Building with Bamboo

# Building with Bamboo

Gernot Minke

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## Cultural, Educational and Sacral Buildings



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# I

# The Technology of Bamboo Building

# 1

# Historical Examples

## Types of Bamboo

The word "bamboo" was introduced by Carl von Linné in 1753. Bamboo is a grass plant like rice, corn and sugar cane. Different to these, the lignin of its tissues becomes after some years a structure as hard as wood, but more flexible and light. Bamboos, in their wild form, grow on all of the continents except Europe, from 51° north to 47° south. There are tropical and subtropical bamboos that thrive in different ecological niches, from cloud forests with humidity levels above 90% like the *Guadua angustifolia* in the Chocó Department of Colombia, to semi-arid zones of India (*Dendrocalamus strictus*). The majority of species are found in warm zones with humidity levels of over 80%, in tropical cloud forests, and in clayey and humid soils; for this reason they are often found near water. A few grow in dry climates or over 4,000 m above sea level. In China and Japan there are also species that can survive temperatures below zero degrees. Approximately 1,200 species exist, of which there are 750 in Asia and 450 in America. Of these last, the greatest diversity is found in Brazil (Hidalgo, 2003). It is estimated that 37 million hectares are covered with bamboo forests: 6 million in China, 9 million in India, 10 million in ten countries of Latin America and the majority in Southeast Asia (Lobovikov et al., 2007). Since antiquity, bamboo has been a construction material used to build basic habitats to complex structures; it has formed part of a set of elements that were an essential part of cultural development in Asia and America. In tropical zones, the bamboos most commonly used in construction are the *Bambusa*, *Chusquea*, *Dendrocalamus*, *Gigantochloa* and *Guadua*. Those of the group *Phyllostachys* prefer temperate zones.

The following is a list of the bamboos most commonly used in construction. Their characteristics are briefly mentioned, with the proviso that data can vary depending on local conditions. More information on the species can be found in Farelly (1938), Young and Haun (1961) and McClure (1966).

### Bambusa

- *Bambusa balcoa*
  Height: 12 – 20 m. Diameter: 8 – 15 cm.
  Origin: India.
  Note: internode thickness of up to 3 cm.
- *Bambusa disimulator*
  Height: 12 m. Diameter: 6 cm.
  Origin: Southern China.
  Note: fine and very hard internode.
- *Bambusa edilis*
  Height: 20 m. Diameter: 16 cm.
  Origin: China.
- *Bambusa polymorpha*
  Height: 27 m. Diameter: 15 cm.
  Origin: China, Bengal, Burma.
- *Bambusa stenostachya*
  Height: 22 m. Diameter: 15 cm.
  Origin: China.
- *Bumbusa vulgaris*
  Height: 18 m. Diameter: 10 cm.
  Origin: Asia, Americas.
  Note: high starch content.
- *Bambusa bambos (L.) Voss*
  Height: 30 m. Diameter: 15 – 18 cm.
  Origin: Southeast Asia.
  Note: thick shell.
- *Bambusa nepalensis*
  Height: 20 m. Diameter: 10 cm.
- *Bambusa oldhami Munro* ("Green bamboo")
  Height: 6 – 12 m. Diameter: 3 – 12 cm.
  Origin: Taiwan.
  Note: strong green colour, short internodes.
- *Bambusa vulgaris, Schrader ex Wendland*
  Height: 6 – 15 m. Diameter: 5 – 10 cm.
  Origin: Southern China.
- *Bambusa vulgaris, Schrader ex Wendland, var. striata*
  Origin: Southeast Asia.
  Note: mutation of *Bambusa vulgaris* with yellow-gold colour and green stripes.

## Chusquea

- *Chusquea culeou*
  Height: 6 m. Diameter: 4 cm.
  Origin: Chile.
  Note: It grows in the southernmost zones of the planet, and has a very strong culm.
- *Chusquea culeou Desvaux* ("coligüe", "colihue" or "culeú" in Chile)
  Height: 4 – 6 m. Diameter: 2 – 4 cm.
  Origin: Central America, South America.
  Note: solid stalk, yellow colour.
- *Chusquea quila Kunth* ("quila" in Chile)
  Origin: Chile.
  Note: solid stalk.

## Dendrocalamus

A group of bamboos with many varieties; they grow very tall and are important for construction.

- *Dendrocalamus balcoa (Bambusa balcoa)*
  Height: 20 m. Diameter: 20 cm.
  Origin: Southeast Asia and India.
- *Dendrocalamus giganteus* ("Giant bamboo")
  One of the largest bamboos, it has a diameter of 30 cm or more. It grows up to 20 cm per day and reaches a height of more than 30 m. The species is originally from India, Burma, Sri Lanka and Thailand, and is used for large structures, for furniture and for the production of paper.
- *Dendrocalamus asper* ("Bucket bamboo" in Brazil)
  Resistant to below-zero temperatures. It does not grow as much as *Dendrocalamus giganteus*; reaches a height of 25 m and has a diameter of 20 cm. Its stalk is very hard and cracks less than *D. giganteus* while drying. Excellent for construction.
- *Dendrocalamus latiflorus*
  Height: 20 m. Diameter: 20 cm.
  Origin: Taiwan, Southern China.
  Note: internodes of up to 70 cm; very thick stalk (more than 2.5 cm).

## Gigantochloa

- *Gigantochloa apus*
  Height: 16 m. Diameter: 10 cm.
  Origin: Malaysia and Indonesia.
- *Gigantochloa atroviolacea* ("Black bamboo")
  Height: 13 m. Diameter: 8 cm.
  Origin: Malaysia and Indonesia.
- *Gigantochloa levis*
  Height: 16 m. Diameter: 10 – 15 cm.
  Origin: Phillipines.

## Guadua

The guadua is a type endemic to South America. Its name was given by Karl Sigismund Kunth in 1822, who took it from the term "guadua" used by the indigenous peoples of Colombia and Ecuador. The forests of guadua are called "guaduales" (*2.4*).

- *Guadua angustifolia Kunth*
  The guadua most commonly used in construction; it has a diameter between 9 cm and 12 cm, exceptionally can reach up to 21 cm. Its daily growth can be 12 cm per day, and after 3 months it reaches 80% to 90% of its definitive height, which can be between 15 m and 30 m high.
  Among its varieties are *bicolor Londoño* and *nigra Londoño*, which have variations of form according to the climate: "onion" with internodes that are long and efficient in tension; "club" with internodes more closely spaced and efficient in compression; "castle", which is less efficient in compression and more suitable for the elaboration of planks; and "goitred", characterised by its irregular stalks.
- *Guadua aculeata*
  Height: 25 m. Diameter: 12 cm.
  Origin: Mexico to Panama.
- *Guadua chacoensis* ("tacuaruzú")
  Height: 20 m. Diameter: 8 – 12 cm.
  Origin: northern Argentina and Bolivian tropics.
- *Guadua paniculata Munro* ("pretty")
  Height: 10 m. Diameter: 3 cm.
  Origin: Bolivian tropic.
  Note: the upper part is solid, while the lower has small openings.
- *Guadua superba Huber* ("tacuarembó")
  Height: 20 m. Diameter: 9 – 12 cm.
  Origin: Bolivian tropics.
  Note: cracks easily.

## Phyllostachys

The bamboos of this group grow in temperate zones and have the characteristic of forming nodes in zigzag or other irregular forms. Is originally from China, nevertheless many species were cultivated in Japan, the Americas and Europe.

- *Phyllostachys aurea* (*2.7*)
  Height: 5 m. Diameter: 2 cm.
  Origin: China and Japan.
- *Phyllostachys bambusoides*
  Height: 22 m. Diameter: 14 cm.
  Origin: Japan.
- *Phyllostachys nigra, var. henonis*
  Height: 16 m. Diameter: 9 cm.
  Origin: China, introduced into Japan and the United States.
- *Phyllostachys pubescens* ("Moso", "Mao Zhu")
  Height: 21 m. Diameter: 17 cm.
  Origen: China, introduced into Japan and the United States.
- *Phyllostachys vivax*
  Height: 21 m. Diameter: 12 cm.
  Origin: China.

# Positive Environmental Effects

## Biomass Production

Bamboo is a rapid-growth natural resource that can produce much more dry biomass per hectare per year than eucalyptus. The production of bamboo biomass depends on many factors and therefore varies significantly. According to Liese and Düking (2009), the production of dry aerial biomass from *Bambusa bambos* in Southern India reaches 47 tonnes per hectare per year if it has been cultivated, while that of *Chusquea culeou* of Central Chile reaches only 10.5 tonnes per hectare per year. According to Riaño et al. (2002), starting from new cultivation, the *Guadua angustifolia* in Cauca Valley, Colombia, produces approximately 100 tonnes per hectare in six years.
According to Cruz Ríos (2009), the production in one plantation of *Guadua angustifolia* reached up to 594.2 tonnes per hectare in seven years.

## Reduction of Soil Erosion

Bamboo has a dense network of roots that anchors earth and helps to lessen erosion due to rain and flooding.

## Water Retention

One hectare of *Guadua angustifolia* can retain over 30,000 liters of water (Sabogal, 1979).

## Regulation of Hydraulic Flow

Retaining water in its stem, bamboo conserves water in the rainy season, using it later in the dry season.

## Temperature Reduction

Thanks to their leaves, bamboo forests reduce air temperature through water evaporation.

## Sequestering of $CO_2$

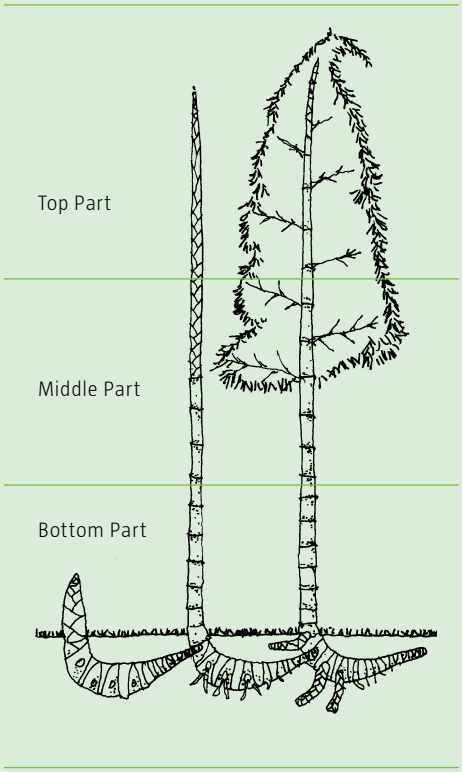
Plants that assimilate $CO_2$ for photosynthesis, storing it in their biomass, make an important contribution to the global climate. Because of its rapid growth, bamboo can take in more $CO_2$ than a tree. The *Guadua angustifolia Kunth* takes in 54 tonnes of $CO_2$ per hectare during its first six years of growth (Londoño, 2003). This might be a relevant fact for international greenhouse gas emission allowance trading. However, this fact is only valid if the bamboo plant that has sequestered the $CO_2$ is transformed into products with long life spans.
According to Cruz Ríos (2009), the absorption of carbon at one plantation of *Guadua angustifolia* is 149.9 tonnes per hectare in the first seven years, which is an average of 21.41 tonnes of carbon per year per hectare, and a natural growth of *Guadua angustifolia*, with a density of 5755 plants per hectare, has absorbed a total of 132.6 tonnes of carbon. After six years, the bamboo stock stabilises the quantity of carbon absorption, due to the fact that this is totally vegetative development. "Being a plant that self-regenerates, bamboo has, with adequate management and harvest, a permanent $CO_2$ absorption, which does not happen with other species. The guadua is planted only once and with good management converts into a permanent plantation." (Cruz Ríos, 2009)

## Primary Energy

According to Janssen (1981), the production of bamboo uses 300 MJ/$m^3$, compared with 600 MJ/$m^3$ for wood.

# Different Uses

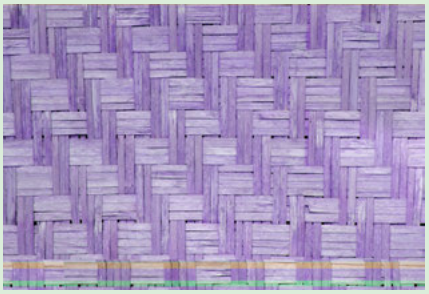
The use depends on the type of bamboo, its age and the part of the plant. Figure *1.1* describes the uses for the bamboo *Guadua angustifolia Kunth*.
Due to its favourable mechanical characteristics, great flexibility, rapid growth, low weight and low cost, bamboo is a construction material with many applications. It is estimated that one billion people live in houses constructed from bamboo (Liese and Düking, 2009); for example, in Bangla Desh over 70% and in Guayaquil, Ecuador, 50% of the population uses it in construction. In seismic zones bamboo construction is preferred due to its lightness and flexibility. In humid tropical zones bamboo is used in construction since it is a local, cheap and easily handled material; furthermore in these areas it allows walls with low thermic mass.




| | USES ACCORDING TO THE PLANT SECTION | | DESCRIPTION | HEIGHT | LENGTH |
|---|---|---|---|---|---|
| Leader | Returns to the earth as organic material | | Apical part of the plant | 20 m | 1.20 – 2 m |
| Stick | Structural straps for roofs, and guides for transitory cultivations | | Part of the stalk with the smallest section | 18 m | 3 m |
| Top | | | | | |
| Middle | In structures such as roof purlins, scaffolding, structural columns for greenhouses | | Because of its diameter, it is the most marketable part of the upper stalk | 15 m | 4 m |
| | Elaboration of planks, slender columns and beams | | Part of the stalk most used, for its diameter | 11 m | 8 m |
| Bottom | Columns in civil works, greenhouses and fences | | In this part, the stalk has the greatest diameter. It is the most resistant part of the plant | 3 m | 3 m |
| Rhizome | Sculptures, furniture and children's toys | | Network of underground stalks | 2m | 2 m |
| **USES ACCORDING TO AGE** | **30 days Food** | **1 year Basketwork** | **2 years Planks, Strips, Laths** | **3 to 4 years Civil Structures, Floors, Laminates** | |

**1.1**

The ideal use of large bamboos like *Guadua angustifolia* depends on their age. In their first days, bamboo hearts are used as human food; between six and 12 months, strips extracted from the external zone of the cane are ideal for making fabrics (*1.2* and *1.3*); at two years the canes are better for making plank boards (see Chapter 7, "Canes, Planks, Strips, Laths and Belts") and normally between three and five years the stalks are ideal for use in construction.



**1.2**

**1.3**

1.4

1.5

The majority of traditional houses in the rural zones of warm humid climates where bamboo grows, are constructed of this material. Figures *1.4* and *1.5* show examples from Indonesia and India. Due to walls of bamboo planks there is sufficient air circulation.

A typical use of bamboo canes is in the construction of scaffolding. In Asia these are found with heights of more than 40 storeys (*1.6*). New is the use of bamboo strips of 1 × 1 cm parallelly forming a structural beam of 12 cm in diameter, composed of approximately 100 laths secured with leather; see p. 90f.

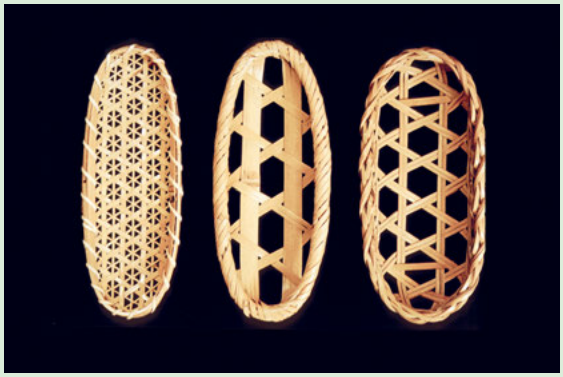
Another common use in regions where bamboo grows is for crafts and everyday objects (*1.7* to *1.10*), musical instruments (*1.11* to *1.13* and *1.19*) and furniture (*1.14* to *1.16*). New is the experimental use in vehicles like bicycles, cars and buses: figure *1.17* shows the design of a bamboo buggy by Jörg Stamm; Julio César Toro has designed and built a rural bus for 20 people (*1.18*). To make the body, the floor and the railings, he used 40 lineal meters of guadua and for the roof he used 63 small boards of macana. The bumper was made of laminates of guadua.

Asia has pioneered the industrial development of the use of bamboo in laminates (see Chapter 7, "Laminated Elements") and fabrics (*1.2*). Recently in Latin America this process has been initiated in Brazil, Colombia, Costa Rica and Ecuador. Fibres treated with a viscose process are being used in China as are those of wood cellulose, giving a very resistant and smooth fabric.

1.6

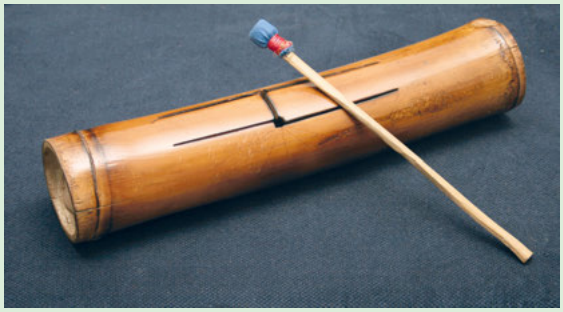
1.7

1.8



1.9

1.10



1.11

1.12

1.13

1.14

1.15

1.16

1.17

The industrial production of paper using bamboo pulp was developed in India around 1910 (Hidalgo, 2003). One of the oldest and most diversified techniques of uniting bamboo elements are fabrics in a plank style (*1.2* and *1.3*). Because of the friction between their elements they form stable structures. Fine strips braided into large ropes were also used in nautical applications. These have a greater resistance to abrasion than those of hemp (Dunkelberg, 1985). Thomas Edison tested thousands of vegetable fibres for use as filaments in light bulbs and found that the fibre of a bamboo from Japan was the best. It lasted 2450 hours when lit. After this discovery, the General Electric Company used this type of filament for 14 years. A scientist from China studied the different applications of bamboo, classifying 1386 different uses (Lübke, 1961).

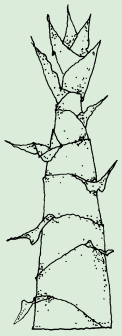
1.18

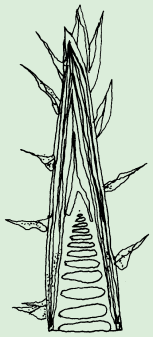
1.19

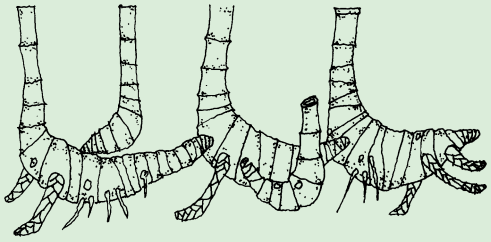
# 2

# The Plant

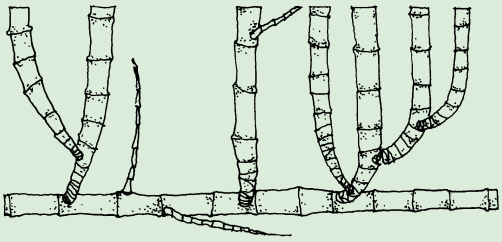
The bamboo stalk grows directly from the rhizome (subterranean stalk). The rhizomes of pachymorphic bamboos grow in all directions, forming a three-dimensional network with a height of up to 2 m (*2.1*). The stems grow very close together, forming a bush (*2.9*). Bamboos with leptomorphic rhizomes grow from a horizontally lineal rhizome (*2.2*). There are also combinations of these types.
Bamboo is characterised by having all of the nodes and internodes of the adult culm compressed in the heart (sprout); only the internodes stretch during its growth, beginning with the lower ones (*2.3*). In the same way, the difference in diameter of the nodes is maintained when the cane reaches its definitive height, obtaining its slightly conical form. The mother plants (first generation plants) have a smaller diameter; in the following three generations, they thicken a little each time (Londoño, 2003). The *Guadua angustifolia Kunth* grows up to 21 cm per day and in one month reaches 80% of its maximum height, which it completes in five more months, reaching between 15 m and 30 m (Londoño, 2003). The productivity is between 1,200 and 1,350 canes per hectare per year. The process of lignification (becoming woody) takes between four and six years; after this period its vascular bundles close and dry out, and the stalk can be used for construction.







2.1



2.2

2.3

2.4

2.5

2.6

2.7

2.8

2.9

During the growth state, the humidity content can be up to 80% in the first part of the stalk, and after four to six years, when the stalk is hard, lowers to approximately 20%. Bamboos which grow on inclined land with little water are stronger and, therefore, more appropriate for construction than bamboos that grow in flat humid areas. They are stronger in compression since their tissue is denser and has more fibres.

Bamboos are grass plants that have very long flowering periods, with a cycle between two and 100 years (for large bamboos between 40 and 80). The flowering of a species can be gregarious; that is, it blooms at the same time all over a continent, or the world, generally only once in its lifetime. Afterwards the plant dies (*2.7* and *2.8*). The *Guadua angustifolia* does not die after its yearly flowering period, which is associated with strong summers, be they occasional or continuous (Londoño, 2003). The colour of bamboo canes is generally green; after becoming woody they change colour to between yellow and brown. Black bamboo and *Bambusa vulgaris* (*2.10* and *2.11*) are exceptions.

2.10

2.11

Reproduction can be by:

- Chusquin method (small plants that emerge from the mother rhizome).
- Parts of the stem with node and bud. If a part of the stem with more nodes is used, one must open the internodes so that water can enter.
- Parts of the rhizome.
- Seeds.