Rethinking Bamboo Architecture as a Sustainable Alternative for Developing Countries: Juvenal Baracco and Simón Vélez

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ABSTRACT: The potential of bamboo as a sustainable material of construction for developing countries is examined through the work of contemporary leading South American architects Juvenal Baracco (b.1940) and Simón Vélez (b.1949). Whereas Baracco draws inspiration from Pre-Columbian and Spanish colonial traditions of *quincha* architecture, Vélez takes full advantage of the structural properties of the *Guadua angustifolia*, creating daring monumental structures of unsurpassed beauty. Light and flexible, yet stronger than steel, this bamboo resists well the stresses buildings face during earthquakes. Both Baracco and Vélez combine tradition and modernity through the use of renewable and sustainable natural resources of rapid growth and outstanding environmental and aesthetic qualities that offer great economic possibilities for diverse regions around the world.

INTRODUCTION

This paper investigates the potential of bamboo as a sustainable material for construction in developing countries, exemplified by the work of contemporary leading South American architects Juvenal Baracco (born in Lima, Peru in 1940) and Simón Vélez (born in Manizales, Colombia in 1949). The term "bioclimatic" has been used to aptly describe Baracco's and Velez's architecture of natural materials and sensitive environmental adaptations which consider issues of economy and sustainability so vitally important today in Third World countries. At the same time, in their search for a synthesis of modernity and tradition, both architects have arrived at spatial compositions of superior aesthetic quality.
The use of bamboo as a building material in South America has had a long history dating back to Pre-Columbian times, when it was used for *bahareque* or *quincha* walls of humble dwellings and other simple structures - a tradition that continues to the present day (Fig. 1). In the 17th century, during the Spanish colonial period, and thereafter, architects in Lima and throughout the Peruvian coast put to good use the antiseismic properties of bamboo, skillfully adapting it to the *quincha* vaulting needed to cover the monumental interior spaces of churches and other major buildings. *Quincha* structures consisting of plaster-coated webs of bundled and matted reeds on timber frames were reinforced with bamboo bent to produce the desired curvilinear shapes (Fig. 2). Light and strong, yet flexible enough to survive severe earthquakes, *quincha* proved to be an effective solution to a problem that had confronted several generations of builders (Rodríguez-Camilloni, 2003).

BAMBOO TYPES COMMONLY USED IN *QUINCHA* CONSTRUCTION

Depending on the geographic location, different types of bamboo were used in *quincha* construction exhibiting physical variations most noticeable in the thickness of the stems, and in the size and distribution of the nodes, internodes, and branches of the culms. Two of these types are the *Bambusa arundinacea*, a thick-walled bamboo with inflated nodes and heavy, solitary, thorny lower branches; and the *Bambusa textilis*, a thin-walled bamboo with cylindrical internodes, non-inflated nodes flared at the sheath scar, and branch buds lacking at the lower nodes and tardily developed above. In contrast, the *Bambusa vulgaris* is a moderately thick-walled bamboo, with inflated nodes, dormant branch buds below, and prominent branch complements above. As is the case with these and all bamboos, the diaphragm forms a transverse strengthening structure at each node (Fig. 3).

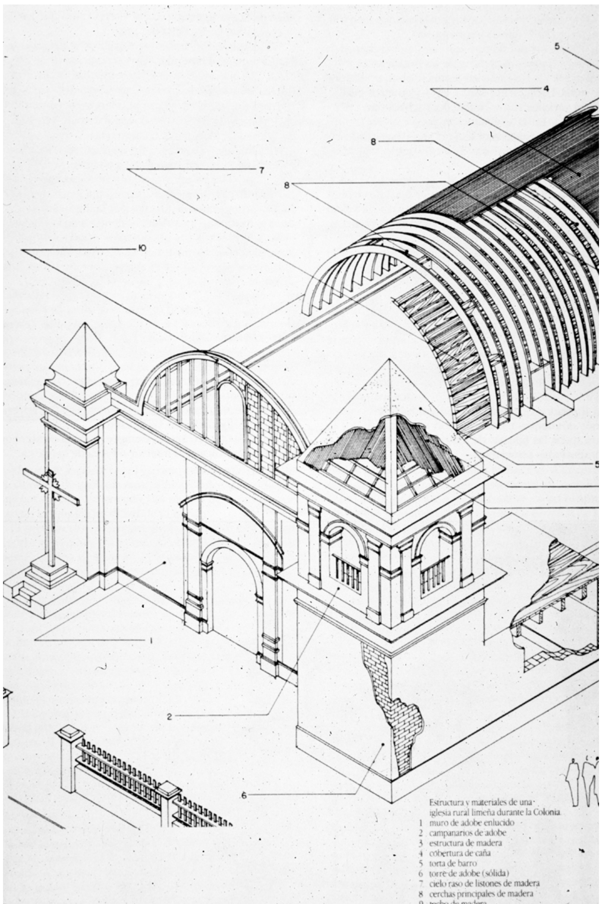

Figure 1(left): Typical traditional hut from the Peruvian coast showing *bahareque* or *quincha* wall construction; (author's photo of 2004), Figure 2 (right): Analytical drawing of Spanish colonial rural church of San Pedro, Carabayllo, in the central Peruvian coast showing *quincha* vaulting system; (Villacorta Santamano)

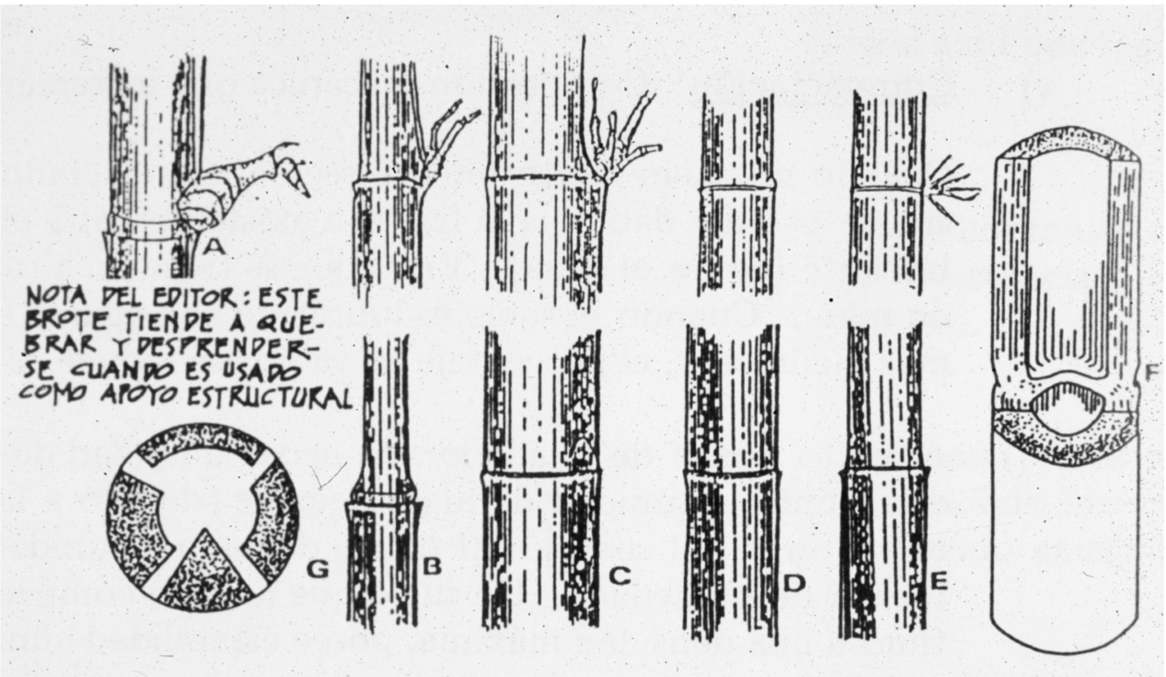

Figure 3: Examples of different bamboos with structural variations in the nodes, internodes and branches of the culms. A: *Bambusa arundinacea*; C: *Bambusa vulgaris*; D: *Bambusa textilis*; (Hartkopf)

JUVENAL BARACCO'S CONTRIBUTION

Drawing inspiration from the Pre-Columbian and Spanish colonial tradition of *quincha* architecture, Peruvian architect and educator Juvenal Baracco has designed and built a group of houses in the 1980s that exhibit elegant combinations of colorful elemental forms with vernacular timber and bamboo construction techniques suitable for an earthquake prone country. Of seminal importance for this development was the project for a Wooden Model House (*Prototipo Casa de Madera*) of 1977 that allowed Baracco to reconsider the use of traditional materials of construction (Carbonell, 1988, 96-101). In many ways, this three-year project turned out to be a decisive turning point in the architect's career, a new beginning that, like a "primitive hut," would inform many of his later domestic designs. It was commissioned to the Technological Group of the Board of the Cartagena Agreement (the 1969 Andean Sub-regional Integration Agreement between Bolivia, Colombia, Ecuador, Peru and Venezuela) as a prototype to promote wood construction technology. Even though the exhibition for which it was intended was never realized, the house was built as a full-scale model. Free from any specific functional constraints, Baracco was able to explore several important theoretical ideas that would serve him well in the future.

Based on the geometry of a perfect square (18.5 x 18.5 m.) in plan, the Wooden Model House presents an arrangement of interior spaces in an "L" defining two sides of a square courtyard or patio, the other two sides of which are enclosed by a wooden screen (Fig. 4). Between the interior rooms and the patio is a continuous corridor deck covered with a wooden trellis. The simple post-and-lintel system of construction uses a standard wooden panel that serves as floor, wall, and roof. The same material is used for the fenestration throughout. Closer analysis reveals that, conceptually, the house is derived from a 9-square grid, with a concentration of the kitchen and bathroom in the corner square (the elbow of the "L") clearly separating the private bedrooms and public living-dining room double-square wings. The remaining four squares are allocated to the patio, adjacent corridors and staircases.

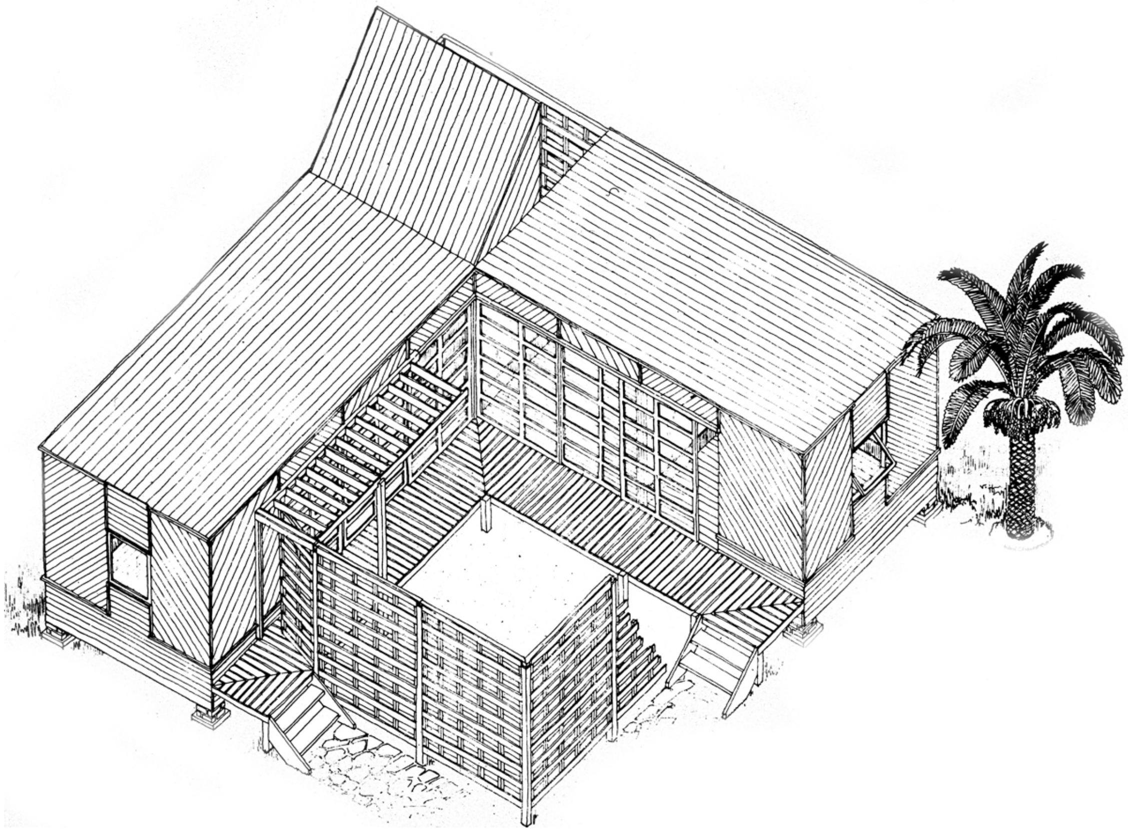

Figure 4: Juvenal Baracco: Wooden Model House, axonometric drawing, 1977; (Carbonell, 1988)

Significantly, the project of the Wooden Model House gave Baracco the opportunity to study anew the structural properties of natural woods such as oak, cedar, eucalyptus and above all, bamboo, which he came to appreciate for its intrinsic beauty. The lessons derived from this experience were best reflected in his La Barca, Lurín beach houses, some 20 miles south of Lima. The La Barca Beach Association was founded in 1981 by a group of property owners to develop a strip of oceanfront private houses. The plan of the subdivision presents a row house arrangement of lots of varying dimensions oriented east-west, so as to take full advantage of the prevailing ocean breezes and the privileged view toward the setting sun (Fig 5). Each of the four designs - the Gezzi House, the Marou-Yori Houses, the Prado-Valdez House, and the Gastañeta-Sarmiento Houses - present a different spatial concept, where Baracco was able to explore his vision of the ideal private house as a rich universe to celebrate the human spirit.

In these four houses, Baracco recognized the potential of responding to the alluring natural setting of the Peruvian desert and the majestic Pacific Ocean, so full of ancient mythical associations. The nearby archaeological site of Pachacamac and two associated islands named after Coniraya and Cavillaca, for example, recall Pre-Columbian gods believed to be responsible for the birth of all living creatures of the earth, the air and the sea. Most pertinent to our discussion here, however, are the Gezzi House and the Gastañeta-Sarmiento Houses. In the Gezzi House, completed in 1984, a cubical volume defined by a 9-square structural grid of rough eucalyptus posts covered with bamboo mats marks the garden patio as the symbolic heart of the residence (Fig. 6). Carefully placed furniture subdivide the space into a variety of areas, while a single but effective wooden lattice provides framed views of the seascape. The intrinsic beauty of these natural materials lends a special primitive yet elegant character to the space, contributing to its undeniable appeal. A street-corridor surrounds this central public space and provides a transition to the private spaces that wrap around three sides of the patio in a "U" distribution, permitting an equal sharing of the oceanfront view. The bright color of the stuccoed brick walls further enhances the pride of place given to the façade, standing in sharp contrast to the monochromatic background of the sandy desert.

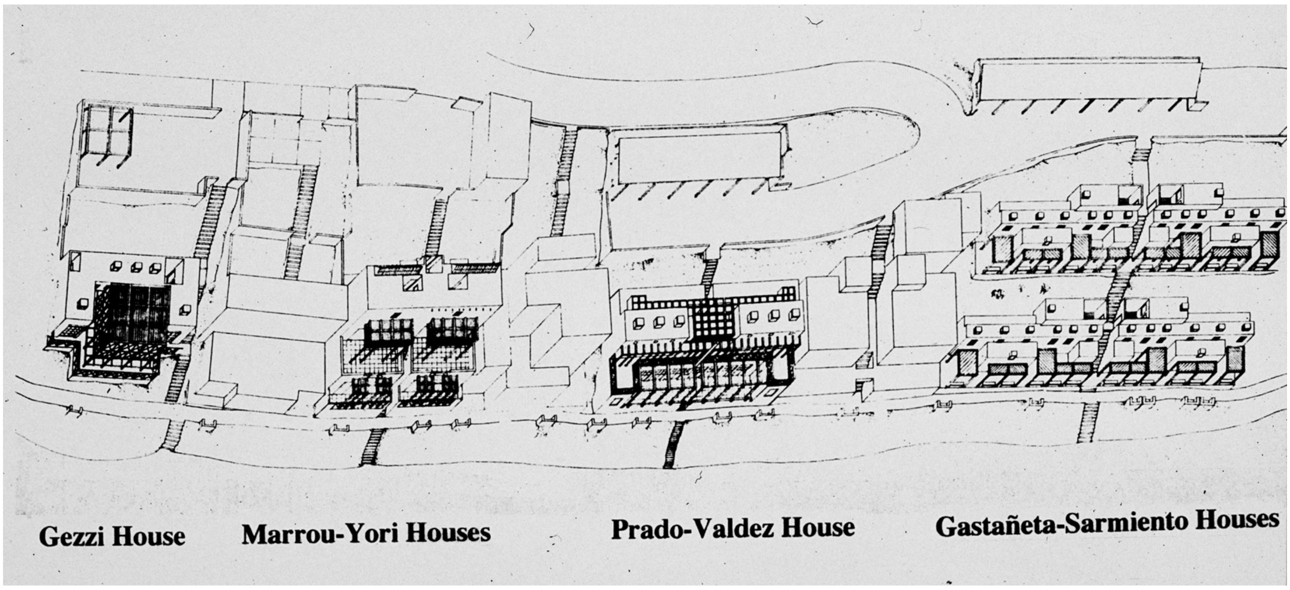

Figure 5: Juvenal Baracco: La Barca Beach Houses, Lurín, Lima, 1983-86, general perspective view from above with author's labels added; (Carbonell, 1988)

Figure 6. Juvenal Baracco: Gezzi House, La Barca, Lurín, Lima, 1984, interior garden patio; (Carbonell, 1988)

The Gastañeta-Sarmiento Houses, completed in 1985, were originally conceived as a cluster of four units, but only two were actually built occupying a total of 231.84 sq. m. of a 988 sq. m. property comprising two adjacent lots. Here the plan follows a linear organization where public and private spaces are linked by a continuous frontal terrace of varying width and a secondary interior corridor (Fig. 7). The social area defines the central nucleus separating the private and public spaces at either side. Together, the two houses present a unified western façade modulated by a delicately proportioned fenestration of square and rectangular openings. The frontal terrace, gained from the slope of the terrain, is roofed with a wooden frame painted bright blue and bamboo matting that recalls the Gezzi House.

Figure 7 (left): Juvenal Baracco: Gastañeta-Sarmiento Houses, La Barca, Lurín, Lima, 1985, west façade; (Carbonell, 1988), Figure 8 (right): Popular how-to publication by the Intermediate Technology Development Group to help promote *quincha* construction technology in low-income and self-help housing; (Lima, 1993)

The houses also exhibit white stuccoed brick masonry with wooden roof rafters covered with mud and cane. Baracco's skillful combination of elemental forms with vernacular timber construction techniques reflect an inspiration derived from the study of Pre-Columbian and Spanish colonial architecture. Specifically, the white and brightly colored stuccoed walls evoke the adobe structures of several Pre-Inca cultures that developed along the Peruvian coast, like the Moche, Chimú or Lima; whereas the extensive use of bamboo recalls the *quincha* antiseismic system of construction. As Baracco himself has indicated, "Some ancestral teachings are remembered, the Pre-Columbian dwellings of the desert: their scale, simplicity, and adaptation to the environment with a maximum economy [of] materials" (Carbonell, 1988, 229). Although modest in scale, Baracco's La Barca beach houses represent a major contribution in the development of contemporary Latin American architecture of far reaching importance. In these works he succeeded in integrating traditional construction techniques with modernism through architectural solutions that take into consideration the climate and local natural materials, with the choice of bamboo being influenced by a strong sense of ecological responsibility. Thanks to his initiative, today other young Peruvian architects are also rediscovering bamboo and *quincha* architecture as an economic, versatile and durable alternative with tremendous potential for low-income and self-help housing (Fig 8).

THE UNIQUE PROPERTIES OF BAMBOO

Modern research (Janssen, 1990) has revealed the remarkable and unique properties of bamboo that have attracted the attention of architects worldwide.In terms of its structural properties, bamboo is an extremely strong fiber, with twice the compressive strength of concrete and roughly the same strength-to-weight ratio of steel in tension, which allows it to handle long spans. Tests have also shown that the hollow tube shape gives a strength factor of 1.9 over the equivalent solid section. The reason for this is that, in a beam, the only fibers doing the work are in the top (compression) and bottom (tension), while the center is dead weight. The strongest bamboo fibers have a greater stress strength than structural woods, and they take much longer to come to ultimate failure (DeBoer, 2008).

With regards to sustainability, bamboo easily surpasses the most demanding criteria for continuous use. It is a renewable natural resource that can be plentiful, local and waste-reducing. For example, as has been shown by DeBoer, the *Phyllostachys* varieties will grow 12-18 inches a day once a grove is established. These bamboos are most suitable for growing and building in the United States and other countries with climates that experience frost. Culms (the living poles) grow as large as they will ever be in the first six-week spurt, then spend the next three years replacing sugars and water with silica and cellulose. Their structural use will then be only after the third year, when the culm is no longer needed by the plant. Plentiful supplies of timber-quality bamboo can be grown in any given region with a careful selection appropriate to the micro-climate, water and nutrient availability.

Since bamboo concentrates a large amount of fiber in a small land area, it can create the rare situation in which a single person is both producer and consumer of a building material. Thus a bamboo builder need not depend upon the whims of the marketplace and can create a long-term source of material. In addition, nothing goes to waste. Bamboo leaves are high in nitrogen, providing a good feed for livestock. And any fallen leaf compost goes to fertilize the next generation (DeBoer, 2008). Yet even more revealing are the statistics for pulling carbon out of the air, potentially reducing the amount of carbon dioxide that contributes to the greenhouse effect. According to the Zero Emissions Research and Initiatives (ZERI), a bamboo forest can sequester 17 times as much carbon as a typical tree forest (ZERI, 2008).

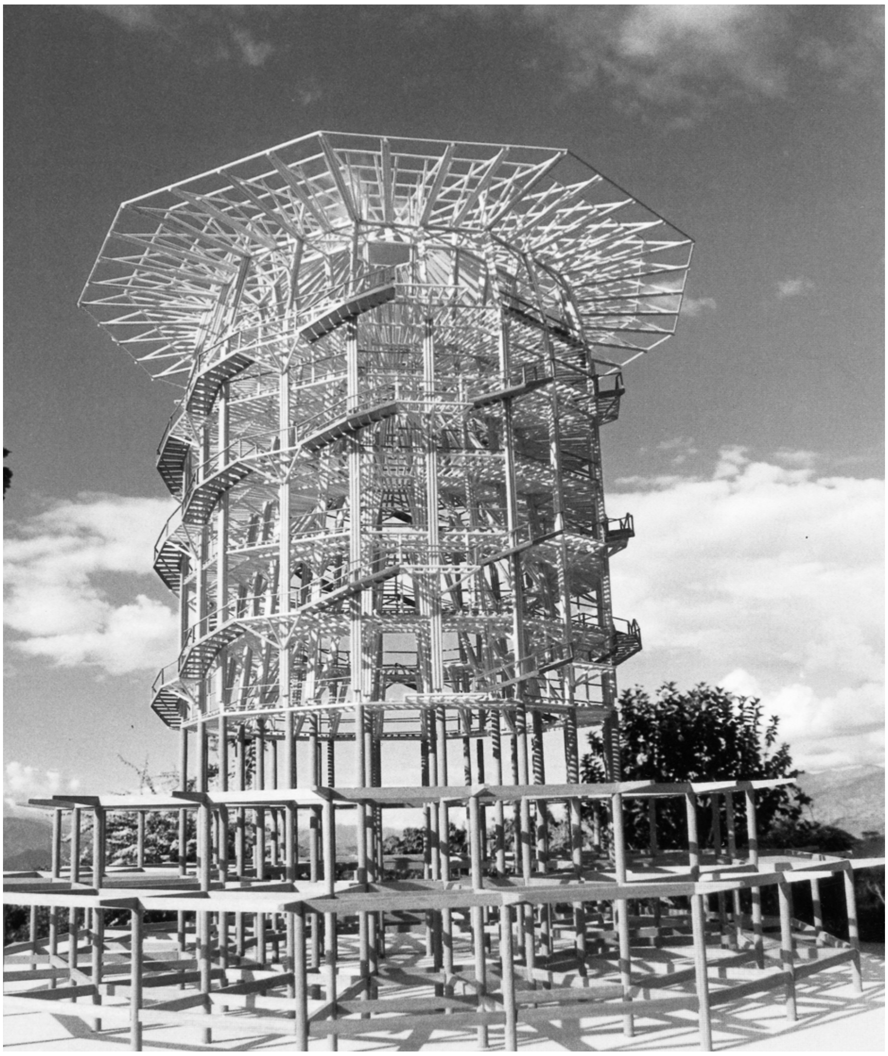

Figure 9: Simón Vélez: Project model for a bamboo belvedere in Parque Guadua, Pereira, Risaralda, 2000; (photo ZERI Foundation)

SIMON VELEZ'S CONTRIBUTION

In the case of the *Guadua angustifolia*, the gigantic and marvelous bamboo of South America that enjoys a rapid growth faster than any other plant on earth and is stronger than steel, architects led by Simón Vélez and his followers in Colombia have found an ideal renewable material of construction for the creation of daring monumental structures of unsurpassed beauty (Fig. 9). Light and flexible, yet strong enough to resist the sort of stresses buildings face during earthquakes, this bamboo had been traditionally used in small and simple structures such as gazebos, trellises and arbors. In the past twenty years, however, Vélez and his followers have designed structures that defy traditional building codes taking full advantage of the structural properties of the *Guadua*. These highly original monumentally scaled creations represent a wide range of building types including exhibition pavilions, greenhouses, churches, farmhouses, bridges and single-family houses. In most of these designs, the bamboo that Vélez has called "nature's prodigy" functions simultaneously as form, structure and ornament (Pratt, 2006).
Critical for the full implementation of bamboo in monumental structures has been the development of a system of joints sufficiently strong to resist the stresses involved:

> Given that bamboo is hollow, connections in edifices made of this material call for a totally different approach than is customary with building in wood. Nails and screws are out of the question because of the innate danger of splintering; moreover, it is necessary to allow for the fact that bamboo canes are always of varying diameters. In this context, it must be said that the carefully selected connections deployed testify to the advantages of the bamboo over wood. A whole host of methods exists for connecting bamboo canes. Many of them, in addition to their practical function, also have an intrinsic value. The spectrum ranges from simple bolt/pin, lashing, and adhesive techniques via combined solutions through to the complex methods employed in Simón Vélez buildings - there, the lashed ends of the bamboo canes are often filled with concrete. Parallel connections, orthogonal connections, and angle joints are amongst the most commonly used shapes. The latter are often bound in a complex manner so that between eight and ten canes converge at one single point [Fig. 10] (Kries, 2000, 109).

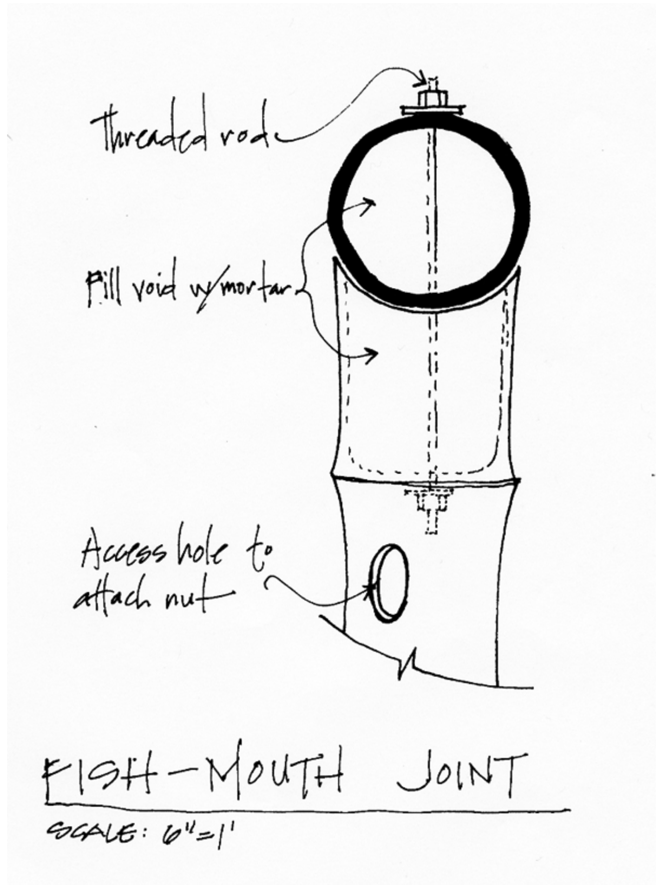

Figure 10 (left): Simón Vélez: Expo Hannover 2000 Guadua Pavilion, joint detail; (Villegas, 2003),
Figure 11 (right): Typical "Fish-mouth" joint detail for bamboo construction; (DeBoer, 2008)

The common problem encountered in the construction of a truss or frame where the bamboo canes come together in the same plane is illustrated by the solution of the "fish-mouth" joint (Fig. 11). This connection requires a coped, curving fit at both ends with an internal bolting which is labor intensive and difficult to achieve. An improved solution developed by Vélez in Colombia uses a three-dimensional bamboo truss with a simple bolted connection where the void between the nodes is filled with a solidifying mortar, thereby increasing the surface area of the joint significantly. In solving the problem of how to inject cement into joints to strengthen them, he succeeded in overcoming a major challenge in the construction of large scale structures with bamboo. Architect Vélez recalls how he arrived at this solution: "Twenty years ago, I got interested in making a small structure in *Guadua*. My previous experience of working with wood did not help in the case of a material that is so different. I wanted to build a cantilever roof that would stand the stress of traction but I could not find a way to make a joint for a hollow material like *Guadua*. One day, it suddenly occurred to me that if I filled with cement the inter-node chamber where the joint was, which in turn would have iron bolts, it might work. And it did" (Villegas, 2003, 44-45).

Vélez had the opportunity to showcase his revolutionary structural system at Expo Hannover 2000, for which he designed and built the now famous 2000 square meter bamboo pavilion for ZERI (Fig. 12). This project, which placed Vélez on the international map as the foremost champion of bamboo in contemporary architecture, presented the architect with a difficult challenge to overcome. In Germany, one of the countries with the strictest construction codes in the world, several skeptical structural engineers, questioning the stability of Vélez's pavilion, demanded that a construction permit be issued only after an identical full-scale model be built in Colombia to be submitted to a series of tests. Undeterred, Vélez accepted the challenge and after raising US$ 100,000 proceeded to build the exhibition model in his native town of Manizales. There, under the close supervision of Professor Klaus Steffens, director of the Institute of Experimental Statics of the University of Bremen, Vélez's *Guadua* pavilion underwent the most rigorous tests to determine its load bearing capacity:

1) The load bearing capacity of the cantilevers (a 7.30 meters overhang) was tested by hanging a weight of more than 650 kilograms in the middle of their spans. A deformation of 7 millimeters was observed, which the structure recovered when it was freed of the load.

2) The capacity of the upper floor was tested by loading it with 55-gallon barrels, which were uniformly spread over the surface and filled with water until they reached a load of 400 kilograms per square meter. The deformation observed under this load came to 5 millimeters or only a fifth of what had been estimated it to be; and, again, were recovered when the load was removed.

3) A third important test involved a simulation of wind stresses and consisted of pulling the structure in a horizontal direction. The procedure involved placing one cable in the middle part and another in the upper part of each of the pediments of the pavilion and then subjecting each cable to a horizontal load of five tons. The horizontal displacement observed this time barely measured 1 centimeter (Villegas, 2003, 58-59).

Figure 12: Simón Vélez: Full-scale exhibition model for ZERI Guadua Pavilion at Expo Hannover 2000 as built in Manizales, Caldas, Colombia in 1999; (photo ZERI Foundation)

With this overwhelming evidence, Professor Steffens was left with no choice but to certify the accuracy of the tests and proceed to recommend a construction permit be issued without delay for the construction of Vélez's pavilion in Germany. Appropriately enough, Expo Hannover 2000 was the world's fair that marked the beginning of the new millennium, showing the world a new global vision and models for restoring equilibrium between man, nature, and technology. When the fair opened, more than 6 million people visited Vélez's *Guadua* pavilion, which quickly gained universal acclaim as a landmark of sustainable architecture (Fig. 13).

Figure 13: Simón Vélez: Expo Hannover 2000 Guadua Pavilion, inauguration ceremony; (Villegas, 2003)

As described by Marcelo Villegas, personal friend and collaborator of Vélez,

> [The Hannover pavilion] has the geometrical shape of a ten-sided polygon [over] a constructed area of 2000 square meters. Its roof is a *Guadua* structure topped by a cement mortar that is waterproofed with a mantle upon which the ceramic roof tiles are placed. This cantilever roof has a weight of 200 kg/square meter, seventy percent of which is made up of overhangs that reach a 7.50 meters span on ground level. The pavilion has a mezzanine of 550 square meters, with a massive concrete slab, 10 cm. thick, which rests on forty columns, each made up of bundles of six trunks of *aliso*-wood, tied together with iron clamps. These columns rest on steel ball and socket joints with steel bolts that allow for the post-tensing of the forces that occur when the diameters of the columns shrink as they dry. The main criterion in the design of this structure was to only use the different varieties of timber and bamboo that naturally grow in this region,whether they are fine or ordinary woods (Villegas, 2003, 52) [Figs. 12, 14].

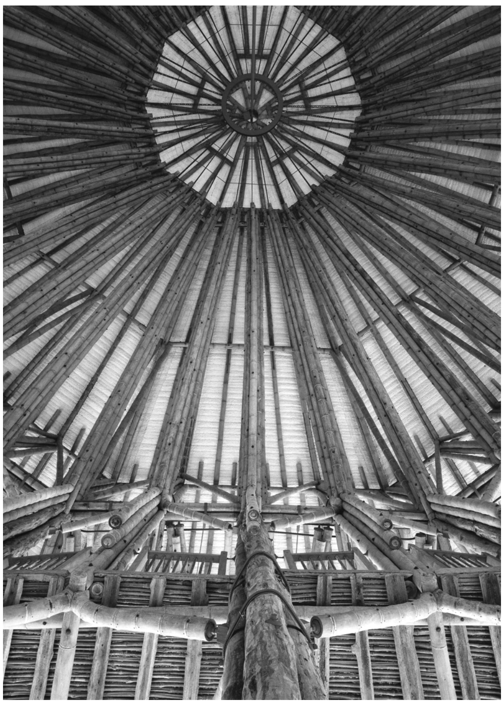

Figure 14 (left): Simón Vélez: Expo Hannover 2000 Guadua Pavilion, interior of roof structure; (Villegas, 2003).
Figure 15 (right): Simón Vélez: Alternative Cathedral, Pereira, Risaralda, interior, 2001; (J.E. Arango)

CONCLUSION

One of the major aims behind the construction of Vélez's Hannover 2000 Pavilion was to change the widespread image of bamboo as a symbol of poverty. Vélez and the Global ZERI Network that commissioned it shared the idea of creating a unique structure that would inspire pride and stimulate the use of this abundant, fast-growing construction material. The tremendous success of this magnificent pavilion ultimately led to its reconstruction in Manizales, Colombia, where it now serves as a symbol of pride for the surrounding coffee farmers. Without a doubt, the *Guadua* pavilion remains the crowning achievement of Simón Velez's career as the architect of "vegetable steel," yet his body of work to date includes an impressive collection of other outstanding works. Many of these have become well known for their spectacular roof structures that make them easily recognizable as Vélez's creations. Not surprisingly, when once asked, "How would you describe your style of building?" Vélez was quick to reply: "I would define myself as a 'roof architect.' I design the roof first and then what comes beneath it. Roofs have to withstand weather and always reflect the culture they come from" (Kries, 2000, 59).

When designing his roofs Vélez has had to pay particular attention to the function of supports, finding ways of emphasizing them visually in ever increasingly dramatic ways. "The sheer size of his buildings require special supports so, in addition to using individual canes, [he] also developed a load-bearing structure made up of several canes joined together to form a bundle. The canes are fastened to one another lengthwise, but only one of them rests on a concrete base [that helps prevent insect infestation]. The remaining canes transfer the forces absorbed at their upper ends to the central support while likewise stabilizing it, preventing it from sideways breakage. Often the stability is enhanced by opting for supports that slope slightly inwards." (Kries, 2000, 77). Seen together from a variety of angles, the bamboo canes make visible the beauty of their natural texture and color highlighted by subtle nuances of light and shadow. Today Simón Vélez's bamboo buildings can be found in Colombia and also in Brazil, Ecuador, Mexico, Jamaica, Panama, China and India. Some of his most representative creations in his native country include: the Factory Hall of 1993 in Pensilvania, beautifully integrated with the landscape; the airy "Plantamos" Greenhouse of 1997 in Usaquén, which is actually a steel structure with glass roof and walls, with a bamboo-lined interior to provide shade for plants; the Alejandro Martínez House of 1997 in Sesquilé, Cundinamarca, showing bamboo's versatility for building in colder climates; the Puerto Peñalisa Country Club of 1992-97 in Ricaurte, Cundinamarca, the largest bamboo structure until the construction of the ZERI pavilion; the Model House (*Casa Prototipo*) of 1999 in Quindío, Risaralda, a prototype for low-cost housing to be built on no more than 100 square meters for only US$ 1,750, if owner built; and the Alternative Cathedral of 2001 in Pereira, Risaralda, covering an area of 700 square meters and constructed in five weeks at a cost of US$ 30,000 using a technique inspired by the natural vaulting of *Guadua* bamboo groves in the wild (Fig. 15).

Like Juvenal Baracco in Peru, Simón Vélez and his followers in Colombia recognize that tradition and modernity can complement each other. Their creativity is enhanced through the use of renewable and sustainable natural resources of rapid growth such as bamboo with its outstanding environmental and aesthetic qualities which offer great economic possibilities for diverse regions around the world. As noted by contemporary architect Renzo Piano, "The 19th century was about new kinds of construction, steel and so forth. And the 20th century created a language for that. Now architects must develop an aesthetic for our discovery about the fragility of nature" (Lacayo, 2008, 91).

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