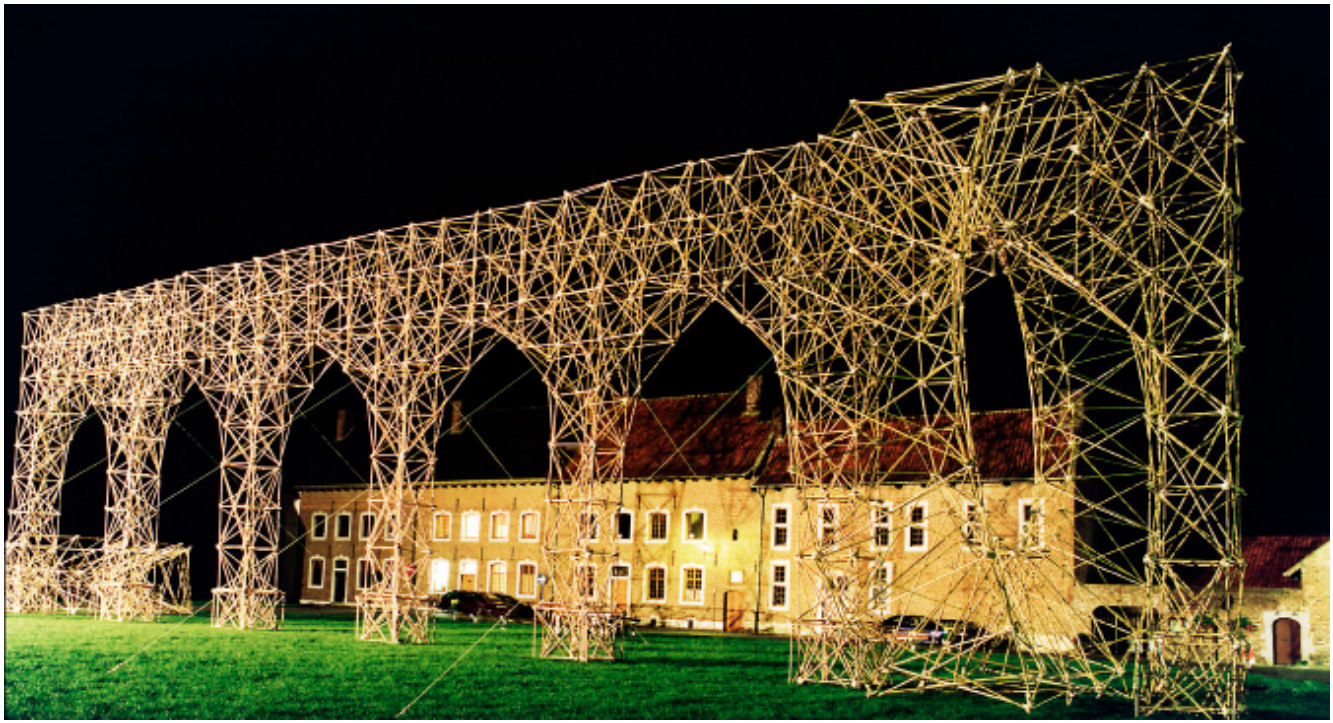
Photo of the famous fence around the Katsura Imperial Villa in Kyoto, Japan

Bamboo is used in many different forms – as splits or poles, woven or lashed together, bent or straight – in order to create a variety of creative patterns, decorative and functional fence designs. In Japan, the simple bamboo fences use every part of the plant - leaves, branches and culms. All of the parts are laid out to be assembled almost as fast as walking.

Bamboo Building Essentials

Bamboo is the way to quickly transform gardens and open places without the intimidation of having to lift heavy materials or commit to it being there forever.

In both of these cases - a garden in Japan by Hiroshi Teshigahara and a restaurant entrance in California by the author, bamboo is used to quickly and elegantly transform the space.



As architects and designers, we are concerned with building edifices that will last the test of time and often forget how much creativity and freedom there is in a temporary structure. Here, unskilled people were taught a simple joint by Antoon Versteegde, the repetition of which led to a fantastic structure in a matter of hours.

Bamboo Scaffolding,

is another example of a temporary structure. Outside of expensive, lightweight composites, few other materials are light enough to be carried by one person, yet strong enough to support 70 stories of itself. Practiced crews can build scaffolding extremely quickly. Inevitably, people who return from visiting Hong Kong for the first time will immediately speak of the bamboo scaffolds that made an impression on them.

Gerard Minakawa and Kevin Rowell of Bamboo DNA have found in bamboo a material that quickly gives personality to temporary music festivals, such as this one in Indio, California.

Here an unexpected treat, a suspension bridge up to a tower held together with a couple of cables through the deck.

Bamboo lends itself well to climbing and to building resilient, repairable playground structures.

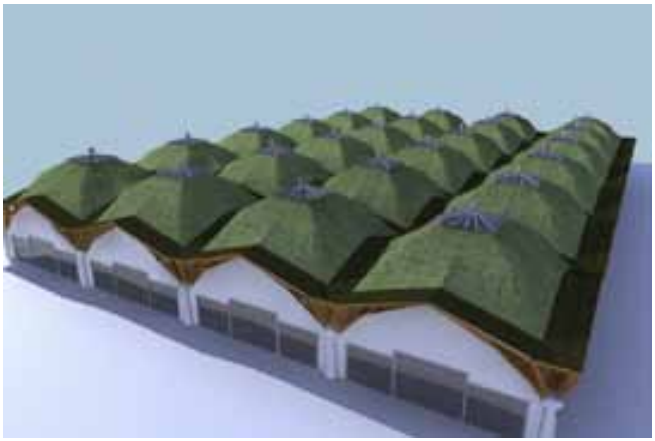
In the heart of bamboo country in Central Colombia, the towns were built entirely of bamboo, including these nearly one hundred year old buildings. The walls were made by plastering bamboo lath in a technique called **Bahareque** or **Quincha**. Disastrous fires a century ago (with no provision to fight them) caused legislation that kept bamboo from being exposed. So, the bamboo frames are visible only in the surrounding rural areas.

After the catastrophic 2001 earthquake in Colombia, 70% of the buildings in Central Colombia collapsed or were declared unusable, yet virtually all of the bamboo buildings survived. After a poitical reappraisal of building materials, Simón Vélez, an architect who made his name designing for the wealthy, decided that the low cost housing design he was about to do would be the most important thing he had ever done. The standard was to build one for US$5000, the budget here was half that – another reason bamboo was embraced. On the next page is some of his more elaborate work, still with the same clear structure of roofs and walls knitted together with expanded metal lath.

Here, Marcelo Villegas experimented with a greenhouse before he and Vélez built a temporary cathedral.

The base of a bamboo pole always has a thicker wall and will curve less than the more flexible upper portion. Think of the parabolic shape of a fishing pole. Use the bamboo the same orientation as it grows and the curves will mimic nature.

Bamboo Building Essentials

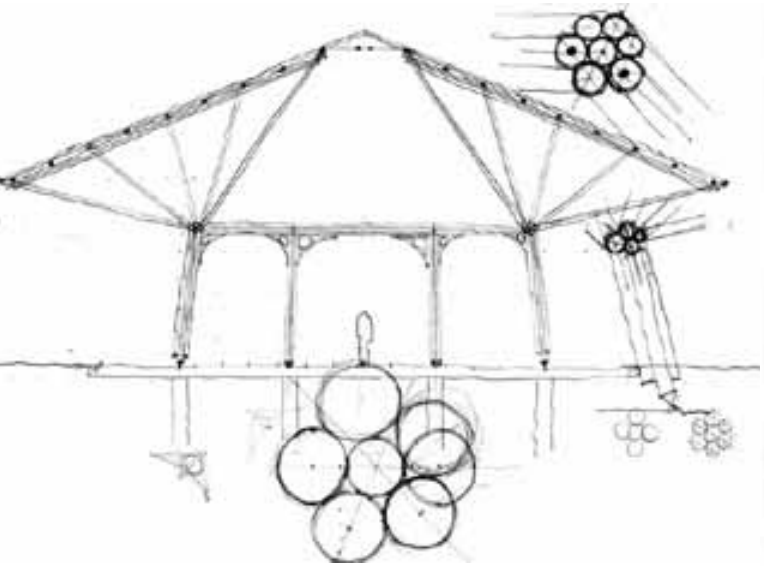


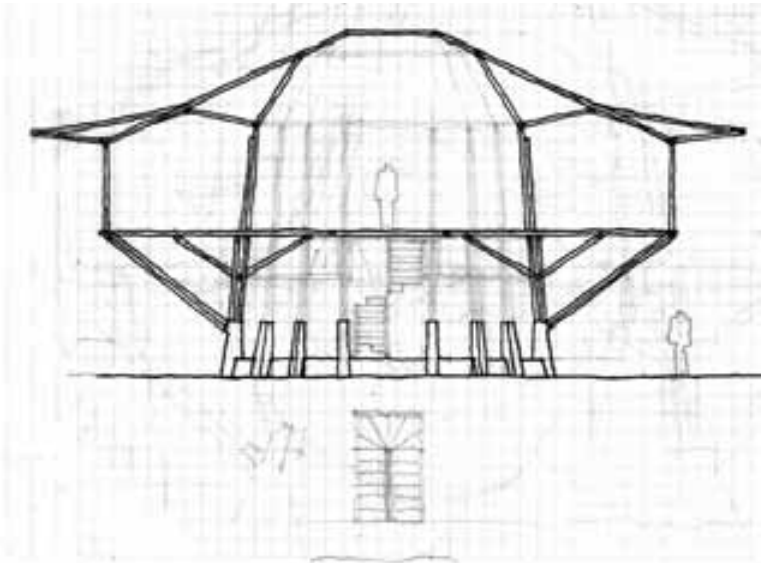
In this Vélez school, the idea was to make a repeatable module and emphasize even daylighting. Relatively short bamboos can work together to produce fairly large clear spans. There is a slight natural curve to each roof, which the construction system allows without causing extra work.

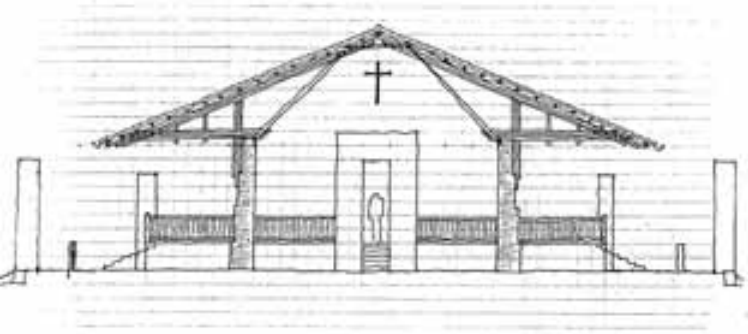
On the island of Bali, there can be found a great blend of traditional form of wooden buildings, modern bamboo joinery & treatment techniques and creativity. Credit here goes to a collaboration between Miya Buxton, Linda Garland, John & Cynthia Hardy, and.especially the West Sumatrans who helped with understanding traditional structure.

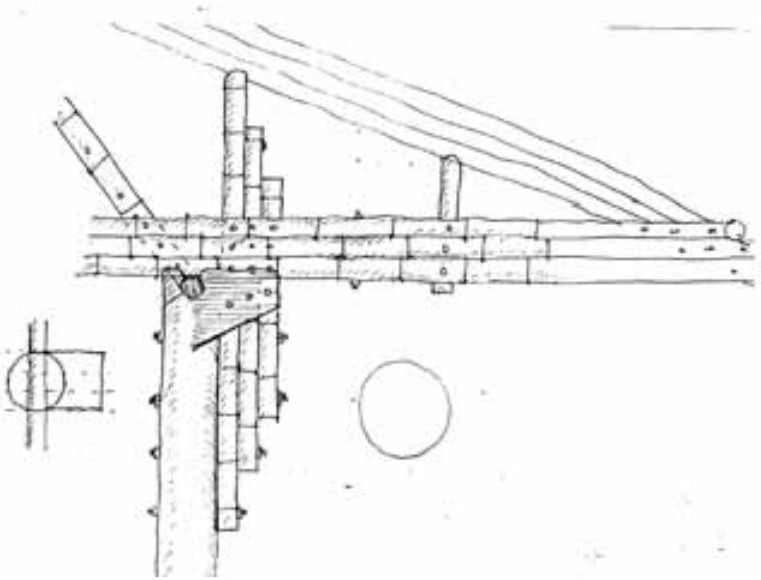
Bamboo Building Essentials

The home of Simón Vélez is a constant search for the understanding of traditional architecture. Some of that influence is from Colombia, where he grew up and some from Bali. He is able to continue experimenting because he buys bits of land from his neighbors, pushes over the old adobe service structures and plants a garden over the top. Then, his buildings gradually grow.





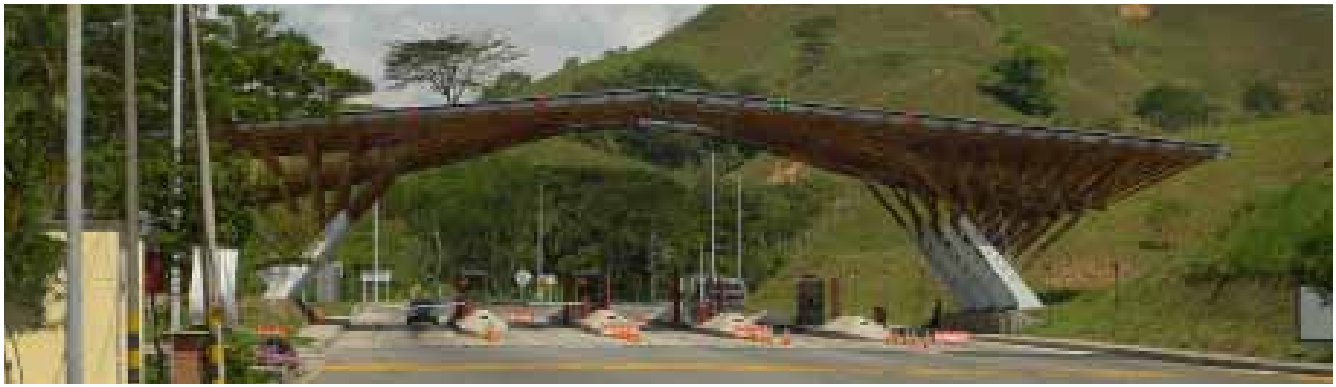




Vélez designs in section as much as in plan. These hand drawings on graph paper serve as the working drawings for construction. By repeating the same truss, most of the challenges of construction can be worked out in this quick sketch.

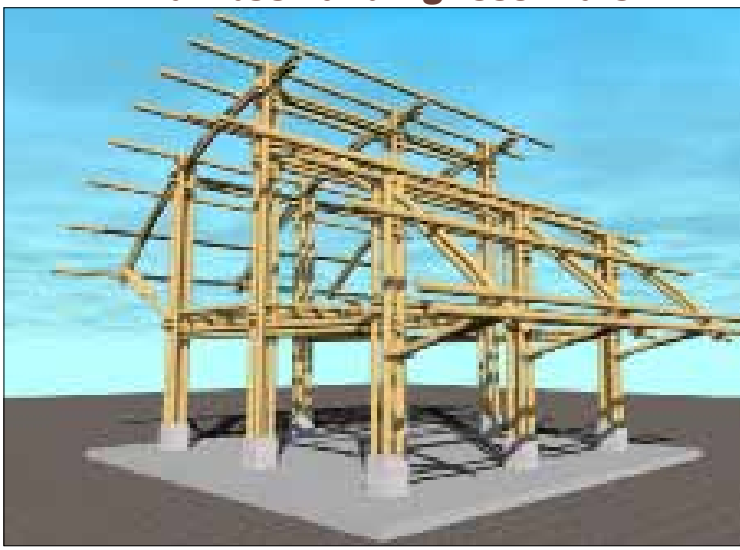
One of the first large scale bamboo buildings. This one a clubhouse for a housing development outside of Bogota, Colombia. Visible on billboards around the city, Vélez' seven meter cantilevered roof (mortared clay tile) is a very convincing argument for the strength of bamboo. By using multiple poles for every line he drew, he gains great strength and redundancy as well as a stronger look consistent with the size of the structure.

next page: this highway tollbooth by Simón Hosie epitomizes the high tech look possible with bamboo.

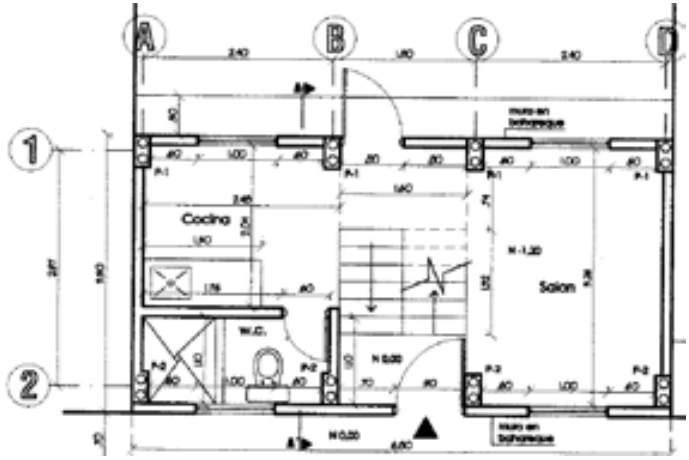


Quite a lot of diversity can be found in approaches to bamboo structures. In the case of the Universidad de Gran Golombia (lower left), the bamboo serves as much a symbol of pride about the place as it does a structural one.

Bamboo Building Essentials



Two of the leading advocates for bamboo architecture have teamed up to teach workshops and continue to extol the virtues of bamboo to a very receptive audience in Latin America. Colombian architects Hector Fabio Silva and Rafael Rojas use both the latest computer rendering techniques as well as the better building practices.



The $5000 house. Public housing on infill urban sites in Colombia. This one by architect Hector Fabio Silva

Bamboo Building Essentials

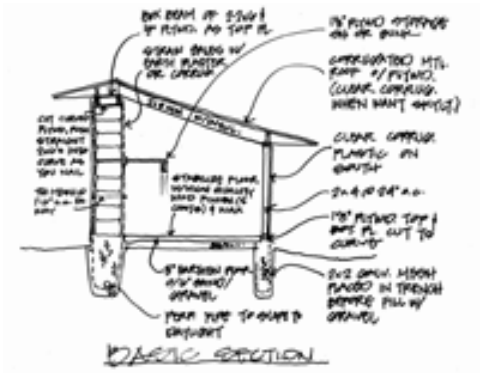
Celina Llerena in Brazil
This example (above and previous page) by Celina Llerena in Tinguá is a great example of urban infill with curving, living roofs to minimize the heating effects of roofs as well as to provide sound insulation.

Bamboo Building Essentials

Joerg Stamm's Three Mountains Jewelry Factory in Bali goes against conventional wisdom and embraces the bending of bamboo. The key is that the poles are anchored well on both ends and that the bent poles go all of the way around the structure so they all work as a unit since the ends of the poles can't move. The poles can bend quite a bit before being at risk of failure but it's not a good approach for the inexperienced.

Expat designers Aldo Landwehr and Joerg Stamm embraced traditional forms and materials to make some beautiful buildings for John & Cynthia Hardy in Bali. www.greenschool.org

Hoseclamps keep the expected splitting from being a factor. The joint in the left centerphoto makes use of a thin strip of bamboo to connect over the pole in between



Two Day Structure

This structure near Portland, Oregon is what emerged when Darrel DeBoer was asked to build something with the fewest number and least expensive materials, yet have it be able to heat itself. The project was completed in two days with 20 people – half of whom were considered skilled. To build a footing with no concrete, first dig a trench, line it with fishing net, and fill the trench with gravel. That will hold the building down to the ground. A couple layers of gravel-filled bags on top of the footings, above ground will protect the bales from moisture. As the bales are stacked, set strings between them every 2' and tie those to the net. The south wall was framed in wood and infilled with French doors (note: glass is 18% of the floor area to heat the building).

This project is an example of how the proper use of mesh can both remove the need for concrete and make a simple structure that can't fall and crush its occupants. Because the mesh doesn't rot and still ties all the parts together, the perpendicular walls will always remain standing. Even in the worst hurricane or earthquake, people will still be able to get out.

Firestone Classroom

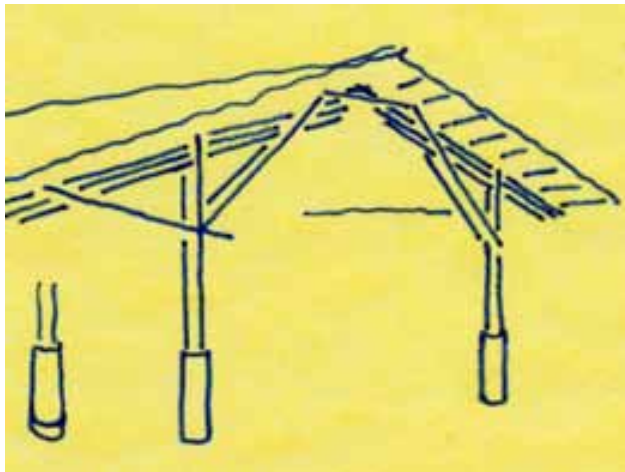
Built at The Firestone Center for Restoration Ecology in Domincal, Costa Rica, the design for this classroom was based on a bridge in an ancient Chinese brush painting, later copied or re-invented by Leonardo DaVinci. During assembly, the poles were laid out on opposite sides of the field then lifted up and a perpendicular pole was slid through. It was then lifted again to insert the next one. Each pole in the barrel vault has two poles under and one over running perpendicular. In theory, it could be able to support itself without bolts. In reality, it took 3 people to lift one wet pole so the bolts gave some peace of mind.

This was the project where it was learned that Indonesian Dendrocalamus asper has a larger diameter and much thicker walls than other versions of the same species from Thailand and elsewhere where it is known more for producing edible shoots than for being used for building material. In this case, the Asper purlins (connecting pieces) and Guadua trusses were grown on the building site and the two species were interchangeable as far as structural properties, size and thickness of cell wall.

Based on a military bridge possibly designed by Leonardo da Vinci who might have copied the idea from a 12th century Chinese painting. The structural concept is that each piece in each truss is supported at least twice from beneath and once from above by a perpendicular purlin. From the construction sequence, it can be seen that the structure gets bigger by lifting one side and sliding in another purlin. In that way, it is ideally self-supporting, requiring no fasteners. However, what we realized was that thick walled, green poles are extremely heavy and poles near the bottom will be crushed by the built-up weight if not bolted and filled.

Rancho Mastatal Project

This truss is a traditional, efficient shape. Stakes were set in the ground at the key intersections, and all of the trusses were built there. The trusses were held up temporarily with "X" braces while connecting pieces (purlins) were added. After two days, all pieces were in place, and the next two days were spent putting mortar into the joints and two more days for adding the metal roof.



Try to locate the bamboo poles so a minimum of mortar will be required to fill below the bolt and the node below the bolt. At the same time, lay it out so the node is end of the pole. Assemble the whole structure, now think about making it dramatically stronger for the high winds, earthquakes, hurricanes or whatever other horizontal forces come your way. First drill 1 1/4" diameter holes with a forstner bit just above the bolt. Inject mortar with either a mortar gun shown here (meant for repointing brick) or push the mortar through an upside down soda bottle with the bottom cut off.

The Hooch

Designer Jo Scheer's idea of what he calls the "hooch" is a structure pared down to its minimum number of parts, where all the work goes into the parts that are visible instead of an expensive foundation or lots of hardware hidden inside the walls. Most of the structure can be fabricated on the ground before pivoting it up into place. The Hooch requires that there are adjacent trees to attach cables to and a stout rock at the center base to pivot on. This particular all-bamboo structure was built in a week by two people. In Puerto Rico, Jo has built several more, including one with a kitchen, bathroom and bedroom all in the same one square foot footprint (www.tropical-treehouse.com).





























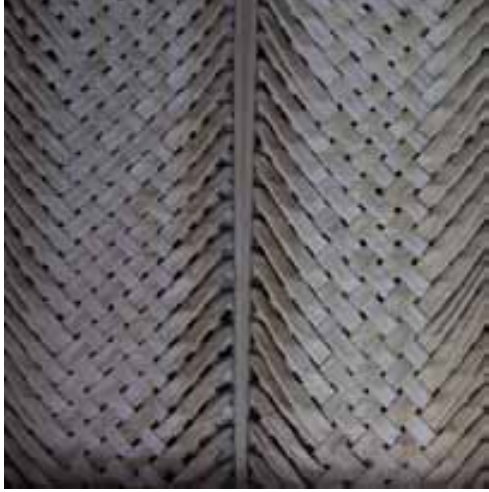














Sculpture and Special Uses:

Freed from the constraint of pure function, a surprising number of people have explored the immense formal possibilities of bamboo. Considering the depth and creativity of these explorations, there is so much to be learned.

Yoh Shoei's Naiju Community Center and Nursery School, Kyushu, Japan.

Think of the most beautiful basket you have seen. Any woven shape can be made of bamboo, especially with splits. Here, the bamboo was left exposed, then another layer of rebar and mortar was used to create the waterproofing of the roof.

Hyperbolic paraboloid in a Colombian public park by Rafael Rojas and Hector Fabio Silva

Bamboo Resources on the Web: www.bamboobuildingessentials.com

For updated links to websites about building with bamboo, along with companion videos and further information about the projects discussed in this book, check our website.

Parting thoughts on the future of bamboo

Bamboo instrument maker and musician Schuberth from Ecuador

Bamboo in North America - a place without a bamboo tradition - will take some considerable momentum to displace wood as a primary building material, but the hope is wider than that. Wood is included when we talk about a future of unprocessed natural materials the rights to which are not controlled by others. The sufficient strength and insulative qualities of natural fibers combined with the moisture-absorbing nature of earthen blocks and plasters will lend a structure of low material cost the strength, affordability and rot resistance to overcome the future high cost of oil, and thus the majority of what have become conventional building materials. Let's begin the transition.

Darrel DeBoer

is a California architect first inspired by a slide show by Simón Vélez at the Big Island Bamboo Conference in Hawai'i a decade ago. Bamboo just fit into all the criteria for a material we could continue to use without wearing something out or poisoning our clients. He has continued to build and spread the gospel of a better building material

Megan Groth

first heard about bamboo architecture at a lecture in Florence, Italy given by architect Mauricio Cardenas. She was awarded a Watson Fellowship to study bamboo building culture in Asia and Latin America, and is currently a masters of architecture student at the University of Washington.