CONSTRUCTION MANUAL

Constructing with bamboo

Third Edition adapted for Peru
Author: Jorge Moran Ubidia
INBAR
English Translation & Editing by: Seth Wachtel
University of San Francisco
Initial English Translation by: Andrea Vallejo

Preface

Since pre-Colombian times bamboo has been used as material for the construction of different kinds of buildings. In the work of Oscar Hidalgo, "Bamboo: The Gift of the Gods" and in "Traditional and Current Uses of Bamboo in Latin America" by Jorge Morán Ubidia, author of this publication, are examples of thousands of uses in the Americas and in others regions of the world.

However, bamboo is regarded as a perishable material, due in part to the loss of traditional knowledge and practices of preservation and by misuse that exposes it to moisture and sun. Currently, bamboo is viewed as a “poor man’s material” for building in some parts of the world and by many professionals, due in part to the lack of widespread infomation on its proper use. What is little known is that bamboo’s durability depends on its correct use and application, just as with steel, concrete and other materials.

Examples of the durability of bamboo, built more than 100 years ago, can be found along the Eje Cafetero in Colombia, and in cities such as Guayaquil, Jipijapa and Montecristi in Ecuador. On the North Coast of Peru in Piura and Tumbes, there is also a long tradition of using bamboo as a material for house construction.

We hope that this manual, besides being a useful tool for construction, can show that bamboo, coupled with sustainable and friendly technological development, can replace or reduce the use of conventional materials such as steel and cement, generating employment opportunities for farmers, producers, workers and professionals, thereby reducing migration and poverty.

Due to its characteristics as a locally available and renewable material, bamboo also offers the possibility of lowering the ecological footprint of the building industry, an important opportunity for one of the most polluting industrial sectors on the planet.

For the Reader

• When referring to bamboo, we refer to the species *Guadua angustifolia*, known in Ecuador as cane or bamboo cane, in Peru as Guayaquil cane or simply Guayaquil and in Colombia as "Guadua". Other frequently used terms in bamboo construction are: reed, to refer to the stem or culm; Latilla (split bamboo cane or strip) and crushed cane (mat, chopped cane, open cane or cane table). In this manual, the term "Bambusal" refers to wild bamboo extensions and guadua (Guayaquil cane), is called Guadual.

• This manual collects and presents traditional and improved bamboo construction techniques that have been validated in several countries in Latin America.

• Guadua or Guayaquil, stands out among other species of its genus for the structural properties of its stems, such as the weight to resistance ratio, which is similar or superior to some woods, and is even comparable to steel and some high tech materials. The ability to absorb energy and allow stronger connections, makes this species of bamboo is an ideal material for earthquake resistant construction.

• By Decree No. 011-2012-HOUSING, March 3, 2012, the E.100 Bamboo standard was approved, which establishes the technical guidelines that must be followed for the design and construction of seismic resistant buildings with bamboo in Peru.

• The preservation and drying processes described in this manual are not necessarily applicable in all countries. Research is being done in this regard, in order to optimize the methods, and to obtain guaranteed and standardized results for general acceptance. This manual contains methods currently in use in Peru, which are supported by professionals and academic researchers in Latin America.

Why build with bamboo?

- It is an excellent and versatile material for construction.
- It is light and resistant.
- It's attractive and natural.
- It is economical and abundant.
- It is a renewable material, regenerates quickly and is eco-friendly.
- Its use requires only inexpensive and easy to use manual tools.

Restoration Project, Chaneay - Arq Ramel & Jebrame

Index

Introduction

The content of this manual has been collected and developed in the Andean region of Latin America, primarily in Peru, Ecuador and Colombia. Although largely applicable to other parts of the world, the issues discussed reflect the reality and experience in these countries.

Section 1 deals with the "raw material" and describes the method for bamboo selection related to the species *Guadua angustifolia*, the main bamboo used in many communities in the region. These methods can be applied to other bamboos that have similar characteristics. Other topics covered in this section are related to the quality of the raw material and include cutting techniques to create building materials ready to use in construction. These methods are compatible with the use of other species, but discussion related to the management of *Guayaquil* are different from species in other regions of the world.

Section 2 describes two preservation methods; one traditional and another using safe chemicals for health and the environment. It also covers the method of drying bamboo reeds.

Sections 3 - 9 describe several important aspects of construction: proper site selection for bamboo construction, foundations, basic installations, joints, supporting structures, walls and panels, roof and mezzanine. The sections are a general overview of the topics and the information is applicable to any type of bamboo construction.

Section 10 describes recommendations for finishes and maintenance of bamboo for lasting strength and preservation of the material's natural beauty.

Finally, section 11 shows examples of bamboo-based projects in Peru and the Andean region, which we hope will serve as a source of inspiration for the users of this manual.

Keys to the good use of bamboo

1 Use good raw material

It is necessary to use mature reeds, due to their natural resistance to rot and lower moisture content. They must also have been properly preserved(immunized) and dried. The use of unripe or fresh canes (without drying), can cause cracks and lead to the failure of the building. For the production of crushed canes and cakes, ripe but fresh canes are used.

2 Keep columns and walls insulated from soil moisture

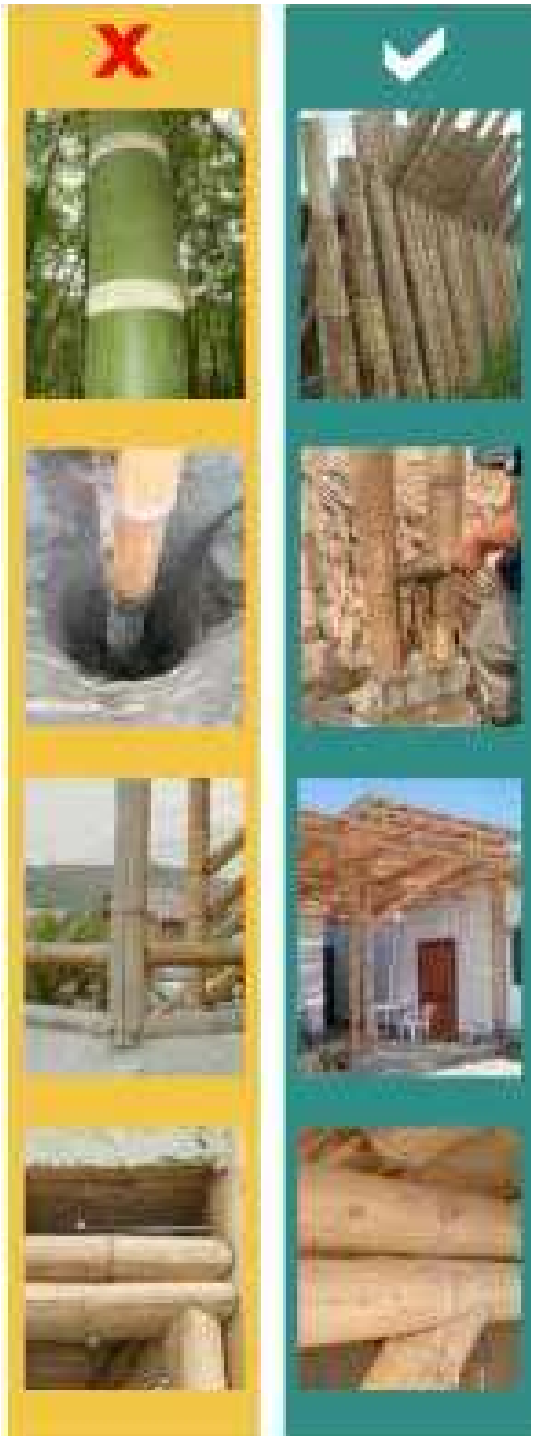
To construct columns or walls with bamboo, it is necessary that they are not embedded directly in the concrete or in the ground, to avoid deterioration (rot). Bamboo has a high capacity to absorb humidity in the environment; from the soil, air and rain.

3 Protect the reeds from rain and direct sunlight

Excessive moisture produces fungi as in any other material and the sun's rays whiten and deteriorate the reeds. This is why it is imperative to protect them from water and direct sun by building deep eaves. If crushed cane is used, it is necessary to coat the material with a sand-cement mortar or a mixture of organic materials mixed with earth (quincha type).

4 Avoid crushing and breakage of reeds

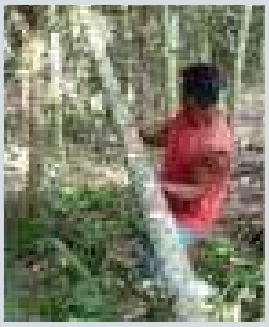
When a localized weight is applied on the internode, bamboo will crush. This can lead to deterioration of the entire structure. To avoid this, loads must be placed on the nodes and/or a concrete filled shank. In addition, it is necessary that there is a node at the ends of each reed to ensure continuous strength.



1 Raw Material

The quality of the construction starts with the selection of the reeds to be used. Mature cane must be acquired or cut, because it is more resistant to rot and insects. It is important to use reeds that do not have fissures or disease. Young bamboo can be crushed and also used in various applications in construction.

Maturity & Quality



Harvesting & cutting of stems

Crushed reed

Latillas (Splits)

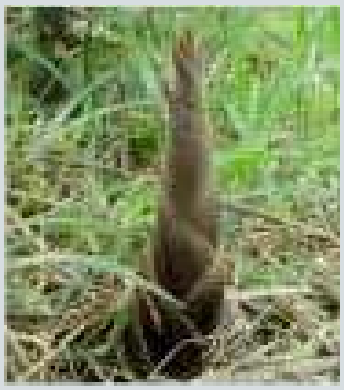
Maturity & Quality

For construction, only ripe, healthy canes without defects in shape should be used. Maturity is reached at 4 years of age. The most reliable method to determine the age of a cane is to mark it in the first year of growth. However, there are some exterior features that can help with your selection.

State of Maturity:

1 New bud

The new stems of bamboo are called shoots and are born from the rhizome. The shoots are protected by brown pods called “caulinar leaves”.



2 Growing bud

Before one year of age, the shoots reach their maximum height, but retain their leaves. As the caulinar leaves are detached, the marking of the cane should be performed.

3 Stalk tender or green

When the stem is between one and three years old, it has lost its leaves and is distinguished by its bright green color. At this stage the stem is still too tender for use in construction.

4 Mature Stalk

When the stem is four or more years old, it is ready for cutting and harvesting. In this "mature" state it is distinguished by an opaque green color, with the stem partially covered with patches of white lichen.

5 Over Age Stalk

When the stems are covered in a whitish-yellow color they have lost their physical and mechanical characteristics for use in construction. In this state, the stem is over-ripened and best used as fuel wood or composted as fertilizer for other plants.

Age marking

Marking stem by age

Each color indicates a different age

Unwanted features on a stem

1 With Gaps or Cracks

Woodpeckers and insects can make holes in bamboo, these stems are not recommended for construction because they may have structural defects. Cracked stems can be used as crushed chips or canes.

2 With Deformation or Varied Diameter

Discolorations and deformation of the stem may indicate a disease that has negatively affected the physical characteristics needed for use in construction.

3 With Very Long Internodes

Stems with internodes greater than 50 centimeters are not recommended for use in construction.

4 Rotten or with Disease Symptoms

Stems with evidence of rot should not be used. Care must be taken not to confuse the rot with white patches of lichens. However, stem discolorations may indicate a disease that has affected the physical characteristics needed to be used in construction.

Mature stem in good condition, with lichens

Cane with hole damage

Cane with deformation

Cane with a disease

Maturity & Quality

Proper cutting techniques are important to ensure an adequate supply of quality canes for construction. In addition, it is important to “fix” the stump after cutting to ensure its natural regeneration, thereby ensuring the sustainability of production.

1 Make the Bevel

With a machete or chainsaw, a bevel cut is struck on the stem in the direction of the fall. It is important to cut the stem just above the lowest visible knot in order to avoid the growth of new branches that can make the management of the plantation more difficult. The use of a chainsaw provides in more acurate and cleaner results.

2 Make the Cut

On the opposite side of the first cut, a second cut is made to fell the cane. It is important to leave an open fall path for the cane to avoid accidents.

3 Releasing & Hauling the Stem

In case the stem is entangled with others by intertwined upper branches, the cane can be released by pulling in the direction of the extraction.

4 Fix the Stump

Water collection should be avoided in the stump, which would cause root rot. With the machete or chainsaw, a cut can be made just above the node to allow water to escape, leaving a flat surface to prevent rainwater accumulation.

5 Breaking & Cracking

With the bamboo laying down, cut the lateral branches using a machete. The cut should be from bottom to top to avoid stripping the bamboo surface. The cane can then be cut to the required measurements.

✗ Bad cut

✗ Rotting caused by a bad cut

Cut at the top edge of the knot

Cut with drain vent

✓ Good cutting

Crushed Reed

Crushed cane has a wide variety of applications in construction. It is used as formwork or lath support for earth or cement-based plaster in ceilings, walls and other applications. The production of crushed cane is made with ripe, freshly harvested canes, using ax and machete. The production of crushed reed requires manual work and manager experience.

1 Chopping or Tapping from One End

Beginning at one end of the cane, cut deep incisions in the knots, with the split separating 1 to 2 centimeters along the way until reaching the middle of the cane.

2 Chopping or Tapping from the Other End

Repeat number 1 above, starting from the other end of the cane.

3 Cut Lengthwise

From one end, use an ax or machete to cut the cane longitudinally, with simultaneous transverse movements. This splits the cane and breaks the interior partitions or intra-node diaphragms.

4 Open the Cane

With the hands and/or feet, force the cane open until completely flat. Then walk across the cane until it stays flat on its own.

5 Clean

Remove the white, inner part of the cane to prevent attraction of insects and fungi; leaving only the harder material. This cleaning is done with machete or flat shovel.

Crushed cane cleaning

1 Freshly crushed cane

2 Cleaning interior knots

3 Soft part extraction

4 Clean crushed cane

Latillas or Splits

Latillas or splits are the longitudinal strips of the reeds. They have several applications in construction. They are made from fresh bamboo for ease of splitting. There are two techniques to do this, one by hand, using a machete or ax, and another with a hand or mechanical splitter. After obtaining the strips, the white material is extracted from the inside of each split, as this material attracts insects, microorganisms, and fungus.

To Split by Hand:

1 Make the Splits

An ax is inserted into the end of the reed, splitting the reed end-to-end by striking the ax head with a hammer or length of wood.

Cutting with a machete

Cutting with an ax

2 Finishing the Splits

With a machete, remove the white material from the inside of each strip to make it uniform. This helps with ease of handling and helps prevent attracting insects or the appearance of fungi.

Cleaning with a machete

With Chipper Tool:

The chipper is a manual or motorized tool that allows you to obtain bamboo splits with a specified width.

1 Selecting and Inserting the Knife Blade

An interchangeable blade set (“butterfly”) is set up. Individual blades are sized according to the desired number and width of splits to be removed.

2 Placing the Cane

The tip of the cane is placed in the center of the butterfly or star which is put against a weight secured to a guide rail. It is recommended that the set up be located on a slight slope to facilitate sliding of the weight.

3 Splitting

The “latillas” are obtained by blows of the plunger or weights that slide on rails. The number of strokes depends on the diameter and hardness of the cane. There are also motorized splitters that mechanically force the splitting.

4 Clean the Splits

The bamboo strips are cleaned; this activity is done by hand.

Cleaning Latillas

1 Latilla before cleaning

2 Interior knot to be removed

3 Soft part extraction

4 Clean latilla

2 Preservation & Drying

Preservation methods should be used to increase the shelf life of bamboo and prevent it from being affected by insects or microorganisms. There are traditional methods and chemical methods. The latter should be properly applied so as not to affect the health of the user and the environment. A recommended method that is both traditional and safe, uses a borax and boric acid application.

Traditional preservation

Chemical preservation

Drying

Traditional Preservation

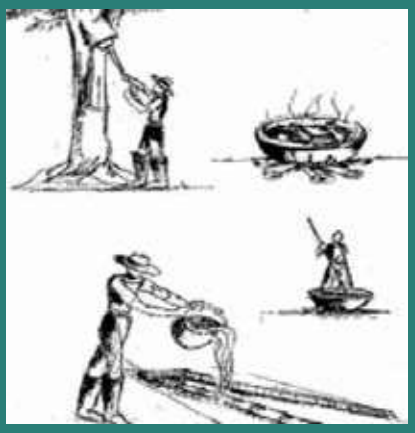
Many preservation methods have been used for centuries by different communities in the Andean region. These methods developed according to characteristics and resources present in areas where they have been used. Vinegar solution is an example of a traditional method. This method is economical, safe and proven by popular wisdom. However, neither this nor other traditional methods can effectively replace chemical preservation.

Untreated:

The cane is left vertical on the cut stump or on a stone, supported by the neighboring bamboos for 3 weeks, leaving branches and leaves intact. In this curing process, starches, sugars and moisture are reduced, limiting the vulnerability of the cane to the attack of insects and microorganisms. The cane temporarily changes from green to orange and smells of alcohol ("rubber cane"). This method is less insect resistant and not preferred.

Other Traditional Methods

1 Latilla before cleaning



2 Interior knot to be removed

3 Soft part extraction

Chemical Preservation

The method of immersion in solution of borax and boric acid is the most recommended, due to its cost and safety for users and the environment. According to some experts, the immersion should be done with bamboo rods that have been dried for a maximum of one week, while they still retain their green color.

1 Preparing the Submersion Well

A tank large enough to submerge multiple bamboo lengths is prepared. It can be excavated in the earth and covered with thick plastic, secured with weights at its edges or built above ground from sheet steel or reinforced concrete. In each case there should be a slight slope at the bottom. For every 100 liters of water, between 2 and 2.5 kg each of borax and boric acid are recommended. These are safe chemicals, but contact with the eyes should be avoided.

2 Perforation of Internal Partitions

To allow the solution to enter the entire length of cane, all the partitions that exist inside the cane are broken out with a long, 1/2” diameter steel rod.

3 Immersion

The pre-washed and dried rods, latillas or crushed cane are introduced in the tank where the preservative has been prepared. They are secured with stones or other weights placed on top so that all the material is submerged. The placement of the round rods on a slope allows the trapped air to escape.

The round cane has to be submerged for a minimum of 2 days, depending on its length, while the crushed canes require at least 24 hours of preservation. Cover the tank to avoid access of rainwater.

4 Draining

Once the immersion process is finished, the excess preservative inside the reeds should be drained. To do this, the reeds are tilted nearly vertical and rotated twice a day for two days. Again, rainwater should be avoided by covering.

Preparation of the solution

1 Borax & Boric acid

2 Dissolve in hot water

3 Fill up the tank

4 Mix in the tank

Drying

Drying completes the process of preparation of the cane. This process can be carried out outdoors or in solar dryers. With a solar dryer, lower humidity levels can be achieved when compared to the outdoor method.

Drying Outdoors:

1 On Trestle

The most common form of drying is to support the reeds on a structure to keep the canes from direct contact with the soil. For uniform drying, a partial and daily rotation of each reeds is recommended for the first 15 days and then less frequently. The drying time can vary from 2 - 6 months depending on weather conditions.

2 Secure & Covered Storage

With this drying method, the process ed rods are protected from direct contact with the sun and rain, which can cause cracks, warping and twisting. In order for the drying process to be effective, separators should be placed between canes to facilitate good ventilation.

Solar Drying:

1 Passive

This method uses a closed greenhouse, whose walls and roof are made of plastic or glass. In this way, higher temperatures are generated inside the environment, which promotes the drying of the canes.

2 Active

In this method, a series of fans are added to the basic infrastructure of the greenhouse, which accelerate the hot air between the canes, reducing the processing time.

Alternative Drying Methods

1 Oven

The rods can be dried in ovens identical to those used for wood.

2 Hot Air Injection

With a fan and plastic hoses connected to the base of each shank, hot air is injected to speed the drying of the cane interior.

3 Safe Location & Building

Properly determining the land where the house is to be built is one of the most important criteria for having a safe and comfortable home. The objective is to locate the house in a place that is not exposed to short or longterm environmental harm.

The aspiration of every human being is to live in a safe and healthy environment, creating a sense of well-being where each community member is in a comfortable and harmonious environment.

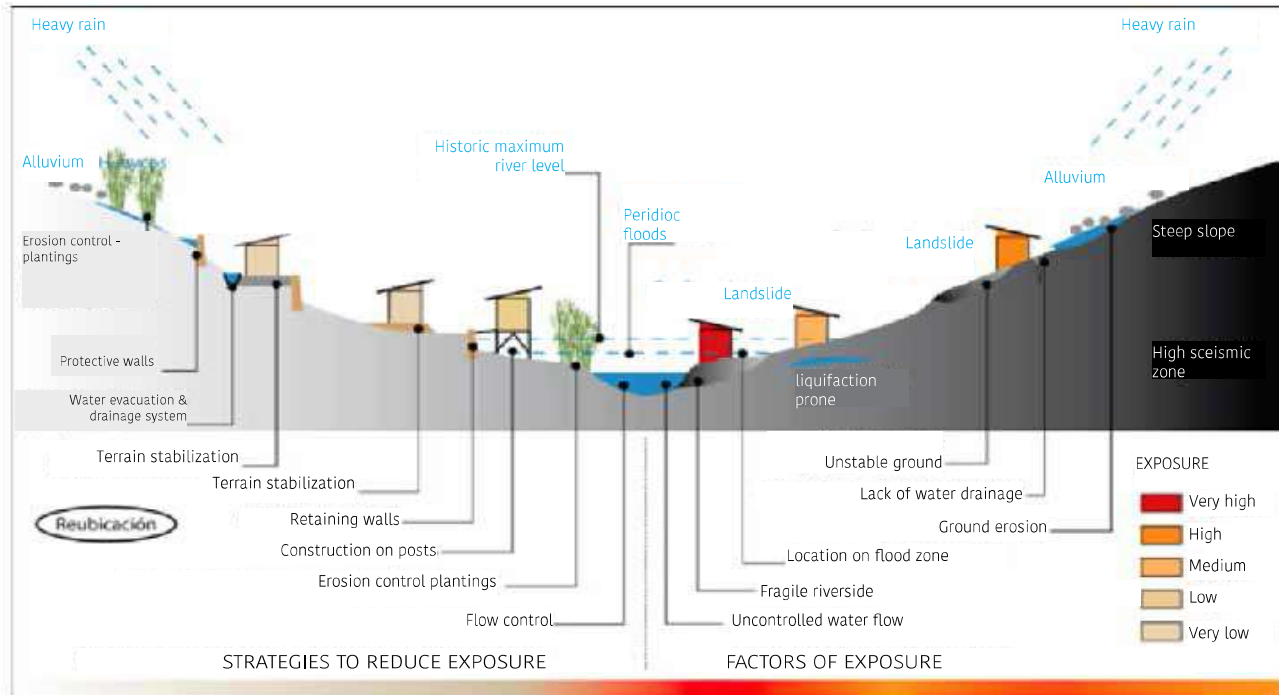
1 A Safe Location

The land of a safe building location must meet the following criteria:

- Not be near streams or rivers where there may be a risk of rising water.
- Avoid terrain with steep slopes where there may be landslides.
- Find dry terrain, not too close to natural waterways where heavy rain can cause flash flooding and landslides.
- Not on unstable soil, landfills or land susceptible to liquefaction.

Ideal sites for building avoid places susceptible to landslides, flooding, and structural damage due to natural events such as earthquakes, hurricanes/monsoons, etc.

Illustration of exposure factors to avoid and strategies for reducing exposure.



2 Healthy Environment

The building site must also be a healthy place, away from places that emit toxic vapors, unpleasant odors, or in locations that may be prone to the spread of disease.

A comfortable home also requires good lighting and natural ventilation, so it is important to consider local weather, sun orientation and prevailing wind direction to properly site the house and determine roof overhangs, and door and window openings.

Proper location of openings & eaves

1 Natural ventilation

2 Protection from direct sunlight

4 Foundations

The correct location for a foundation is on a site free from flood, settlement or slide danger. This allows for the construction of solid floors. Even without the danger from flooding, the site must be elevated enough to not be affected by rain or moisture.

Foundation Excavation with Steel Reinforcement

Foundation Wall over Foundation Base

Floor Slab

Foundation Type and Sizing

Since foundations are what supports the building, it is critical that professional soils and structural engineering be done prior to sizing and making the foundation. A soil analysis is necessary to determine the composition and capacity of the ground to support the load of the building. Depending on the results, the foundation can be simple concrete, cyclopean(concrete with embedded stones) or reinforced concrete. Whatever foundation is decided upon the foundation zone should be cleared of weeds and any layers of organic materials.

1 Tracing & Leveling

The chalk outline shows the foundation perimeter. Twine stretched between wooden stakes driven a meter past the building corners, mark these edges. Square (90 degree) walls can be set using the 3:4:5 triangle method. Two parallel sets of string are used to indicate the width of the foundation. Establishing floor levels on a sloped site can be done using water filled transparent tubing and marking desired level points on stakes at the house corners.

2 Excavation of the Foundation

Excavation is done following to the chalk lines on the ground. The depth and width depends on the soils analysis and the engineered size of the foundation. Concrete is mixed and poured (example ratio 1: 3: 5 - cement, sand, stone), with steel (rebar) reinforcement embedded and extending up to connect to the foundation wall. For proper drainage and water protection, the ground should slope away from the building and the foundation should come up above the level of the ground.

Foundation Wall

Foundation walls or overlays are the bottom of the building structure that serves as an anchorage and support where loads are transmitted to the foundation. They also serve to protect the bamboo structure from the ground and prevent contact with moisture. Foundation walls can be made of reinforced concrete or prefabricated blocks.

1 Constructing the Foundation Wall

The foundation wall is placed above the foundation. It can be formed reinforced concrete or prefabricated blocks (CMU).

The minimum foundation wall height is 20 cm. However, in very rainy areas, a taller wall and a drainage channel are recommended to protect and guide the water away from the building. In the case of concrete blocks, it is recommended to add reinforcing steel and fill the interior cells with concrete.

2 Installing the Metal Connectors

Steel reinforcing bars extending from the foundation should continue beyond the foundation wall to connect the bamboo columns or wall panels.

Foundations

Floor

Before proceeding with creating the floor, any necessary plumbing and electric conduit must be placed and covered with earth fill to the correct level for adding the finish floor. Any loose fill material must be compacted to avoid settling over time. The final floor level should be at least 15 centimeters (6”) above the natural terrain or in urban areas at the level of the sidewalk.

1 Interior Fill

With the perimeter foundation wall complete, the ground floor should be filled to 20cm (8”) below the level of the foundation wall with compacted earth. This fill must be free of organic material and ideally be made up of a mix of earth, sand and gravel for stability.

2 Hydrate & Compact

During compaction, the fill material should be hydrated with water to be moist but not wet, and be completely compacted with a wooden ram or a compacting machine. It is important to compact in layers of 5-10cm (2-4”) to be sure compaction is consistent and not prone to future settling.

3 Installing Subsurface Pipes

Once the fill material is compacted, it is time to place any fresh water and waste water piping and any electrical conduit. These should be located with proper slope and building entries and exits.

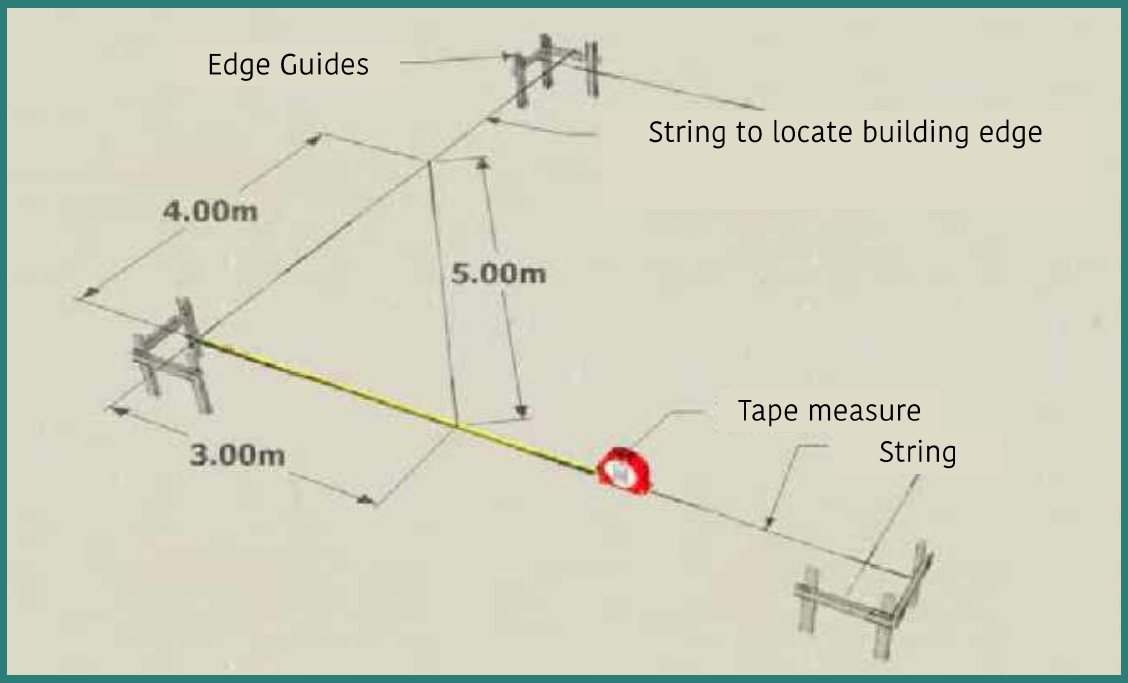
4 Leveling

In preparation for the finish floor, locate the floor level using a bubble level and string stretched between the foundation walls. Place equally spaced, 10cm thick piles of sand-cement mortar and embed a piece of cane at equal heights. The canes will serve as reference masters for laying the floor.

5 Pouring Concrete Floors

Using the bamboo leveling masters, pour a basic concrete floor (1: 3: 5 - Cement, Sand, Stone) and level with long, straight board. If a ceramic or cement tile is desired, scratch or roughen the surface of the concrete within a couple of hours of pouring. This will provide the necessary surface needed for tile adhesion.

Straight-line Tracing



Constructing the bamboo structure over the foundation

Finished building with installations & finishes

5 Electrical & Sanitary Installations

Electrical wires and water pipes should always be installed prior to laying the floor and in some cases before placing the walls. The following illustrations show different installation locations in a bamboo dwelling.

Electrical Installation

Water Installation

Wastewater Installation

Electrical Installations

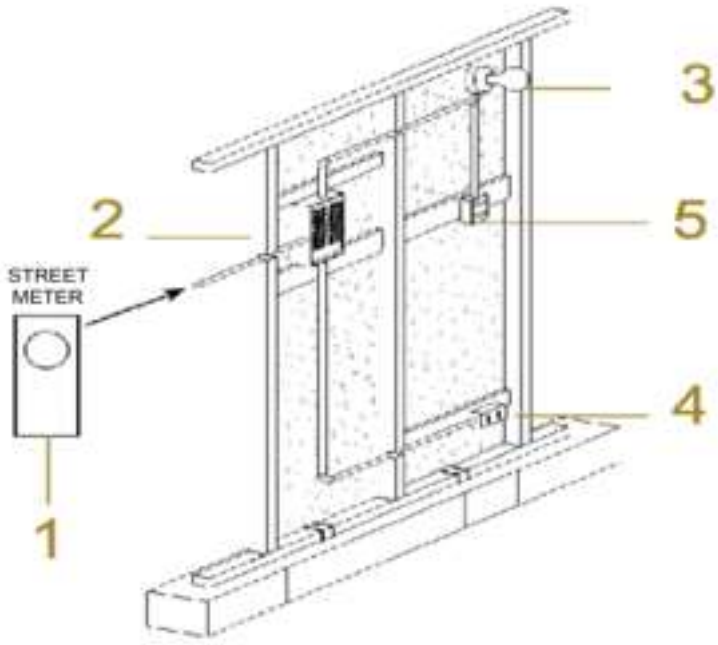
Electrical service to homes most often begins with an electric meter receiving electricity from the public grid. The meter is located at approximately 1.5 meters (5') on an exterior wall. The meter is connected to a circuit-breaker board, where the electrical wires are connected and distributed to electrical outlets and lighting locations in the house. The wiring runs inside the walls and ceilings and connects to light and plug receptacles that are embedded and flush with the wall and ceiling surface.

Standard Installation

1 Electrical installations can be built into the bamboo structural walls. If bamboo cuts are required, they should not exceed 1/5 of the diameter of the bamboo.

2 For fire and voltage protection, electrical wires must be run through conduit or otherwise shielded. Wiring terminates and any splicing occurs in metal electrical boxes with properly insulated connectors and hardware.

3 Caution must be taken that the electrical installation not be cut or perforated by the nails during construction.



Electric Installation Components:

1 The Meter

2 Circuit Board

3 Overhead Light

4 Electrical Outlet

5 Switch

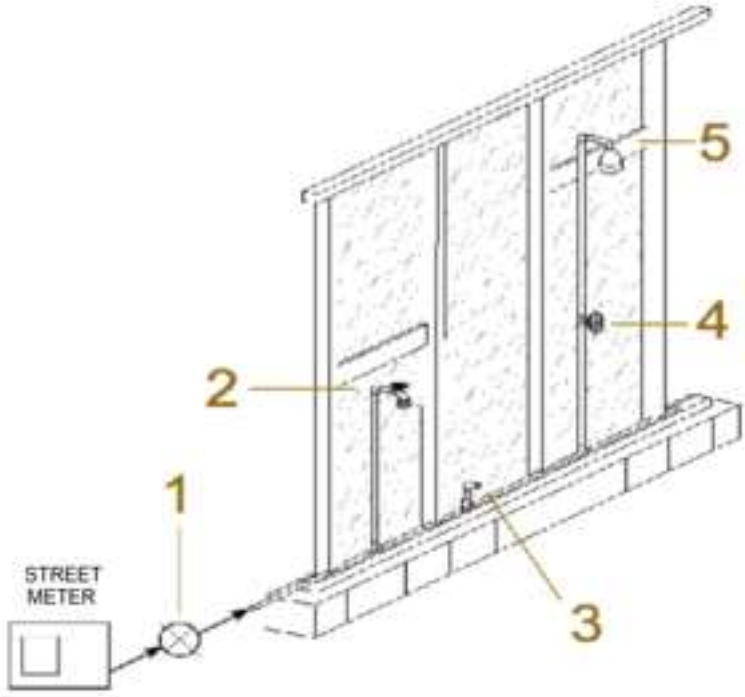
Water Installations

Drinking water installations in houses most often start at a meter, usually located near the sidewalk in front of the dwelling. The meter receives the water from the public grid and the water flows to outlet points (sink, toilet, shower, hose spigot, etc.) in the home. When the public water pressure is insufficient, an underfloor or underground cistern is often built to hold the water, which is fed to an elevated tank where gravity supplies water pressure to the house.

Standard Installation

1 Water pipes and outlets must not be embedded within bamboo structural elements such as walls and ceilings. Instead, they must be attached to the wall and ceiling surfaces to prevent a leak from damaging the building.

2 The water supply system must be equipped with stop valves (shut-off keys) located just after the meter, on each floor of the building, and in each room with more than three water appliances.



Water Installation Components:

1 Control Valve

2 Sink faucet

3 Toilet Connection

4 Shower Valve

5 Shower Head

Wastewater Installations

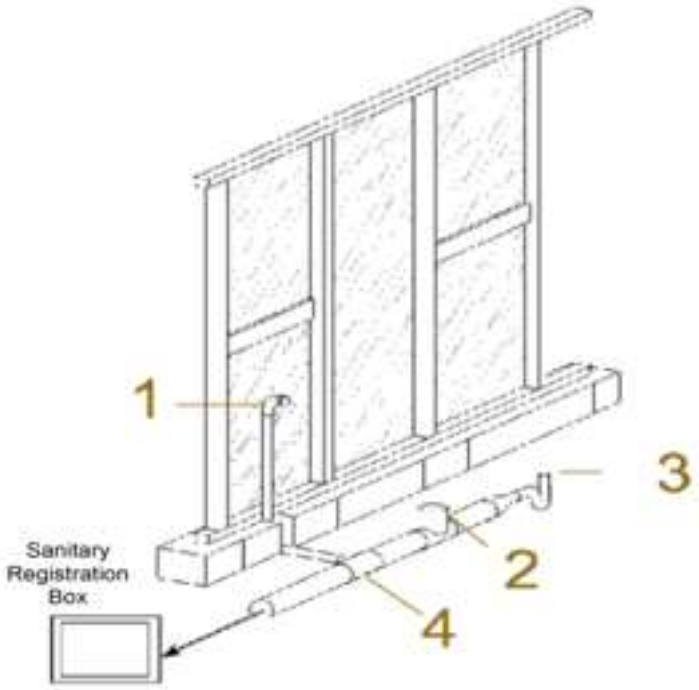
Sinks, showers, and washing machines are connected to 2” drain pipes. Toilets connect to 4” drain pipes. Both systems connect to a 4 “mainline” pipe, which has checkboxes or cleanouts (control sites, for cleaning and maintenance). The wastewater then flows to the public sewer system or septic tank.

Standard Installation

1 Wastewater installations must not be embedded within the structural elements of bamboo.

2 The slope of the manifolds and branches must be uniform and not less than 1%.

3 Connections between manifolds and drain pipe should be 45° or less unless they flow to and from a registration box.



Wastewater Installation Components:

1 Washroom Drainpipe

2 4” Toilet Drain

3 2* Shower Drainpipe

4 2¨to 4¨ Pipe Connection

6 Joints

By “joints” we are talking about the connections used to join bamboo, crushed canes or other materials (such as wood) to each other. Because bamboo is hollow and cylindrical, it is not possible to apply typical connections used in wood construction. The use of nails and wires should also be very limited, because they can cause cracks and are not very effective in bamboo construction. Following are suitable techniques for making bamboo joints using traditional assemblies, metal connectors and mortar filling.

Fish Mouth Notch

Through Bolt

Cap Bolt Connection

Longitudinal Union

Mortar Fill Hole

Nails & Wire

Notches & Assemblies

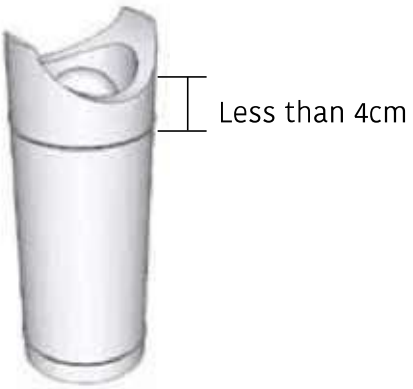
To join perpendicular bamboo rods, one must shape the end notch to match the diameter and angle of the other rod. The more accurate the match, the stronger the connection. The two basic notches are: fish mouth and flute peak. Before shaping a notch, draw its shape on the end of the cane. For maximum strength, the deepest part of the notch must be 4cm (1.5”) or less from an internode.

“Fish Mouth” Cut

The “fish mouth” cut is used to attach the end of a bamboo cane to a perpendicular cane.

To get an even stronger connection, flanges or short segments can be cut at the lowest point of the fish mouth (2cm or 3cm from the immediate lower knot) as shown in the illustration. These are inserted into a perforation made in the other cane.

To make these types of joints, mallet and chisel are required. They can also be made with a bow saw, coping saw, grinder, jigsaw, or hole saw.



Fish Mouth

Fish Mouth
with Flanges

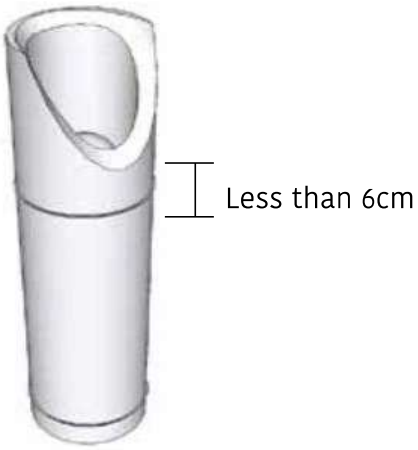
Alternatives

There are other ways to make the joints without using notches, but they tend to be much more expensive.

“Flute Peak” Cut

To join the end of a round cane to another, at an angle other than 90 degrees, the notched “flute peak” should be used.

A characteristic of the “flute peak” is that there is always a part of the end that remains a square cut. This square end can also be used as a flange for a more secure connection.



Flute Peak

Flute Peak with Flange

Application of a flute peak with a flange

Application of a flute peak & a fish mouth cut

Trace & cut a notch

1 Tracing with Measuring Tape

2 Using PVC Mold to Trace

3 Cutting with Chisel & Hammer

4 Cutting with Jigsaw

Through Bolts

To securely connect bamboo joints and bamboo to other materials, it can be useful to use threaded rod as through bolts. Depending on material availability and budget, galvanized steel threaded rods with nuts and washers, or hardwood dowels, or smooth steel rods may be used. Following are five applications of through bolts.

1 To fix two or more aligned bamboos

For two or more parallel bamboo poles, a perpendicular hole is drilled for threaded rod, which is secured by tightening nuts on either end. This method is particularly useful in making columns or beams.

2 To make a joint between two or more bamboos

For two or more lapping and angled bamboo poles, a bolt is threaded perpendicular to the rods.

3 To form a “Flute Peak” joint

For “flute peak” joints the use of bolts with threaded rods is recommended. The direction of the bolt is perpendicular to the cut in the flute peak.

4 To attach one bamboo to another

The bamboo is crossed with a bolt perpendicular to the reeds. If required, the distance between the two bamboos can be adjusted through nuts and locknuts as shown in the photo.

5 To attach two bamboo panels

Through bolts are recommended when bamboo panels have to be joined together, particularly when they are at angles. By adjusting the nuts and counter nuts, threaded rods can also be used to align and regulate the distance between panels.

6 To fix a bamboo wall or panel to the bearing structure

The supporting structural frame is composed of columns, beams and diagonals. To attach a wall panel to a supporting structure, a horizontal bolt is passed through a column in the structural wall frame. When there is no access to the interior of the wall, make a pin connection using a smooth steel rod or hardwood dowel.

1 Bolt with threaded rod, nuts and washers made of steel

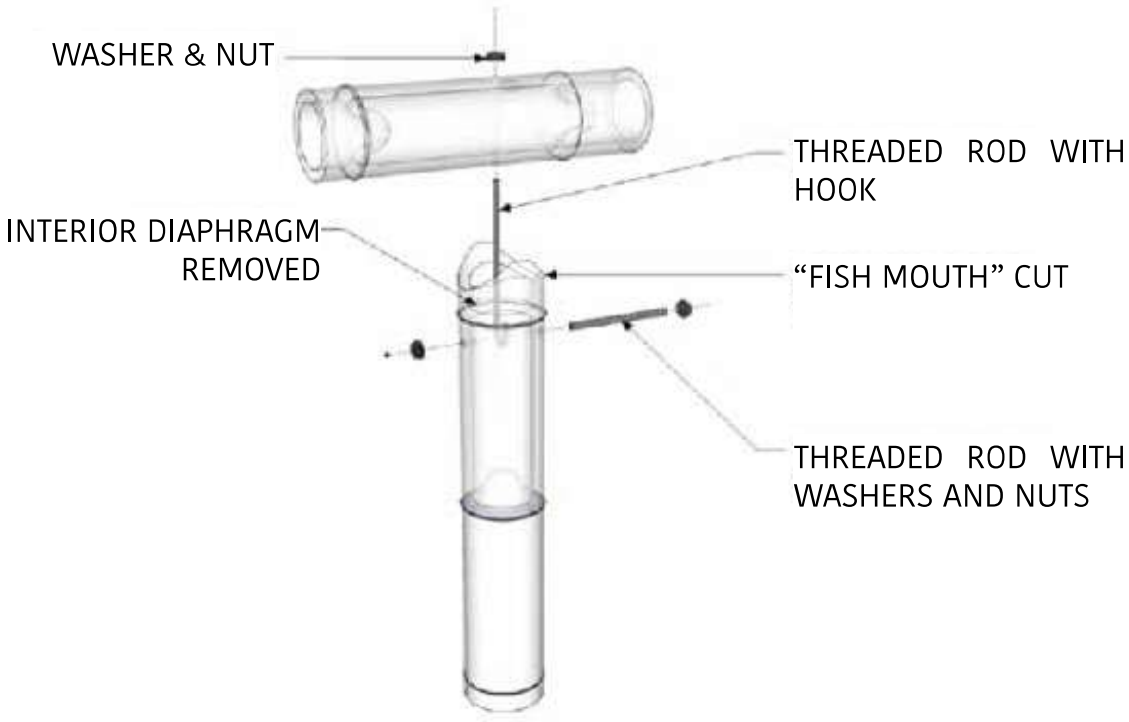
2 Smooth Steel Rods

3 Wooden Blocks

4 Pre-drilling with a an extension bit

Cap Bolt Cinch Joint

This type of joint is only applicable for fish mouth joints. It requires two pieces of threaded rod: a rod with thread at one end and a J-hook at the other (for tensioning) and a steel rod of shorter length (for anchoring). The tensioning rod, goes through the shank that does not have a fish mouth, penetrates the fish mouth shank and hooks around the anchor bolt. The advantage of this joint is that it can be secured by tightening the nut on the tensioning rod and the connection remains hidden.



1 Remove inner diaphragm

For threaded rod connections, remove the internal diaphragm of the knot with a chisel or sharp rod, allowing the threaded rod with the J-end to hook around the perpendicular steel rod in the other bamboo.

2 Attach the anchor bolt

The tensioning bolt is positioned over the joint to estimate the drill location of the anchor bolt. Then drill with the bit and slide the anchor bolt through the hole.

3 Locating the tension bolt & drilling

Locate the tensioning bolt bore holes, by placing the hooked end over the joint and marking the cane(s) perpendicular to the fish mouth. Mark and drill the holes.

4 Installing & securing the tension bolt

Hook the J bolt around the anchor bolt and thread the straight portion through the perpendicular cane. Place the washer and nut on the threaded end and tighten the tensioning bolt to secure the joint.

Prepare the tension bolt

Form a hook. Heat the rod to facilitate the process.

Weld a washer to the end of the tension rod as an alternative to a J-hook.

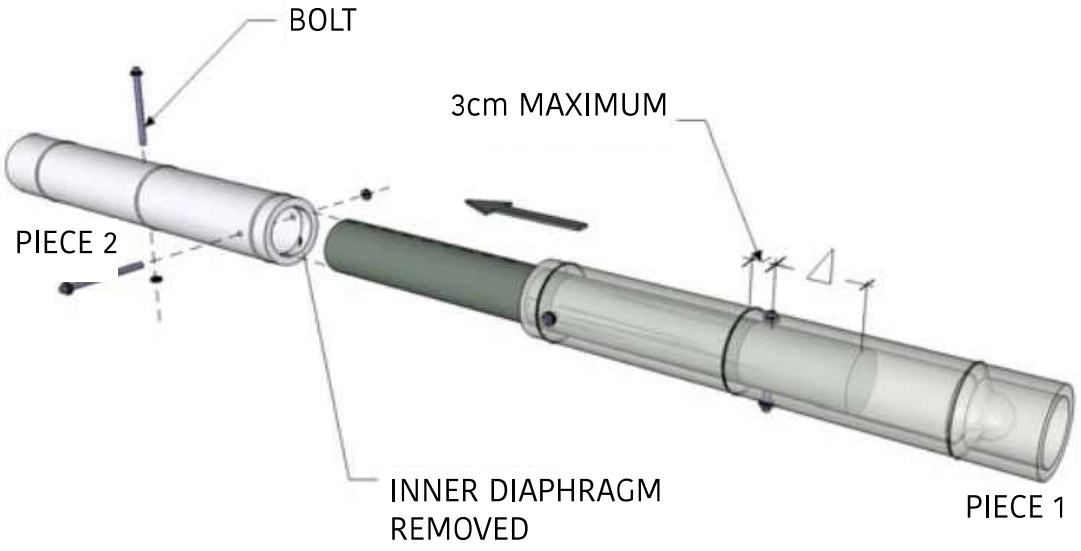
If the rod is smooth, thread the other end.

End of the rod with thread.

Longitudinal Unions

To join two rods longitudinally, bamboos of similar diameter are selected. The ends to be joined are each cut near a node (less than 6cm) for additional strength and resistance to splitting.

Sleeve Rod Connection



1 Insert a segment of wood or bamboo

The natural membrane (septum) inside the ends of each of the reeds to be joined is removed and a smaller diameter reed or a segment of wood is inserted at least half way into the internode of each reed. The diameter of the insert must be close to the inside diameter of the reeds being joined.

2 Coupling the rods node to node

A cane or wood segment is butted against the end of the other cane and the two are coupled, node to node.

Two rods joined with pressure rope and placement of two bolts.

3 Fasten using ropes & bolts

Insert tight fitting cane or wood dowel into each rod end. Use rope to hold the joint tight while holes are drilled through each bamboo and the connecting dowel. Bolts are placed and secured with nuts and washers.

4 Locating the stud bolts

The stud bolts are placed so that they are perpendicular to each other to resist bamboo cracking.

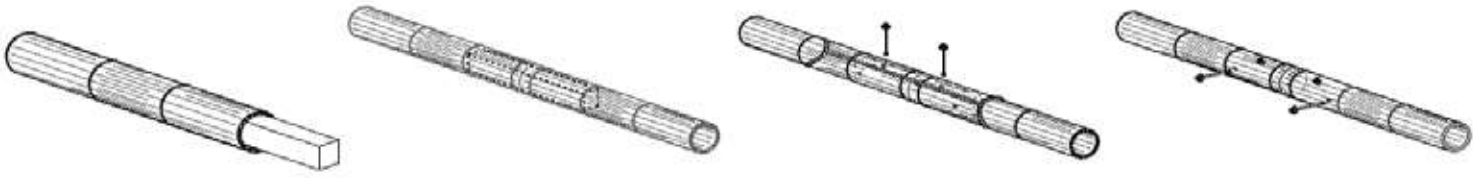
Positioning the bolts

In this connection two pairs of bolts perpendicular to each other are applied. In order to avoid breaking the rod, it is necessary that each pair of bolts are placed perpendicular to each other.

Bolt badly located

Good bolt location

Steps:



1 Insert a segment of wood or reed.

2 Coupling the rods node to node.

3 Fasten using ropes & bolts

4 Location of the stud bolts.

Mortar Filling

The bamboo voids or interior cells are filled to reinforce joint locations. This technique serves to solidify the bolt connections, remedying minor errors, resist reed crushing and to increase the resistance of the bamboo to splitting. This technique is especially useful when used to attach bamboo columns to foundations, where steel rods have been embedded. The steps for making this connection are described below.

1 Attach steel rod in the foundation

An embedded 3/8" or 1/2" diameter steel rod, should be at each location of a bamboo column and should extend at least 40 centimeters above the foundation.

2 Place the columns & drill holes

Remove the node diaphragms of the bamboo column to the height of the steel rod coming out of the foundation. Use a 3-4cm hole saw to cut a hole in the bamboo at least 5 cm above the steel rod height.

3 Fill the void

Using a funnel, pour a semi-liquid mortar of three parts coarse sand and one part cement (3: 1) up to the level of the hole. During filling, vibrate or tap the column to ensure uniform distribution of the mortar.

4 Close the hole

Fill the hole made with the hole saw with the circular piece of bamboo that was removed.

Nails & Wire

Nails and baling wire are used only for specific applications since they tend to damage bamboo and are not attractive if exposed. Nails crack bamboo whether it is whole cane or in split form. Inexpensive nails and wire also rust and eventually fail in exposed applications. However, 1.5" long nails and wire are used to attach crushed reed and bamboo strips to wood framing material.

Fasten crushed reed

Nails are first driven half way and then No. 18 galvanized wire is wrapped around and stretched between each nail head. The nails can then be hammered flush or bent over to provide a stronger hold.

Pre-nailing

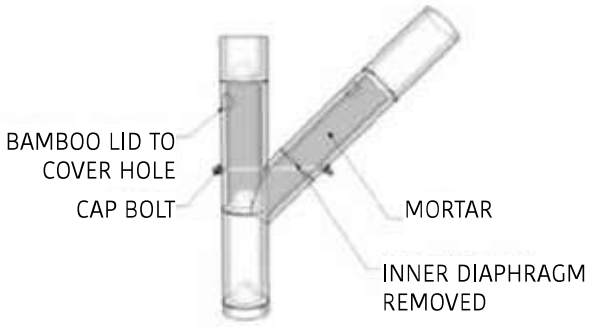
Final nailing after assembling the wire

Other Joints in E.100 Standard

For all joints, bamboo rods must be selected and cut so that there is a node at or close (maximum of 6cm) to each end. Bamboo should not be joined with nails.

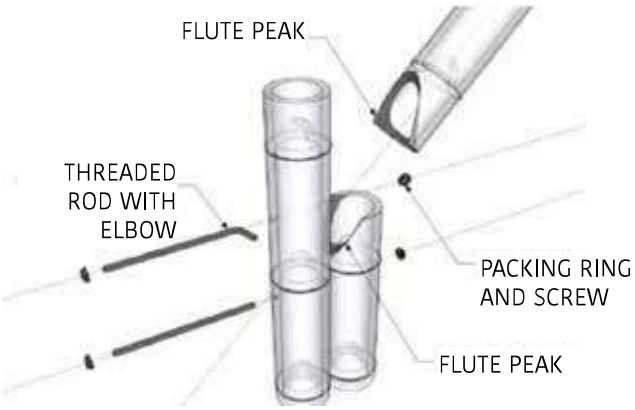
Diagonal connection with mortar reinforcement

To prevent the bolt from cutting the bamboo under the load that passes through the joint, the joint is reinforced by filling the hollows of both bamboos with mortar.



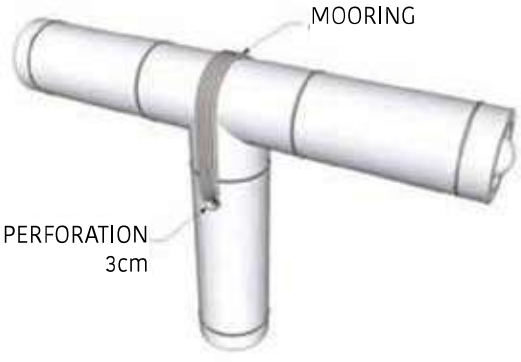
Diagonal connection with reinforcing bamboo

To prevent the bolt from tearing the bamboo under the load passing through the joint, the diagonal connection is reinforced with an additional vertical bamboo bolted to the column, with an added hook bolt that engages the diagonal piece.



Perpendicular connection with mooring

The mooring can be rope, metal, nylon or plastic. It is important to ensure proper tension of the mooring and periodically check it after construction.



7 Bearing Structure

The bearing structure is the skeleton of a building and must support the weight of walls, ceilings, people, furniture as well as the forces of earthquakes, wind or other impacts. In the bearing structure, there are vertical elements (right columns), horizontal elements (beams or sills), and angled elements (diagonals). The stability of the building depends on the quality of the bearing structure. The bearing structure must comply with the ISO 22156:2004(en) “Bamboo — Structural Design” International Standard.

Framed Structure

Bahareque Walls

Framed Structure

In a framed structure, the round bamboo assumes all the loads of the bearing structure. There are two primary approaches: the first is to build the structure directly on a foundation starting with the columns; while the second uses prefabricating structural components made on the site, which are then placing on the foundation. The second method usually facilitates and optimizes the work, especially if the building is composed of repetitive components.

Build on site

1 Place columns

Once the foundation and foundation wall have been completed, the columns should be placed on the embedded steel rods extending from foundation. Depending on the weight and design of the building, 1, 2 or more bamboos are used.

2 Place beams

Bamboo beams are placed on the columns by suitable joints. These beams may consist of 1, 2 or more rods, depending on the spacing between columns and weight of the roof (as determined by structural design).

3 Place diagonals & struts

To avoid lateral movements of the structure, (earthquakes, wind, etc.) diagonal bracing is placed according to the structural design. Diagonals are usually located at the corners or vertices of the building. “Flute peak” joints are most commonly used in this application. Before assembling and securing the structure, vertical elements must be plumbed and horizontal elements aligned.

4 Set columns

The column connections to the foundation are then set by filling the bamboo joint hollows with sand-cement mortar. Care must be taken to verify the level and plumb at each connection.

Prefabricating the main structural components

1 Prefabrication in the ground

First, the components to be prefabricated are laid out on the floor. It can be an entire frame or part of a frame. As bamboos are irregular, only the center axes of the reeds are used as a reference. The bamboo reeds are connected according to the drawn plan.

2 Assemble the structure

Once the main components are prefabricated, they are positioned on the foundation. The use of ropes and scaffolds is recommended to facilitate the erection of the structure. The use of temporary struts helps secure the components. Horizontal elements are then placed and temporarily secured prior to making the final joint connections.

3 Set the structure

The structural frame is then set by making each of the threaded rod connections for diagonal bracing, frame to frame connections, and corner joints. Connections requiring solid connections, such as foundation connections and loaded joints (according to structural design), are filled with mortar.

Examples of placing diagonals to achieve a stable structure

✗ Unstable structure in both axes

✗ Unstable structure in one axis

✓ Stable structure

Bahareque Wall

Bahareque is used in Andean zones of Colombia and Ecuador. Variations exist in many countries around the world. The name originates in Arabia, referring to a double wall filled with earth. In hot, humid regions the wall is left unfilled. Bahareque is constructed using vertical cane joined by horizontal cane, stiffened by diagonal pieces, and covered on both sides by splits or flattened bamboo. There are several types of coatings. Below is a description of a mortar coated, "improved bahareque" wall.

1 Building the bamboo skeleton

As with full framed structures, the cane skeleton of bahareque walls can be mounted in situ or prefabricated on the ground and then connected to the foundation wall. It is very important to check the plumb and square of the panels before joining them.

2 Secure crushed reed

Crushed cane is nailed to the bearing structure in a horizontal manner with the rough side on the outside for better plaster adhesion. It is necessary to pre-drill slats for nailing to avoid splits and a weakened surface (See page 51).

3 Filling the wall progressively

A moist sand and rock slurry fills the gap between the crushed reed sides, which act as formwork. Care should be take to be sure the fill is firm enough not to flow out through the cracks of the crushed reeds when compacted. The filling is done progressively, in 50cm lifts. As each layer dries, new crushed bamboo sheets are secured to each side of the wall frame to allow the next level to be filled and compacted.

4 Place the wire mesh

A wire mesh (poultry wire) is secured to the exterior side of the wall.

5 Apply final coating

Cement or earth-based mortar is applied as a coating on the exterior wall, and if desired, on the interior wall. It is important to have completed any nailing or other activities that may affect the coating prior to plastering. A first layer (scratch coat) is applied and allowed to dry before placing a second thinner layer for the final finish. Three layers are also common.

From top to bottom:
- crushed reed with wire mesh
- first mortar layer
- final mortar layer

Preparing the filling

1 Earth Sieve

2 Earth with Sand

3 Mixing of Materials

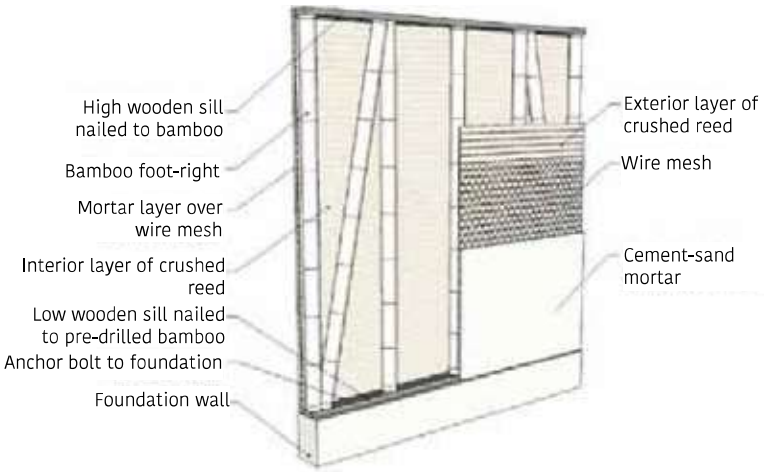
4 Filling Material

Structural bahareque walls according to E.100 norm

A Bahareque structure is a bamboo or bamboo and wood frame, made with horizontal elements (sills), vertical elements (foot-rights), diagonals and coatings. The bamboo rods have a diameter of 8cm or greater.

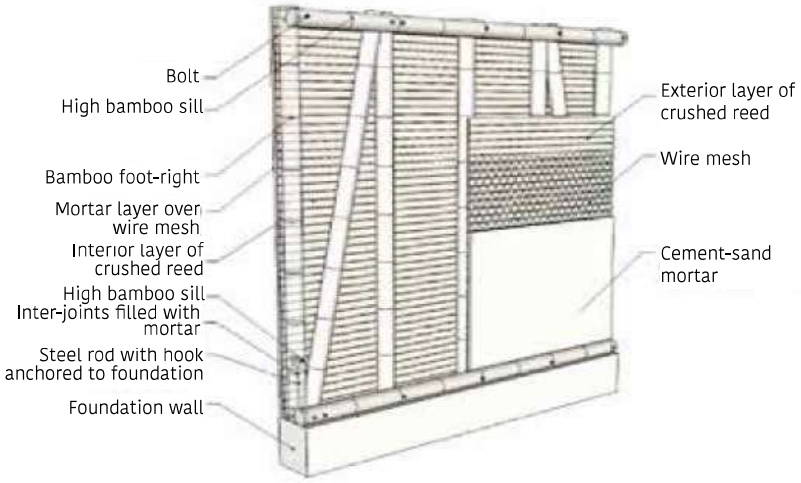
1 Walls with wooden sills

The wooden sills will have a minimum width equal to the diameter of the bamboo used as foot-rights. The minimum thickness of the upper and lower sills shall be 35 mm and 25 mm respectively.

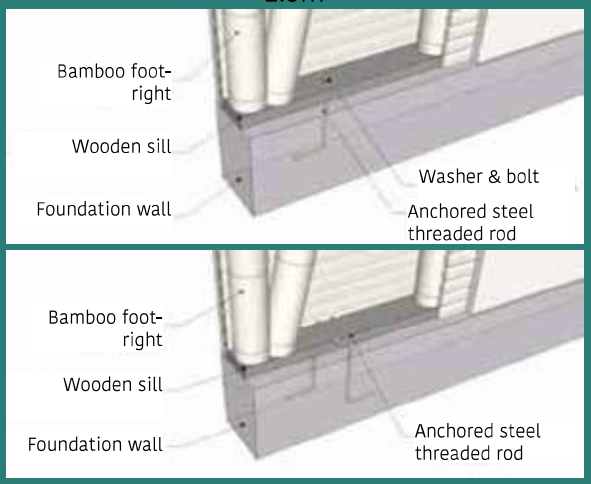


2 Walls with bamboo sills

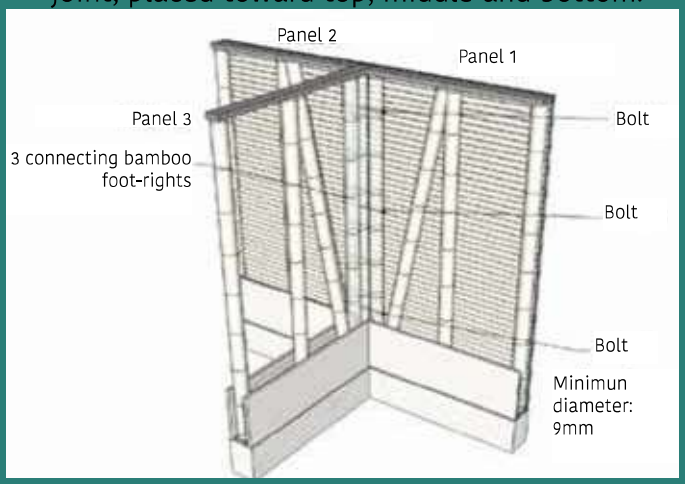
According to the E100 Standard, Bahareque framed walls should not exceed 2.5m in height. It is also recommended that internodes at joint connections be filled with cement mortar.



Bamboo frames with bahareque panels on wood sill plates have a maximum height of 2.5m



Union between walls by bolts or straps. There must be at least three connections per joint, placed toward top, middle and bottom.



8 Non-Structural Walls & Panels

Bamboo is an excellent material for building a variety of walls and panels. The difference between panels and walls is that the panels are prefabricated (they are taken already assembled to the site) while walls are built on site in their final location. Where possible, prefabrication is recommended as it is faster and cheaper. The examples below come from very different places, so they respond to different climates and use local resources. Each type has advantages and disadvantages as a space divider or enclosure. None are structural.

"Quincha" Wall

"Ipirti" Wall

"Romero" Panel

Panel Variety

"Quincha" Wall

This type of wall has its origin in Peru, although similar techniques are used in other parts of the world. In this manual, a quincha wall is a wall surface made with crushed cane and coated with a mixture of manure, earth and straw.

1 Secure the crushed reeds

Using 1 1/2 inch nails, the crushed reeds are secured to the bearing structure or wall. (See page 49). The rough side of the bamboo faces out to receive the coating. As the crushed reeds are slightly trapezoidal, they can be alternated in order to keep the placement level.

2 Cut the leftovers of the crushed reed

With a chalk line or pencil and straight board, mark the edge of the wall and cut the crushed reed with a grinder.

3 Prepare the mortar

Earth plaster is made from mud and straw that are mixed until a paste consistency is obtained. Natural thickeners, such as cactus mucilages or dung may be added. Cow dung is preferable because of its fine fibers. The straw can be of any type, but lengths should not exceed 10 cm.

4 Apply the mortar

A first layer of plaster, approximately 2cm thick, is applied to the crushed reed and evenly distributed. Protect from rain and direct sun and allow to dry for a week. It is important to finish all nailing or other high impact activities, to avoid damaging the coating.

5 Second layer of coating

With the first coat of plaster well dried, mix one part manure and 2 parts mixture of sand (70%) and clay (30%), and apply a second coat without straw. This will be the finish plaster.

6 Whitening or lime layer

To increase water protection and have a "finished" look, the finished plaster can be painted with a mixture of lime with water.

Whitened "Quincha" Wall.
("Agua Blanca" Museum)

Coating materials

Cow Dung

Clay with Sand

Straw

=

Material mixed with water

"Ipirti" Wall

This wall type originated in India, where it was built by the IPIRTI organization. It is characterized by a bamboo mesh made with horizontal and vertical strips that are fastened to hardwood or steel dowels protruding from vertical bamboo posts. Small gauge poultry wire mesh is applied and covered with mortar.

1 Drill the holes

Holes are drilled every 15 cm in the vertical and horizontal reeds that form the structure of the wall. All drilling should be aligned from reed to reed to keep the bamboo mesh level. Where a vertical bamboo post is located in the middle of a wall, the holes are made through the whole cane, so that the holes are aligned with those of the other bamboo posts.

2 Insert the wooden or steel rods

Hardwood or steel dowels are made and inserted into the holes. Dowels inserted through reeds located in the middle of wall, must have more length since they extend out from both sides of the post.

3 Fasten the bamboo strips

Using tie wire or baling wire, the horizontal bamboo splits or "latillas" are attached to the dowels. Vertical splits are then connected to the horizontal splits using wire or string, so that they form grids. The width of the splits is between 3-4cm (1.25-1.5").

3 Laying the chicken wire mesh

The chicken wire mesh is laid across the outside of the wall and tied to the bamboo splits with galvanized, No. 18 wire.

4 Applying the coating

A temporary backing of boards is put on the outside of the grid, so cement-sand (1:3) or Quincha mortar (see page 59) can be applied on the inside of the wall. The plaster is allowed to harden (but not dry), so outside plaster can be applied. Note: Plastering, drying, and recoating is done only after nailing or other impact activities are completed.

Two anchoring methods

Tie rods or dowels passing through canes located in the middle of a wall.

Single-side anchors in vertical canes at the end of the wall.

Preparing wooden dowels

Wooden pieces

Wood piece being trimmed to dowel shape

Wooden dowel embedded as anchor

"Romero" Panel

This wall type is named after the architect who designed the system. It is built separately and then attached to the structural frame of the building. The primary application is for interior wall divisions where a decorative surface is desired. The plaster finish is characterized by equally spaced, exposed bamboo splits running diagonally across the wall surface.

1 Attach the mesh on a bamboo frame

First a panel frame is built using wide splits of bamboo bolted together at the ends. Poultry wire or expanded lathe is laid over the panel and nailed into pre-drilled holes.

2 Fasten the diagonal strips

Diagonal bamboo splits are attached to both sides of the mesh covered panel frame using 1.5 inch nails. The rough side of the splits should face out for better plaster adhesion.

3 Lift & clamp the wall

The wall is positioned and attached to the 10mil (3/8”) wood or steel dowels embedded in the bamboo posts.

4 Apply the coating

A first coat of cement-lime-sand coating (1:1:3) is applied over the mesh and between the diagonal splits. After curing 8 days, a second layer of cement and sand (1:3) is applied. Both layers should be hydrated continuously to avoid cracking.

5 Bleaching & varnishing

A good finish is obtained by whitewashing the plaster with a lime wash coat and lacquering the exposed bamboo splits and structural members.

Other Type of Panels

The variations of Bamboo panel designs are innumerable. Panel construction is flexible, allowing many combinations using whole bamboo, crushed bamboo sheets, bamboo splits and wood. Panels can be used as room divisions, visual screens, ventilation grilles, doors, windows, or simply as decorative elements.

With crushed reed

Crushed bamboo is combined with wood and round cane. To make a panel, pieces of crushed cane are attached to a wooden or bamboo frame. If desired, these panels can be coated with plaster.

With bamboo strips

Finish details and ventilation grilles can be made with parallel bamboo strips or small diameter reeds attached to a wood or bamboo frame.

With sanded bamboo strips

By sanding the bamboo strips on all four sides, they can be integrated into fine carpentry work such as cabinets, doors and windows.

9 Mezzanines & Roofs

In bamboo construction, the roof and mezzanine are elements that require great care in terms of design, engineering and construction. The roof has a key role as the protective "hat" against rain and direct sunlight, while the mezzanine has to carry high weight and movement loads.

Mezzanine

Roofs

Mezzanine

The E.100 standard of the National Building Regulations allows building of up to two floors with bamboo. This provides the opportunity for a mezzanine. To avoid overloading the bamboo structural frame, the mezzanine has to be made of light materials, such as wood or bamboo. Unless justified by a structural calculation, a concrete slab cannot be used. Below is an example mezzanine with a bamboo structure that supports crushed bamboo sheets covered by a thin cement subfloor.

1 Place the beams

Due to the relatively high loads on a mezzanine, the beams are usually composed of two or more parallel bamboos. To work properly as a single element, these bamboos have to be bolted together.

2 Filling the joints at the ends

The stem cavity of the beams need be filled with cement mortar where the ends rest on a wall and support weight above. This solidifies the cane at the highest pressure point and prevents crushing (see page 48).

3 Placing the reed & wire mesh

Crushed reed, with smooth side down, is laid across the beams. Wire mesh is rolled out over the crushed reed and secured.

4 Pouring the subfloor

To level irregularities in the bamboo structure, a 5cm subfloor is poured with an average thickness of 5cm. The mix may be the standard cement-sand-aggregate, but the use of lightweight concrete with volcanic rock or Technopor beads is also recommended to reduce the structural load.

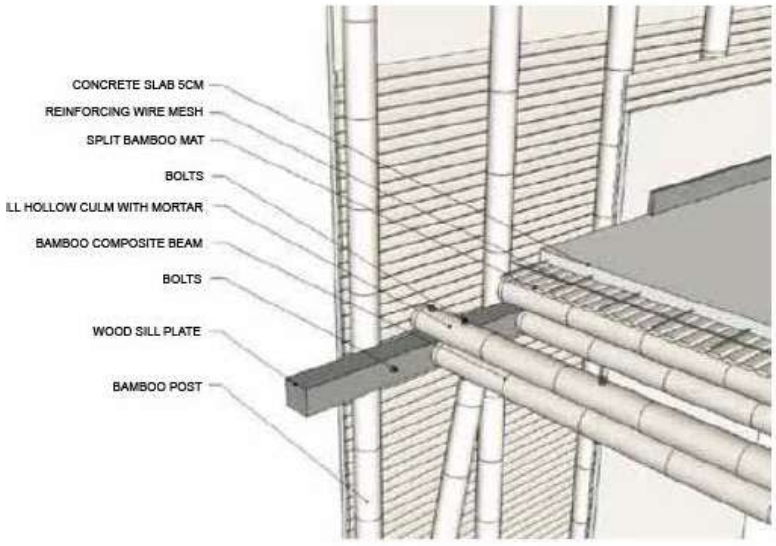
Considerations in the E100 Standard

- The floor surface of the mezzanine must be made with light materials, with a maximum weight of 120 Kg / m2, unless more weight is justified by structural calculations.

- If a closed ceiling is constructed below the mezzanine structure, ventilation should be provided to the interior spaces of the structure.

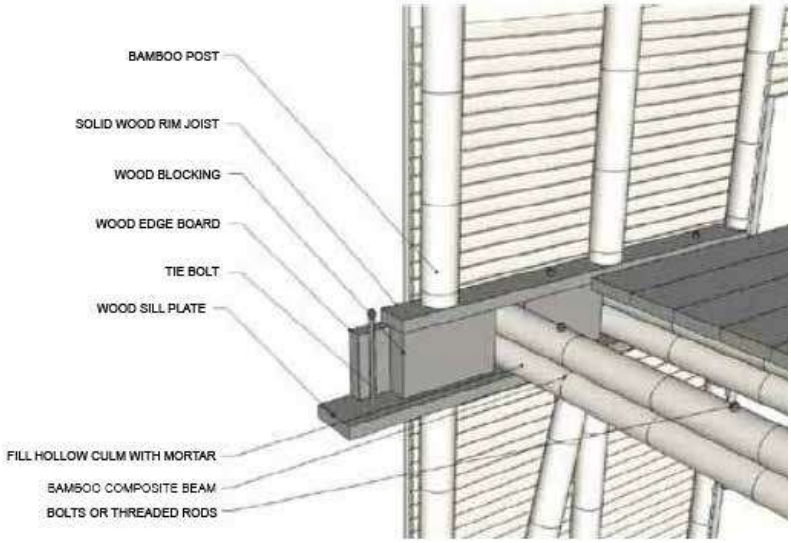
Example of a crushed cane floor coated with a concrete subfloor

The bamboo floor beams are supported on a wooden ledger attached to the wall. Stem cavities at the beam ends are filled with mortar to prevent crushing. With this method, the beams are only carrying the weight of the floor, as the additional wall and roof loads are carried by the wall structure directly to the foundation.



Example of a floor with wooden decking

Bamboo floor beams sit on a wood top plate resting on the first-floor wall frame. To prevent overturning and to carry the wall and roof weight, wood blocking is placed between and flush with the beam height. For easier leveling of the finish floor, it is recommended that long wood slats or boards be laid across and attached to the beams.



Roofs

There is a wide variety of roof types and roofing materials of various costs and features. In the case of bamboo construction, it is important to use lightweight roofing materials and flashing details that are proven not to leak. This is critical since the bamboo and wood of the structure must be protected from moisture. It is also important to protect bamboo from direct sunlight, so the roofs of bamboo buildings often have generous eaves. Below are commonly used options.

Structure

1 Place the roof structure

The roof is erected on the supporting structure of the building, with a framing system that matches the chosen roofing material and structural calculations. Roof framing begins with the trusses or rafters at the two ends of the roof. A string is then drawn between them to align the other framing. Unless justified by engineering, eaves should not exceed 60cm (2') without additional support. Support members are usually a cane placed diagonally called a "friend foot" or angle brace.

2 Placing the diagonal pieces

To prevent deformation of the roof, especially in cases of non-rigid roofs with long rafters, collar tie braces are used. Collar ties may be made of bamboo or wood and are attached to the rafters.

3 Fill the supporting points with mortar

Structural calculations will locate the beams and collar ties that need a mortar filled cavity at their points of support or stress. These locations can also be determined by identifying the points in the structure where there is weight or stress.

Strapping

"Friend Foot" brace supporting the eaves.

Collar ties ensure the rigidity of the roof.

Roof covered with crushed cane and corrugated roofing

1 Place the ceiling

Crushed cane, with the rough part facing out, is placed on top of the roof purlins. Rough or lumpy edges are smoothed with a grinder. This application serves as thermal and acoustic insulation for better interior comfort, but it must be kept clean or treated to avoid attracting insects.

2 Laying wooden slats

To secure the roof, 1“x2” wooden slats are bolted to the structural beams of the roof. Their spacing from peak to eave depends on the size and spanning capabilities of the roofing material to be placed on top.

3 Place the roofing

The roofing is screwed to the slats using rubber head guards to prevent water infiltration.

4 Optional gutter

Drip edges or gutters can be placed to control water runoff and provide a better look to the roof. This helps ensures a watertight roof.

Asphalt coating on top of wood panels

1 Laying wooden slats & panels

Wood purlins are bolted to the roof rafters. Purlin size depends on roofing weight and the distance between rafters. Purlin spacing depends on the size and spanning capabilities of the roofing material.

2 Place the wooden frieze

A fascia board is placed at gable and drip ends of the roof for added rain protection and aesthetics. Fascia boards can be attached to metal brackets, screwed to wood purlins or bolted to bamboo purlins.

3 Place the asphalt covering

Plywood or other rigid panel is attached to the purlins, a protective membrane is placed, and asphalt roofing is installed. Attachment (staple, nail, wire, glue, or heat) depends on roofing type (roll or tile).

Roofing alternatives

Roof tiles

Thatch

Tensile fabric

10 Finishes and Maintenance

Every bamboo structure requires a good finish to maintain aesthetic quality and increase durability. Finishes can be done with waxes, lacquers, varnishes or paints. The frequency of maintenance depends on the degree of exposure and the level of structural requirements of the parts.

1 Seal cavities at ends of reeds

Cover the end cavity of the cane with a piece of mesh and then coat it with mortar, gypsum or a sawdust mixed with wood glue. Painting the ends is also an option.

2 Treatment for outdoor exposure

Crushed reeds, splits, and round canes with outdoor exposure must be protected by regular maintenance. Oil based paint or exterior lacquer are recommended. For bamboo exposed to weather, maintenance must be carried out at least every six months. For outdoor bamboo that is protected from the elements, maintenance should be at least once a year.

3 Treatment of the interior parts

Bamboo in interior locations should be treated with sealant, varnish or similar products. Maintenance is recommended every two years.

4 Cut bolt excess and protect ends from corrosion

Excess bolt length protruding from the nuts should be cut to prevent accidents, and will provide a more finished appearance. Cut bolt ends must be coated with anti-rust paint, unless bolts are stainless steel.

5 Examine the structure periodically after construction:

- It is necessary to adjust or replace bamboo elements that have shifted due to shrinkage, movement or any other reason that has them out of alignment.

- If there are cracks, excessive deformations, rotting or insect infestation on structural parts, they must be replaced and appropriate treatment must be carried out to eliminate the problem.

- If the joints are deteriorating (oxidized or rusting), they must be replaced.

Damage types

Cracks

Mold

Loss of coloring

11 Examples of Bamboo Construction in Peru & the Andean Region

Construction with bamboo in Peru

Works from Architects YannBarnet & Faouzi Jabrane
Housing, Urbanism & Construction Institute -USMP

1. Jesus company Church, Pisco - Ica

2. Social housing, San Clemente - Ica

Works in Lima

“El Camion” Restaurant - Villa El Salvador
Architects Michelle Llona, Fernando Mosquera, Rafael Zambrano

Extension to the Ministry of the Environment, San Isidro
Architects Mauricio González and Lorena Nolte

Building in the jungle - Satipo

Multipurpose room from Arawak University - Architect Mauricio Gonzalez

Construction with bamboo in the Andean Region

Works from Architect Simon Velez in Colombia

Bamboo Sanctuary

Zeri Pavilion

Foundation School for Life in Cali, Colombia - Architect Andres Bappler

Construction examples in Ecuador

Center of Documentation of Bamboo, Catholic University of Guayaquil
Architect J.Morán Ubida

Museum Lovers of Sumpa, Sta. Elena
Architect Daniela Loaiza.

Home Offices of Christ, Guayaquil,
Architect Saul Vera

Bamboo: Frequently asked questions

What is the growth rate of Bamboo?

The speed of growth of bamboo varies depending on the species of bamboo, climate, types of soil, etc. In scientific studies carried out in Ecuador, growth was 13.5 cm (5 □“) per day.

What maturity is correct for harvesting a bamboo like Guadua angustifolia?

The proper level of maturity for bamboo harvest, where cane reaches its greatest capacity strength, is estimated depending on the conditions of the site. On average, this is about 4 years, making bamboo far more renewable that the 20-30-year harvest cycle for trees. Bamboo also has the capacity to generate new shoots, without the need to re-plant. This is why bamboo is considered a highly renewable resource.

Can bamboo replace wood in construction?

Yes it can. There is no structure built of wood that can not be built with bamboo.

Is bamboo highly flammable?

Fire does not spread easily in bamboo. Preservation with borax and boric acid adds further protection. Coating bamboo helps retard combustion, so plaster is recommended for walls and ceilings of fire prone environments such as kitchens and workshops.

Is bamboo an earthquake resistant material?

Bamboo is light, flexible and strong due to its cylindrical and hollow form. When used with proper structural design, bamboo is resistant to earthquakes and is a good material solution for locations where soil has low carrying capacity. See E.100 Bamboo Standard for proper application.

Is bamboo a durable material?

If harvested at proper maturity, preserved against insects and rot, properly dried, protected from moisture and direct sunlight, and has proper maintenance, bamboo's durability can be more than 50 years.

Do bamboo buildings need constant maintenance?

As with all construction materials, maintenance is required to remove dust and fungi, prevent moisture infiltration, and maintain the original texture and color.

Is it cheaper to build with bamboo?

As with all materials, the cost of construction depends greatly on the design of the project and its location. In the case of housing, for which a large part of the budget goes to facilities, finishes and carpentry, building with bamboo does not provide significant savings compared to confined masonry or wood construction. However, for projects that require large spaces with a light roof, the use of bamboo is usually a very economical option.

Glossary

Cane: technical term referring to the stem of already harvested bamboo.

Bearing structure: set of columns, beams and diagonals of a building.

Plunger: weight that moves to cause a movement or impact.

Notch: cut shape at the end of a cane to form a union with another or other canes.

Caulinar leaves: temporal leaves that protect the bud of the bamboos and that come off when they leave the branches.

Innocuous: non-toxic or does not cause damage.

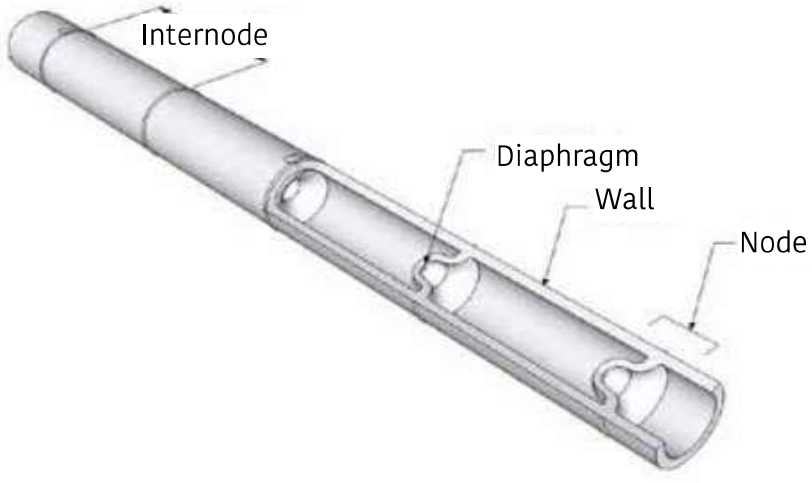
Lichens: whitish spots in the form of specks on the surface of bamboo canes, which can indicate cane maturity if partially covering the culm.

Buckling: deformation suffered by the columns because they are too small in diameter, too long and/or not sufficiently supported or braced.

Node: part of the rhizomatic system of standing bamboo that holds the branches and leaves and separates culms along the cane.

Stump: base of stem remaining after cutting a cane.

Vocabulary of the parts of the reed



INBAR is an intergovernmental body established in 1997 to promote social, economic and environmental development through the use of bamboo and rattan in the most vulnerable communities.

With regional offices in Asia, Africa and Latin America, INBAR has global experience working with governments, businesses and local communities in more than 50 countries, identifying new and innovative uses of bamboo and rattan.

This manual uses a step-by-step approach, utilizing graphics, brief descriptions and photographs, to describe how to build with Guayaquil cane (Guadua angustifolia). The manual applies the E.100 Bamboo Standard of Peru, in a technical and efficient way to illustrate how to build earthquake resistant, comfortable, safe and durable buildings.

International Network for Bamboo and Rattan (INBAR) International Bamboo and Rattan Network
Tel: (593) 255 8381 Quito, Ecuador
E-mail: inbarlac@gmail.com / www.inbar.int

In partnership with:

Ministry of Housing Construction and Sanitation of Peru
Tel: (511) 211-7930
Website: www.vivienda.gob.pe

University of San Martín de Porres (USMP)
Institute of Housing, Urbanism and Construction (IVUC)
Website: www.usmp.edu.pe/ivuc

This project was carried out thanks to the financial support of: