AIZHAN SYIDANOVA

EXAMINATION OF BAMBOO AS A CONSTRUCTION MATERIAL

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A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
AIZHAN SYIDANOVA

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Architecture

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Approval of Director of Graduate School of Applied Sciences

Prof. Dr. Nadire CAVUS

We certify this thesis is satisfactory for the award of the degree of Masters of Science in Architecture

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

The thesis refers to the theme of the material of bamboo as a building material. Questions of "what bamboo is" and "how bamboo can be used in construction" are tried to be answered. Bamboo as a building material has been used for a long time, but many people still perceive it as a poor man's material. In this thesis, it is shown that in the present and future the bamboo is considered as a stable material, various buildings were built from small pavilions to buildings with several floors. The history of using bamboo and in what areas it can be used in the future was described. The main goal of the thesis is to expose the material of bamboo as a building material and what can be built from it. What kinds of bamboo can be used in construction and what methods should be used in the construction of buildings is examined. Tables with bamboo buildings and their comparison with each other, what construction approaches architects often use and what is important for bamboo as a building material are shown. Expected from the bamboo is great advancement as a building material and assurance of the fact that it is environmentally friendly material.

Keywords: Bamboo material; construction material; sustainable architecture; connections; preservation

ÖZET

Tezin konusu, bir yapı malzemesi olarak bambu malzemesini ifade eder. “Bambu nedir?” ve “Bambu inşaatta nasıl kullanılabilir?” soruları cevaplanmaya çalışılmıştır. Bir yapı malzemesi olarak bambu uzun süredir kullanılıyordu, ama çoğu insan hala bambuyu fakir insanların malzemesi olarak algılamaktadır. Bu tezde, bambunun bugün ve gelecekte istikrarlı bir yapı malzemesi olarak kabul edildiği, küçük binalardan çok katlı binalara kadar çeşitli binaların inşa edildiği gösterilmiştir. Bambu kullanımının tarihçesi ve gelecekte hangi alanlarda kullanılabileceği anlatılmıştır. Tezin ana amacı, bambu malzemesini bir yapı malzemesi olarak ortaya çıkarmak ve bambu ile ne inşa edilebileceğini ortaya koymaktır. Bina inşaatında hangi tür bambunun kullanılabileceği ve binaların yapımında hangi yöntemlerin kullanılması gerektiği irdelenmiştir. Bambu binaları içeren tablolar ve bunların birbirleriyle karşılaştırmaları, mimarların sıklıkla kullandığı inşaat yaklaşımları ve bir yapı malzemesi olarak bambu için nelerin önemli olduğu gösterilmiştir. Bambudan beklenilen, bir inşaat malzemesi olarak büyük bir ilerlemedir ve çevre dostu bir malzeme olduğu gerçeğinin güvencesidir.

Anahtar kelimeler: Bambu malzeme; yapı malzemesi; sürdürülebilir mimarlık; bağlantılar; koruma

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CHAPTER ONE
INTRODUCTION

There are many herbs in the world, grasses grow in the meadows, but their stems are thin and weak, if an ant croaks on them or a butterfly sits down, the grass will bend under their weight. The reed is much larger and stronger; it is the grass growing in ponds along the banks of rivers. Birds can hang their nests, and children cut out the cane from the reeds. However, there is grass, much stronger than reeds; Bamboo is a giant among the herbs.

Bamboo has a long and interesting history, numbering more than 5000 years. The ancient Chinese used this versatile grass for many projects, including shooting, construction, weaving, books, and paper.
It is unknown where the bamboo first appeared and where its homeland is. The grass grows in a tropical and subtropical climate, in natural conditions; bamboo grows in Asia, Europe, America, Africa, and Australia as well in Oceania.
The material of the 21st century is durable, light and does not absorb water. Bamboo is a utilitarian plant. Bamboo seeds can be eaten in the same way as bamboo shoots. Bamboo is used as furniture, so huts, sailing ships, masts, carpets, curtains, pots, paper, clothes, and much more are built.

1.1 The Thesis Problems

Bamboo can be freely called an environmentally friendly material. However, people ask themselves how it can be used as a building material. What types can be used in construction? How to prepare the material for use as a building material? What techniques can be used in the construction of a house, pavilion or any other building?

1.2 The Aim of the Thesis

The purpose of this thesis is to study the bamboo plant as a building material. To do that knowledge of the initial use of bamboo, how bamboo can affect the environment, the types of bamboo that can be used in construction. How to use bamboo as a building material. How to protect the material from external factors, how to use and where to use bamboo in the architectural and design area are examined and put forward.

1.3 The Important of the Thesis

The importance of this thesis is that there has been no other academic study in literature in detail about the plant bamboo as a construction material. There are many types of bamboo and what types can be used in building construction is examined. Since the bamboo is a green plant that can be attacked by insects, the thesis describes how to protect bamboo not only from insects but also from mold. The technique of using bamboo, combining bamboo with each other and how to use hollow culms for construction from the foundation to the roof are described in detail. In addition, the importance of thematic research, a complete overview of several buildings made of bamboo, gives an opportunity to learn bamboo from the best side.

1.4 Scope of the Study

The research envelope consists of studying bamboo as a material used in construction. Methods of using and protecting the material, a detailed study of different building techniques of bamboo use in construction, bamboo use as an environmental material in the future are examine. Study of several buildings constructed of bamboo material is given.

1.5 Limitations of the Study

Description of the material as a plant and the definition of bamboo as a green material, methods of protecting bamboo and methods of using bamboo as a building material, types

of bamboo that are used only in construction and disassembly of construction methods based on nine buildings are held during the thesis study.

1.6 Methodology

First, knowledge about bamboo and especially its use in the construction sector is given. Theoretical analysis of the material of bamboo is based on a deep comprehension of the fact that in our architectural life there is not so much material that would not destroy the environment. As a plant, bamboo is a fast-growing and strong material; however, it requires special care before using it in the construction sector. In addition, the bamboo plant has 1300 types, but not all can be used as a building material, a table with types of bamboo that can be used in construction has been compiled for in-depth study. Special bonding methods and constructive methods described in this study can be used mainly for only bamboo material. In this work, also examples of architectural buildings that were made of bamboo material were examined in comparison, which will help architects learn the material more in detail.

1.7 Overview of the Thesis

Bamboo is a unique building material, due to which it has rigidity and density. While the tensile strength remains unchanged throughout the bamboo plant, the strength of the plant fiber increases with aging.

The material presented about the old material in a new form, for many years scientists have observed the development of bamboo, its power is able to replace iron. Back in the old days, people used bamboo, but the material was not long-lived, in the 21st century, architects - engineers found several ways to protect bamboo, as they found new methods for using bamboo in construction.

The first chapter describes general information, as well as the purpose of the task and the limitations of this work.

The second chapter gives information about the history of bamboo, where it came from, the first sources and records of this old material. The chapter also describes the plant itself, its biological and anatomical form. It takes into account its genus, types of bamboo, and also tells in what areas of activity it is possible to use bamboo. Sustainable architecture also welcomes eco-friendly material. In this chapter you can find the answer to the question "what is sustainable architecture?" and find out how sustainable the architecture and bamboo can work together.

The third chapter begins with knowledge about how to properly protect bamboo from external factors and describes in detail the methods of protection. It also talks about bamboo as a building material used in construction work. Starting from the foundation reaching the roof of the building, as well as the advantages and disadvantages of the material.

The importance of the fourth chapter is that there are different types of construction of bamboo, bamboo can wrap the house protecting it from external factors, or the material is used from laying the foundation up to the roof. A few examples that show the uniqueness of bamboo in architecture is examined and compared in this chapter.

The fifth and the final chapter is the conclusion and its summarize all chapters.

CHAPTER TWO
THE ORIGIN OF BAMBOO / BAMBOO AS A SUSTAINABLE MATERIAL

2.1 Bamboo as a Plant

Bamboo (Lat. Bambusa) is a plant from the genus of evergreens of the Cereals family. The genus includes 130 species and about 1300 subspecies of plants. Bamboo is found mainly in the tropical and subtropical regions of Asia and is distributed in the humid tropics.

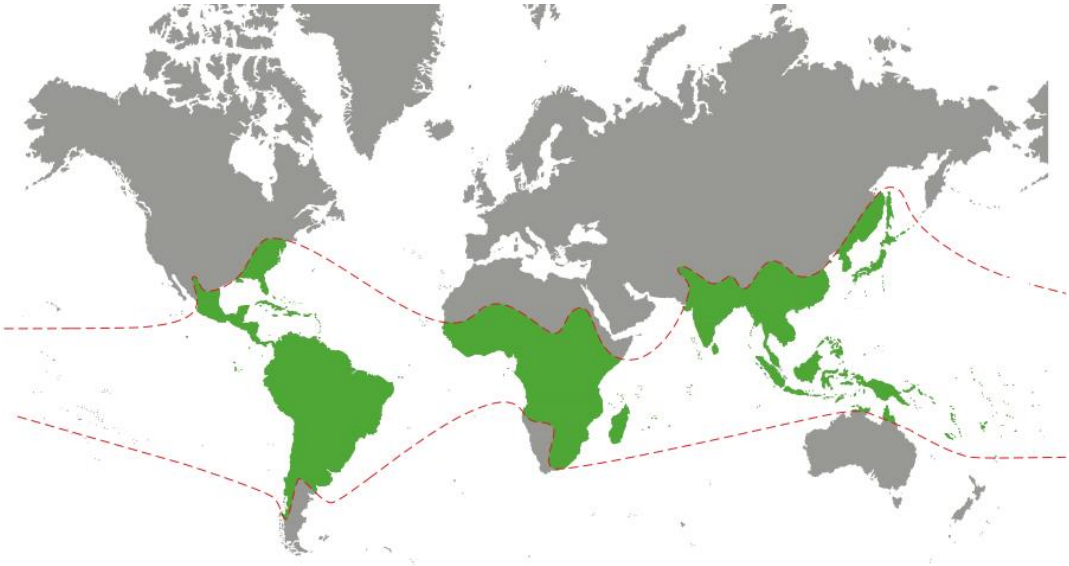


Figure 1: Global natural habitat of bamboo (Chair of Architecture and Construction Dirk E. Hebel, 2012)

Depending on the genus, the growth of bamboo varies from 20-50 centimeters to 40 meters, it is one of the fastest growing plants in the world and can grow to 0.75 meters per day. Curly bamboo lianas reach up to 120 cm in length. The development and growth of bamboo can depend on climatic conditions, the growth of tropical species of bamboo may depend on the level of humidity, during the rainy season, the activity of growth increases. Other groups of

bamboo species designed for a subtropical and temperate climate with cold or cool winters, their growth activity is controlled by seasonal conditions (Nilsson, 2010).

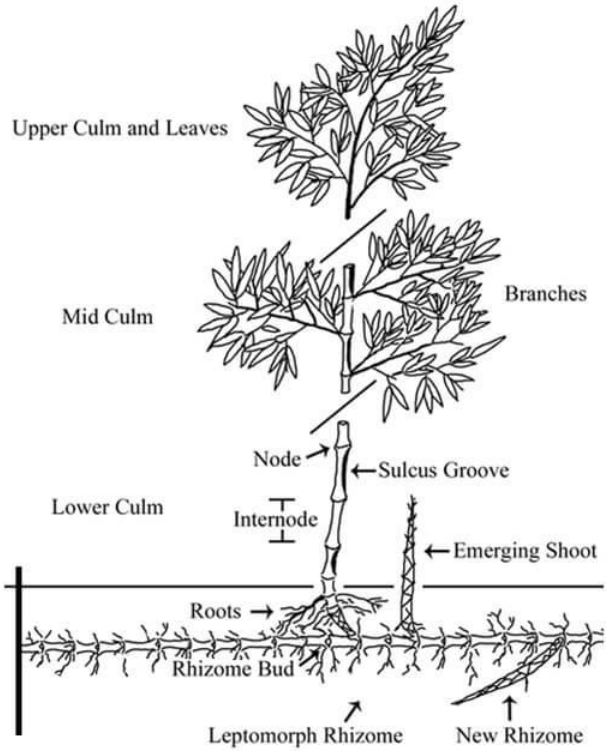


Figure 2: Parts of Bamboo (LeBeau, 2014)

Bamboo is a tropical and subtropical plant that grows naturally in Asia, America, and Africa. In addition, if herbaceous bamboo grows exclusively in the tropics, then some richer species of bamboo meet and feel good in the more northern cold areas. In the eastern Andes, one can find bamboo Chusquea Aristata at an altitude of 4700 m above sea level, which here form impenetrable thickets that meet up to the snowboarder. In the Himalayas, at an altitude of 3800 m. Currently, Bambusa Metake from Japan and several species of bamboo from China are perfectly acclimatized and grow in Central Europe (Nilsson, 2010).

In the family of cereals (Poaceae) there is a large subfamily of plants called Bambusoideae (Latin Bambusoideae), which has about 1200 representatives. In turn, the subfamily of bamboo includes two main types of bamboo, which are representatives of two taxonomic tribes. In this bamboo tribute (Bambuseae) are represented lignified plants with a thin high

stem, often branched, often aerial, graceful crowns, grassy leaves, and sometimes-giant wide inflorescences. The second tribe is olive (olyreae): these plants resemble ordinary herbs that do not signify, but form thickets and usually do not exceed one meter in height (Nilsson, 2010).

2.2 Initial Use of Bamboo

The history about Bamboo is more than 5000 years ago. From ancient time, people used this grass for many projects including shooting, construction, weaving, books and paper. The first known study of bamboo was record, during the Jin Dynasty, China, in a book, which included 61 different types; there was biological description and cultivation method. The reason why bamboo has such an ancient history in China and widespread use, because over 400 species of grass grow on the territory of this country, ranking first in the number of growing bamboo throughout the world (LiveJournal, 2015).

In 206 BC, the main craft of the Khan Dynasty was the production of paper, and they produced it precisely from bamboo. It was profitable from 3000 kg of bamboo to make 1000 kg of paper. There was one drawback with this paper; it was heavy due to mixing with other materials (LiveJournal, 2015).

1037-1101 AD Bamboo was used for all kinds of items necessary for life. This plant was used for firewood, paper, rafts, tiles, hats, shoes, capes and much more (Amazuluinc, 2014).

In 1486 during the Ming dynasty in China bamboo made coal, which is a sustainable and healthy alternative to traditional coal. Bamboo charcoal creates clean air and reduces residues of contaminants (Amazuluinc, 2014).

Patented the first bamboo bicycles in 1894 in England. Bicycles from bamboo are still produced and new types are being created (Amazuluinc, 2014).

During the Second World War, Gucci designers showed creativity and created the Gucci Bamboo Bag. Since the resources were not enough, the company used bamboo as handles for bags. Developers of Gucci have developed a patented method of heating and bending bamboo, this was done in order for the handle of the bag to retain its shape after cooling and fastening (Amazuluinc, 2014).

1997 The international bamboo and rattan network exists for the development of environmental sustainability using bamboo and rattan. It was founded in 1997 and believes that stability can be achieved in poor areas around the world if one finds ways to use these plants creatively (Amazuluinc, 2014).

Medicine is another area where one can not do without the beneficial properties of bamboo. It helps with heartburn as it has the property of cooling, with fainting, treatment of epilepsy, reduces phlegm in the throat. In India and Tibet apply during fever and spasms, and is also part of aphrodisiacs and tonics (SashaLAB, 2017).

2.3 Bamboo Nowadays

A multifunctional plant like bamboo, depending on the treatment, can vary in properties. It can be firm and stable, also soft and elastic. Some use it in building houses, covering floors, and others for sewing textiles. In the 21st century, this material used in:

- Woodworking industry
- Pulp and paper industry
- Textile industry
- Bioenergetics from grass
- Food and Beverages
- Automotive industry
- High technology area
- Agriculture

For example: the fabric of bamboo, as well as the fillers are hypoallergenic, absorb moisture, are strong, for long socks, do not soak up smells and do not retain dust.

In everyday life thanks to the ecological properties of raw bamboo can be found in your kitchen in the form of wooden spoons, baskets and bowls, which are usually varnished and painted. Big competition bamboo makes up plastic, as it is environmentally friendly. Covers, keyboards and even computer mice are made of polished wood.

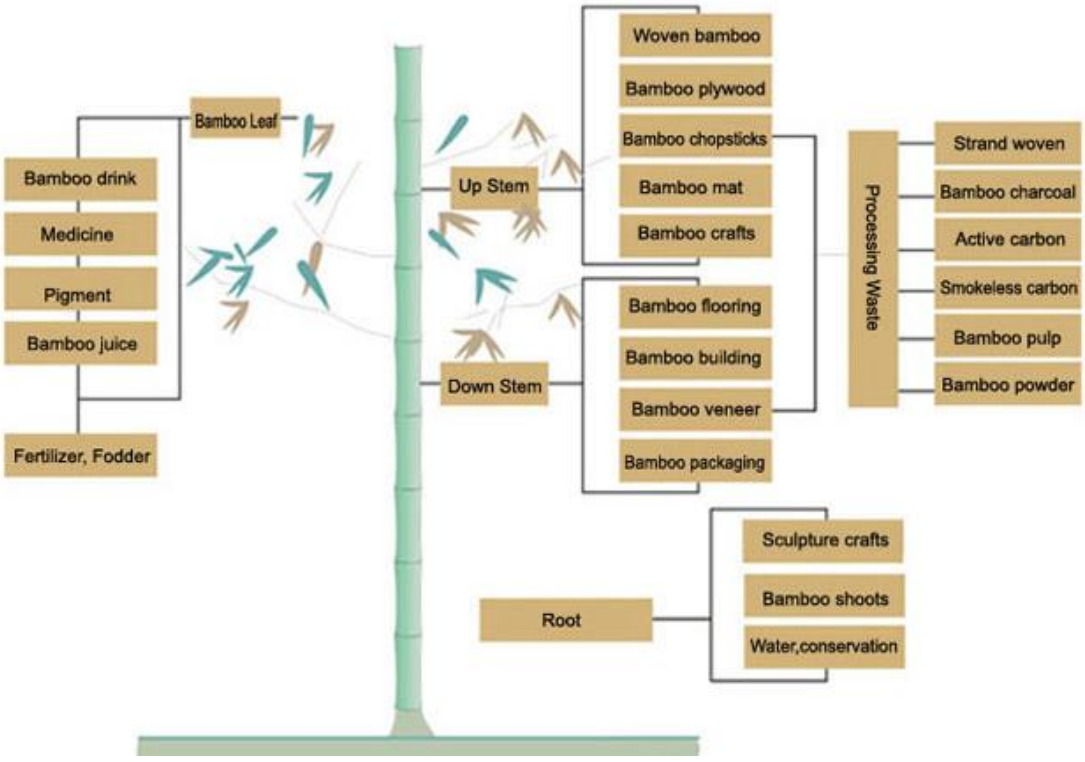


Figure 3: Bamboo comprehensive utilization (Bamboo flooring blog, 2001)

2.4 Types of Bamboo and Their Feature Specification

Bamboo (Bamusa) belongs to the family Cereals, about 115 genera of bamboo and about 1300 species. Almost all varieties of these plants come from the Far East. Bamboo is an evergreen plant, it is a stiffened stalk, on which lanceolate leaves and solitary flowers, or in

paniculate inflorescence, are located at the top. Bamboo - monocarpic plants and after flowering they perish (Bamboo plant blog, 2001-2017).

The bamboo trunk is a long natural "column", a uniformly thick and dense cylinder, with a smooth, siliceous, naturally polished surface. At regular intervals, annular nodes interrupt it, each individual interstitial site being a completely isolated waterproof vessel. Its size and shape are highly diverse, proportions and length of individual internode length, in thickness and strength of partitions, in straightness, smoothness and durability, there is a bamboo heavy and light, with different wall thickness. Being very strong, bamboo is at the same time elastic; neither in the raw, nor in the dry form, it has no specific smell or taste.

Table 4.3 in Chapter 4 shows all 45 types of bamboo that can be used for construction.

2.5 Sustainability in 21st Century

In the twenty-first century, the main goal of sustainable design is to reduce or prevent the depletion of critical resources such as energy, water and raw materials, including coal, gas and so on. Also reduces the environmental degradation caused by the growth, development and maintenance throughout their life cycle, and creates such conditions designed to not only habitable but also comfortable, safe and productive.

Resources used for construction (energy, water, raw materials), allocate waste (construction and demolition) and allocate potentially harmful emissions into the atmosphere. Architects, designers and builders have to face the difficult task of meeting the needs for new buildings and structures that are affordable, safe, healthy and productive while minimizing any negative consequences for society, the environment and the economy. Under the best circumstances, building structures should lead to positive results in all three areas (Environmental Encyclopedia, 2003).

Sustainable architecture is the construction of buildings that create the best living conditions for a person. Improving and minimizing the use of harmful resources in architecture and

design. This effect on building materials and construction methods, as well as the use of sources such as heating, cooling, power, water and so on.

The sense of exploitation is that the structures are designed in such a way as to support their users, which provides a favorable environment, the development of life for the better and the prevention of waste generation in order to maintain long-term survival for people and environmental.

The enumeration with five substantial points of sustainable architecture by The United Nations (Environmental Encyclopedia, 2003):

- A healthy internal environment. It is worth taking the necessary measures to ensure that building materials do not release toxic substances and gases into the internal atmosphere. It is important to take additional measures to clean and renew indoor air through filtration and sowing,

- Efficiency of sources. It is necessary to take all possible measures to ensure minimum energy consumption and other construction resources. Heating, cooling and lighting systems should use machinery and products that preserve or exclude the use of energy. Reducing the use of water and wastewater,

- Environmentally friendly materials. Considering all permissible measures for the use of building materials, which minimize the destruction of the environment. The tree as a material should be chosen on the basis of methods that will not destroy the forest. Other products for construction should be considered based on the production of toxic waste. In addition, the criterion in which the environmental and social costs of production of construction materials should be taken into account, and taken into the statement in accordance with the objectives of sustainable development,

- Ecological method. It is important to take all the necessary ways to link the architectural and building concept of the building with the construction site given the

region and the climate. If necessary, take measures to "cure" and improve the ecology of the construction site. It is imperative to create conditions for using and increasing energy efficiency and to take measures to link the form of construction and the relations between inhabitants and nature,

- Best design. Take measures to achieve a productive, promising and elegant interrelationship between the use and circulation of building shapes, mechanical structures and construction technologies. It is necessary to seek and express symbolic relations with the corresponding history, the Earth and spiritual principles. Ready-made buildings should be perfectly constructed, simple to use and beautiful.

The signs listed above cannot be attributed to all natural raw materials. The materials that are completely suitable for these signs are wood (woods that are familiar to us, as well as reeds, cork, straw), natural cotton, wool, silk, sand, natural stone, rubber, natural linseed oil and some others. Glass and metal, too, can be considered to be far from the most harmful.
There is a conditional classification of eco materials into three types: natural origin, natural and artificial and materials of chemical (artificial) origin.

2.6 Sustainability and Bamboo

The materials that are completely suitable for these signs are wood (woods that are familiar to us, as well as reeds, cork, straw), natural cotton, wool, silk, sand, natural stone, rubber, natural linseed oil and some others. Glass and metal, too, can be considered to be far from the most harmful.

There is a conditional classification of eco materials into three types: natural origin, natural and artificial and materials of chemical (artificial) origin.

Given the global environmental situation on the planet, scientists are constantly looking for new ways to conserve greenery on the continents, to introduce new, and safer and more

progressive production technologies. Innovations in the production of bamboo fiber helped to make a big step forward.

Bamboo fibres favorably differ from many others, because in addition to all the advantages of natural fibres have unique properties:

- Hypoallergenic,
- Antibacterial properties that persist even after prolonged use,
- High wear resistance, resistance to burnout,
- Hygroscopic,
- The ability to retain ultraviolet rays,
- Natural antistatic effect.

Knitwear made of bamboo perfectly worn, does not crease, does not stretch, does not shed, it is very comfortable in bamboo products; they keep heat well, when it is hot and warm when it is cold (WordPress, 2008-2018).

Some of the facts - sustainability of bamboo are:

- It is grown without pesticides or chemical fertilizers,
- It requires no irrigation,
- It rarely need to replanting,
- It grows rapidly and can be harvested in 3-5 years,
- It produces 35% more oxygen that an equivalent stand of trees,
- It sequesters carbon dioxide and is carbon neutral,
- It is a critical element in the balance of oxygen and carbon dioxide in the atmosphere,
- It is an excellent soil erosion inhibitor,
- It grows in a wide range of environments,
- Its production into fibres has lower environmental impact than other forms of fibre, especially synthetic ones.

CHAPTER THREE
BAMBOO AS A CONSTRUCTION MATERIAL

In the construction industry, not all types of bamboo can be used. In the construction industry, if the bamboo does not pass a certain processing of treatment, also cannot be used. Harvesting and protection from insects is the beginning for bamboo as a building material.

Figure 4: Dry bamboo culms (Schröder, November 30, 2014)

Bamboo's criteria for building industry:

- When using bamboo it is worth making sure that it is dried during the drying process, not dry bamboo can lead to kinks and is not subject to use in structures,
- Bamboo should be older than 3 years. It is recommended to use mature bamboo 4-6 years,
- Bamboo must be decontaminated from insects and a certain treatment,
- Bamboo blooms can't be used in construction, can lead to the withering of the bamboo itself,

- Before use it is worth checking for the presence of cracks, can lead to kinks,
- The term of bamboo service depends on the type, length of the bed, wall thickness, and harvesting time.

3.1 Bamboo Preservation

3.1.1 Preparation methods of bamboo

Figure 5: Untreated bamboo poles (Schröder, November 30, 2014)

Durability of bamboo. The outer hard part and the lower part of the culms is more durable than part of the inner wall deteriorating faster as it is soft. Some characteristics of bamboo are similar to wood, but the characteristics of the microstructure are different. Similarly, the structure of bamboo does not release toxic deposits (Schröder, November 30, 2014).

Figure 6: Curative bamboo poles (Schröder, November 30, 2014)

The bamboo which people use in construction cannot be picked up correctly, or is prone to improper handling, many people don't use any treatment, so the construction of their buildings can collapse in just a couple of years, because of that bamboo is still considered as a poor man's material. The countries that account for the majority of bamboo are not sufficiently informed about professional treatment. Not all methods that they use provide good results, this leads to the destruction of the construction of bamboo. For protection it is worth using chemical preservatives, they provide good protection even under adverse conditions (Schröder, November 30, 2014).

The choice of a suitable method of treatment depends on various factors:

- Green or dry bamboo,
- Bamboo shape: round bamboo or half,
- End applications; in contact with the earth, is exposed to the atmosphere, under cover, structural / non-structural,
- Scale; the amount to be treated, and the available time,

• Potential causes of decay; biotic (fungi / insects) and abiotic (fissures / weathering).

Treating bamboo for long-term use is a more economical and sustainable method. In addition, with the application of proper procedures, the lifespan of bamboo can increase to 50 years (Schröder, 2014).

3.1.2 Bamboo infection with insects

Beetles and termites are the most common insects in bamboo. The high probability of infection by insects is due to the presence of starch and other carbohydrates in bamboo.

(a) First view on bamboo infection (b) Second view on bamboo infection

Figure 7: Bamboo infection with insects, (Schröder, November 17, 2012)

The first stage - adult beetles lay eggs, in bamboo apertures before death, after from the egg there is a larva that devours bamboo from the inside. The third stage is pupation, since bamboo is protected; a warm and humid climate gives a good breeding ground. At the fourth stage, the beetle gnaws holes in the bamboo and leaves. For laying eggs, they return to bamboo. This continuous cycle can destroy not one bamboo forest (Schröder, November 17, 2012).

Therefore, bamboo must be chemically treated to avoid contamination. This food for insects can destroy the material or make it unsuitable for use.

Figure 8: Insect devours bamboo from the inside (Schröder, November 17, 2012)

3.1.3 Mold and spores

Mold and spores are common if bamboo is not completely dry. In addition, shipping bamboo in sea freight containers to the international market, too, can affect the occurrence of spores and mold **(**Schröder, November 16, 2012).

Figure 9: Mold forming on bamboo (Schröder, November 16, 2012)

A high moisture content in the reed makes it possible to reproduce the spore until the moisture completely evaporates. The appearance of mold can occur from one to two times (Schröder, November 16, 2012).

For example: The appearance of bamboo Phyllostachys aurea is often treated with flame (heat treatment). Thicker bamboo species, such as Guadua angustifolia, are treated with boron solution.

For green bamboo, apply heat treatment, most of the moisture remains inside the canes. The dried bamboo is subjected to boron treatment. Therefore, some finished bamboo products are initially more sensitive to molding. However, if you load an ocean freight container with bamboo in a tropical environment where a long transport time takes 30 days or more and ship to an environment where the temperature is much cooler, the cargo may fall under the phenomenon known as "cargo sweat" or "container rain". Extreme temperature fluctuations can cause condensation inside the container, which causes spore growth and the appearance of mold (Schröder, November 16, 2012).

How to clean a mold from bamboo?
In the fast and effective removal of stains can help commercial product Mold Armor FG502. You can also use alternative methods to combat mold. Clean the bamboo mold and white spores with a soft brush and wipe the area with a wet rag. After cleaning the bamboo, you can use lemon oil or a solution of vinegar and water for completely remove the mold. To clean the furniture from bamboo, it is recommended to apply three layers of polyurethane after removing the mold; this will ensure the preservation of furniture. Before applying the polyurethane, you need to clean the furniture with turpentine and completely dry it. If you do not do this, mold can grow under polyurethane coating and cause blisters (Schröder, November 16, 2012).

3.1.4 Leaching bamboo or storing bamboo in water

Bamboo leaching is a traditional method, it is used by indigenous communities and farmers in the Asian and Latin American regions. People transported bamboo from mountain areas and jungles to cities using bamboo rafts. Transportation of bamboo over rivers usually took up to four weeks, during which time leaching occurred. The content of starch in the poles

was reduced, thereby increasing the durability of the material (Schröder, November 14, 2012).

Figure 10: Bamboo raft: Ng Sebastian - Incito tour (Schröder, November 14, 2012)

People still use the method of immersing bamboo in water, especially when bamboo needs to be transported from remote areas. However, single leaching does not guarantee long-term protection, but helps to remove starch and increases permeability for future treatment by diffusion and pressure treatment. This protects bamboo from attack by beetles and parasites (Schröder, November 14, 2012).

Figure 11: Immersing bamboo in water (Schröder, November 14, 2012)

How to store bamboo in water? Bamboo is stored in tanks with water, while adding chemicals. Stages that must be applied necessarily:

- Bamboo knots should be punctured, so water will easily penetrate into the bamboo canes,
- It is necessary to bind the bamboo together or to separate and store them in tanks or in running water,
- Storage of bamboo in the tank. It is necessary to change the water weekly; this will prevent the growth of bacteria that can cause unpleasant odor and discoloration of bamboo,
- It is necessary to use loadings for full immersion of bamboo in water,
- Bamboo should be immersed in water with times, after extraction, it is worth using further chemical treatment. Bamboo should be immersed for at least 3 - 4 weeks (Schröder, November 14, 2012),
- Bamboo that has been leached for 3 months or more may become stained in the epidermis. This will reduce its physical and mechanical properties (Schröder, November 14, 2012).

3.1.5 Bamboo treatment with chemicals

Chemicals can provide short-term and long-term protection. The use or non-use of special equipment also affects how the substance that processes the material for the long-term protection of the material. Chemical preservatives are used to protect the material from attack by beetles, mold and prevent the material from changing the effects of climate. The choice of chemicals as protection for bamboo must be chosen very carefully, as this can affect the environment (Schröder, November 13, 2012).

"Ratio" and "Concentration"
The ratio of the chemical solution is based on kilograms per 100 liters of water. The ratio of the chemical solution to the equivalent concentration (Schröder, November 13, 2012).

All chemical solutions are indicated in kilograms per hundred liters of water. For example, a solution of three chemical elements in a ratio of 2: 2: 0.5. It is a mixture of 2 kg of chemical element per 2 kg of the second chemical element and 0.5 kg of the third chemical element per 100 liters of water, this is a concentrate of 4.5%. If we want to increase the concentrate by 9%, then the ratio changes by 4: 4: 1 (Schröder, November 13, 2012).

Preservatives are divided into two types:
• Non-fixed preservatives,
• Preservatives of the fixing type.

Non-fixed preservatives
This type of protection consists of boron salts, which helps to prevent the occurrence of termites, mold and protects against the appearance of fungi. Boron salts are added to water, bamboo is soaked in this water, after the water evaporates and leaves the salts inside the bamboo. This method is not toxic; it can be used for products that contact with food (Schröder, November 13, 2012).

Boric Acid Borax

Brown and boric acid is one of the most commonly used methods of preserving bamboo, since it is effective and environmentally friendly. The product is flame retardant and does not contain dangerous decomposition. Dehydrate of sodium tetrahydrohydrate is a powdery, white substance that does not emit an odor. It is not a flammable or explosive product, has an acute low oral and dermal toxicity. The product itself is flame retardant and does not contain dangerous decomposition. The product has an unlimited shelf life and does not depend on temperature. Boric Acid Borax is dissolved in water, after it can be sprayed onto the material, bamboo can be immersed or impregnated with this substance (Schröder, November 13, 2012).

Formula 1: boric acid / borax, ratio 1: 1.5; Formula 2: boric acid / borax / sodium dichromate, ratio 2: 2: 0.5; Concentration 4-5%, this type of protection is used for bamboos that will not be exposed to weather or ground (Schröder, November 13, 2012).

Preservatives of the fixing type

These types of protection consist of mixtures of different salts in a certain quantitative ratio, when interacting with each other, they become chemically fixed.

Consistency:

Copper-Chromium-Arsenic (CCA)

Preservative of a broad spectrum of action, Patented as AsCu. Provides protection for 50 years or more, the use of such a composition is desirable in the open air, since arsenic is a poison and a carcinogen, but the use in small quantities does not affect human health. In addition, the composition will cause the bamboo to green color (Schröder, November 13, 2012).

Formula: arsenic pentoxide / copper sulphate / sodium dichromate, ratio 1: 3: 4; For structures that exposed to weather, it is worth using 6% of the composition, but bamboo should not be in contact with the ground. If the bamboo during construction will be in contact with the ground, the concentrate should be 10% (Schröder, November 13, 2012).

Copper-Chrome-Boron (CCB)

It is an alternative to CCA, but because of the boron degree of fixation is lower, is less effective.

Formula: boric acid / copper sulphate / sodium dichromate, ratio 1.5: 3: 4; Concentration 6-8% indoor use and cannot be contacted with weather and soil. Concentration 8-10% outdoor use and can be contacted with weather and soil (Schröder, November 13, 2012).

Zinc-Chrome

It is a refractory preservative designed to protect the material from fire and provides good protection against insects. However, bamboo can absorb moisture from the air and will give a wet look during the rainy season.

Formula: Zinc chloride / sodium dichromate, ratio 1: 1; Concentration 10% outdoor use and can be contacted with weather and soil (Schröder, November 13, 2012).

Creosote

Colorless, sometimes yellowish or yellowish-green, flammable, hardly soluble in water, an oily liquid with a strong odor, derived from wood and coal tar. Preservative is used for external use, a chemical substance that is often used in the processing of railway sleepers and impregnation of wooden posts. Protects the material from infection with insects and fungi, it is used only for external processing in contact with the soil (Schröder, November 13, 2012).

Light Organic Solvent-based Preservatives (LOSP)

A protective agent that contains fungicides - killing mushrooms and insecticides - against insects. This is a finished product that does not require any mixing. The agent does not change the color of the material, but it may contain a residual odor that will fade with time. This product is a carrier of toxic molecules, but after application, toxic molecules evaporate leaving only a protective layer that does not harm the environment. Such concentrates are

economical in use, large factories often find it convenient to buy a large batch of such substances (Schröder, November 13, 2012).

Trichlorophenol (TCP)
A 5% solution of fungicide with insecticides, for a wide range, is an ecological preservative. Sometimes diluted with mineral turpentine oil, the product becomes more economical (Schröder, November 13, 2012).

Copper/Zinc soaps
The organic compound of copper and zinc is known as a metal soap, a disinfectant. In the composition there are insecticides, the product is more expensive than TCP, but more ecological and does not have an acute odor (Schröder, November 13, 2012).

3.1.6 Drying bamboo poles

Drying bamboo takes a lot of time, because this material easily absorbs moisture, it is called a hygroscopic material. Humidity is 50% - 60%, it can also depend on the climatic conditions of cutting down and the type of bamboo. During the drying process, the diameter of the bamboo can be reduced from 10% to 16%, and the wall thickness from 15% to 17% (Schröder, November 12, 2012).

The usual and well-known method of drying bamboo is "drying in the air." After chemical treatment, all bamboo is laid and stored under a canopy or under a roof.

Figure 12: Drying in the air under tent (Schröder, November 12, 2012)

Figure 13: Drying in the air under a roof (Schröder, November 12, 2012)

Important factors when drying bamboo:

- First, you need to protect bamboo from direct contact with the ground, avoiding humidity, insects and infection with fungus,
- It is necessary to avoid changing the humidity. Round poles shouldn't be exposed to direct sunlight, for a long time, might form cracks in poles. However, the bamboos, divided into lengths, can be dried in the open sun,
- In time to remove infected clusters, infection of the entire storage area should not go,
- There should be a circulation of air in a room with bamboo,
- Vertical packing gives the bamboo to dry for a shorter period and is less defeated by a fungal attack. However, it is worthwhile to follow the poles so that there is no curvature or provide a good support system,
- Horizontal laying is usually used for large batches of bamboo, they are laid on large sheets, sheets can consist of plastic or glass, or use dividers as shown in figure 13 The lower bamboo batch can crack from the weight, for this, it is laid not in large layers and carefully checked,
- Every 15 days, bamboo should be turned in the longitudinal direction, for even drying.

The method of air-drying takes from 6 to 12 weeks. This may depend on the humidity of the bamboo, the thickness (Schröder, November 12, 2012).

Post-harvesting transpiration

Transpiration is the process of movement and evaporation of 99% of water from a plant through leaves and stems. The traditional method of drying bamboo, is used by farmers and indigenous communities. The drying process takes place on a bamboo plantation, in order to avoid contact with the soil, the cut bamboo is placed on a stone and leaned against another bamboo. Attached to each other for 3 - 4 weeks, the bamboo begins to lose its moisture (Schröder, November 12, 2012).

Kiln oven drying

The drying kiln method is suitable only for bamboo split, the process quickly dries out pieces of bamboo. However, this method is not suitable for whole bamboo, as high temperature gives cracks in the bamboo (Schröder, November 12, 2012).

3.2 Joints

3.2.1 Double butt bent joint

For the Double Butt Bent Joint, two bamboo poles were used. The first is horizontal, the second is vertical.

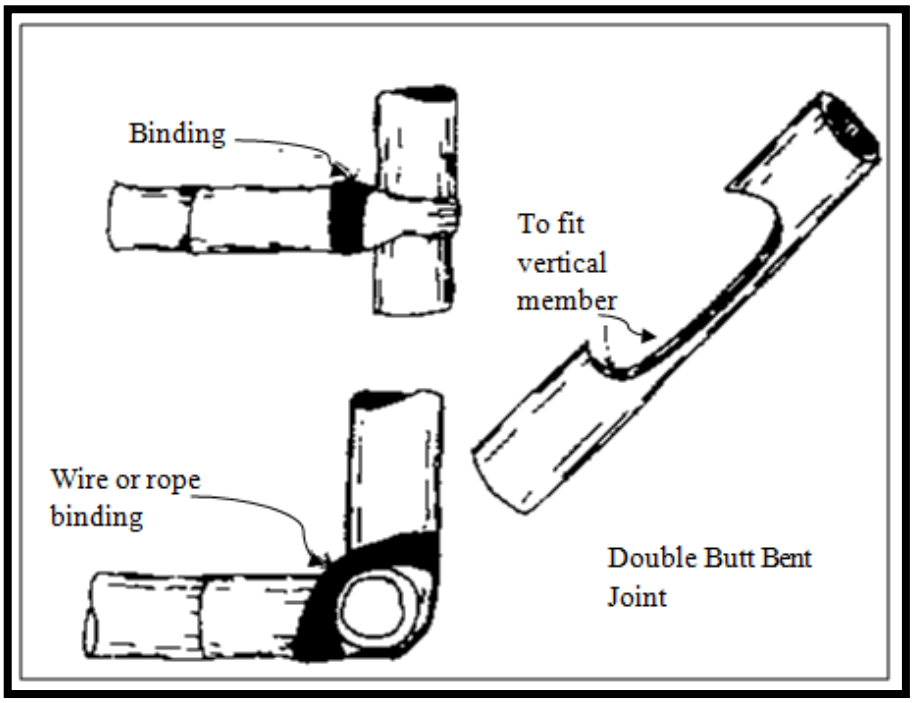


Figure 14: Double butt bent joint (Lennart P. Bengtsson, James H. Whitaker, 1988)

After making a measurement for the notch and calculating the length, depth, radius figure 15: Notch dimension for horizontal bamboo pole, you need to cut the horizontal pole according to the calculations (Lennart P. Bengtsson, James H. Whitaker, 1988):

- Length of the notch: $L= (3\pi/4)d$

- Depth of the notch: $h \leq (d/2)(1+\sin 45°)$
- Radius of the notch: $R=d/2$
- Angle: $\beta=135°$

And fit vertical member to horizontal pole and tie it with the rope.

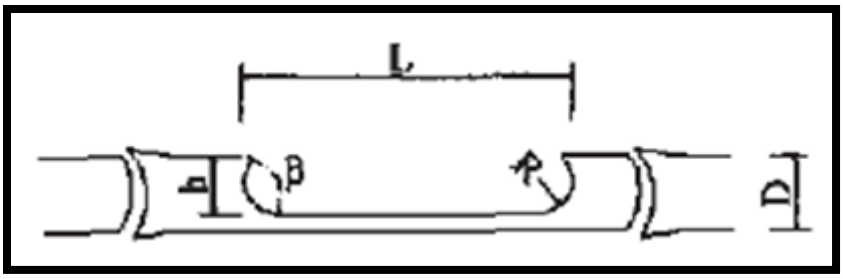


Figure 15: Notch dimension for horizontal bamboo pole (Lennart P. Bengtsson, James H. Whitaker, 1988)

This joint method can provide a beautiful and smooth joint surface, and also does not need complicated fixing methods. However, it requires accurate production skills and equipment, accurate cutting on bamboo (Lennart P. Bengtsson, James H. Whitaker, 1988).

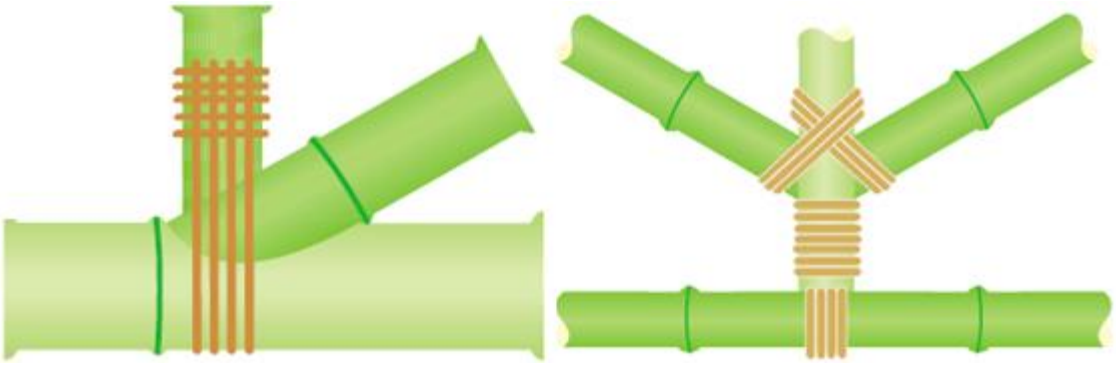
3.2.2 Friction – tight rope connections

The Friction – Tight Rope connection is the most common way to connect bamboo. Originally used natural materials, such as bast, strips of bamboo, rattan / hemp and palm fibre from coconut / sago, are used as a rope for connecting bamboo poles. At present, iron wire and plastic straps / ropes are also used for connection with friction (Janssen, 2000).

The Friction – Tight Rope connection technique can be used in almost all circumstances that may appear during the construction of a building and reduces the likelihood of a bamboo fracture. It is easier to compact because it is possible to apply epoxy or other materials as a coating. However, the choice of rope material can affect the construction, so you need to check the rope for damage from moisture, putrefaction and provide protection from insects (Janssen, 2000).

The system requires skills in performing fastening operations.

Figure 16: Connection with bamboo strips (Socrates, 2012)



(a) Type of bamboo connection (b) Type of bamboo connection

Figure 17: Bamboo connections with rope (Janssen, 2000)

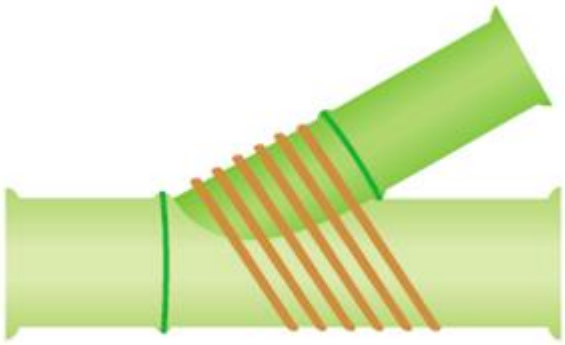


Figure 18: Bamboo connection with rope (Janssen, 2000)

This method is easy to build and simple for making bamboo. it can also be very strong with sufficient attachment technique.

3.2.3 Plug – In / Bolt Connection

Taking advantage of a secondary interlocking element, this type of connection is widely used in context with rope connections.

Figure 19: Bracket interlocking stud (Socrates, 2012)

In this case, the bolts have to transfer tractive and compressive forces. In addition, this can be seen in garden fences and furniture (Socrates, 2012).

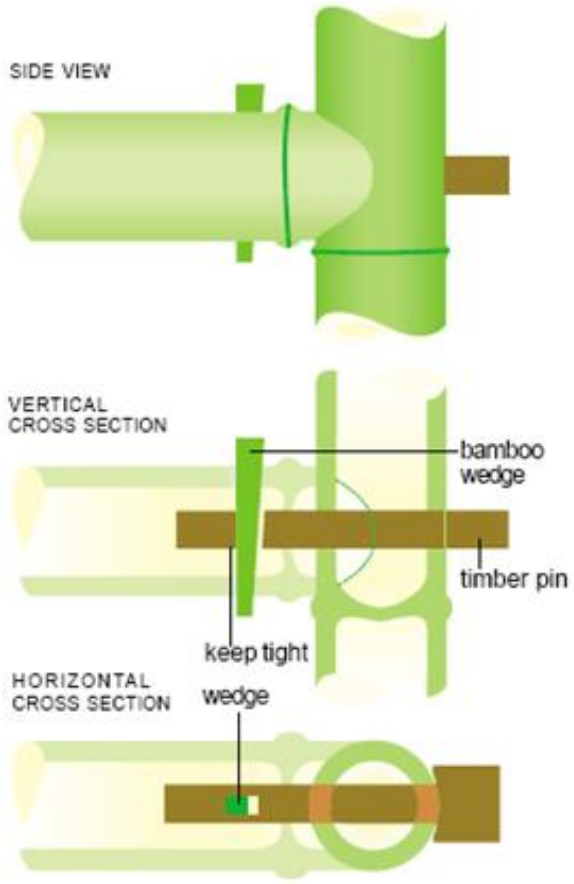


Figure 20: How to make the plug-in connector (Janssen, 2000)

This type of connection is used with a blocking element that can be made of wood and bamboo, and a cannon joint is used. This type of connection is most often seen in garden fences and furniture.

To begin with, drill the vertical and horizontal bamboo beams; the vertical that is connected to the wooden cipher should have holes larger than the horizontal pole. The used pin (made of wood or bamboo) connects two bamboo poles, and then a bamboo wedge is fixed to strengthen the connection. After that, you need to cut off the protruding parts of the curtain and make the surface of the plug smooth. To strengthen the bond use an adhesive or a rope (Socrates, 2012).

3.2.4 Positive Fitting Connection

Figure 21: Positive fitting bamboo connection (Regenerative Design Institute, 2006)

This compound has found wide application in traditional bamboo buildings, often used in the design of stairs and furniture. Figure 21 shows how an additional wedge is cut; this is one of the processes when creating a positive fitting. Figure 22 shows how to use the rope when connecting to save the connector instead of using wedges.

Positive Fitting connection creates a beautiful view of the bamboo in the design. The connection can be combined with other connections, such as plug-in technology, attachment technique. A big plus of compound is that you can reduce the cost of bamboo pillars. In addition, when small gaps are detected on the surface, the assembly can be easily sealed and fixed (Janssen, 2000).

However, it is necessary to consider the connection of two bamboos, when constructing a construction, the diameters of bamboos should be different. In addition, when creating a hole on the bamboo poles, the work of experienced masters is important, as if not working correctly, the strength may decrease and may cause cracking and splitting.

Figure 22: Positive fitting connections, which use rope to keep the connector in place instead of using weed (The Theklians, 2010).

3.2.5 Special construction design

This type of bamboo connection is based on plug – in joint and friction tight rope joint. A special and durable design, very unique and easy to build. An effective and easy way of connecting does not require high skills of working with bamboo.

Figure 23: How to make the plug-in connector (BambuBuild, 2016)

This "sandwich" design does not require a structural frame and does not request special tools, only the bolt and nuts. The posts are connected to each other, three bamboos are used, four postures of bamboo are added from the top in the middle, five are used at the bottom, but the number of bamboo can vary depending on the characteristics of the building.

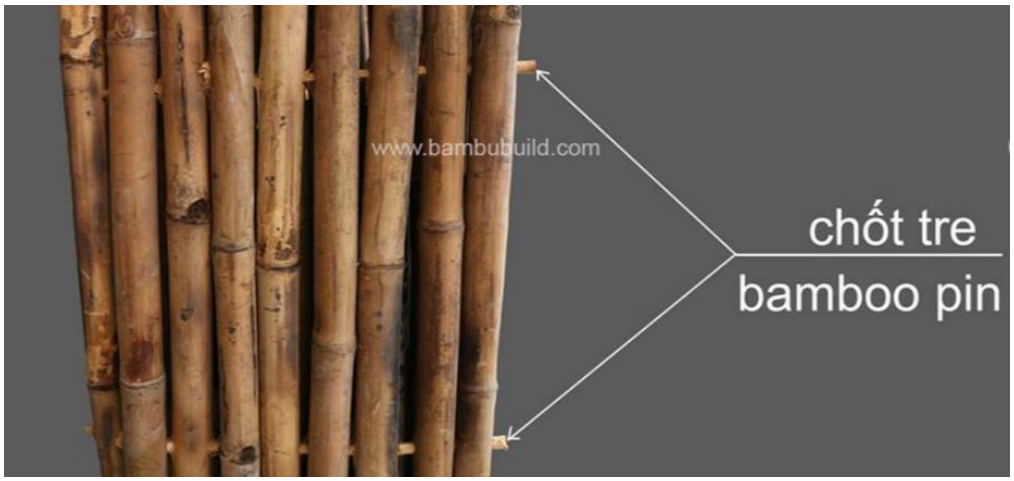


Figure 24: How to make the plug-in connector (BambuBuild, 2016)

(a) Type of bamboo connection

(b) Type of bamboo connection

Figure 25: How to make the plug-in connector (BambuBuild, 2016)

3.2.6 Interlocking Connection

Bamboo poles and around them are usually glued and joined by blocking compounds. Interlocking connections can be made through a wood, metal anchor technique. Figure 26 shows the junction of six bamboo poles directed in different directions, made in metal anchor technology (Janssen, 2000).

Figure 26: Interlocking connection with metal anchor technique (Socrates, 2012)

In blocking compounds, it is very often possible to find a connection with a wood core. For interior decoration of the wood, different parts can be used that do not violate the requirements, glue can be used to attach it to the inner surface of the bamboo. During the installation of the wooden cylinder, two slots must be present to track the cracking in the bamboo cane. Figure 26 shows how a bolt, a metal ring and a wooden cane are connected together.

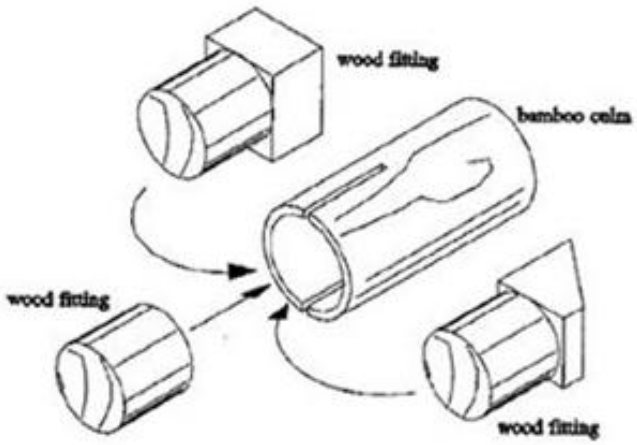


Figure 27: Possible inner parts (wood cane) (Socrates, 2012)

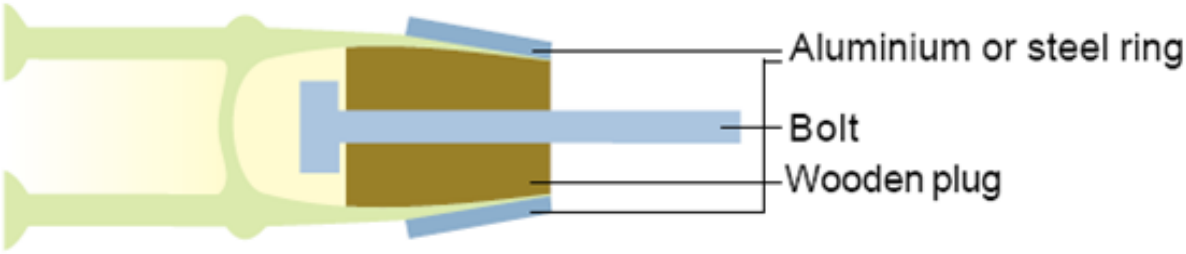


Figure 28: Combination connection (Janssen, 2000)

Pros:

1. This connection can be used in several cases.
2. To make it more durable, use a metal compound.
3. No need for nail support when operating a wooden core or other additional means.
4. Controlled by metal anchors.

Cons:

1. Additional materials will require more money.
2. It is important to have special equipment and experience.
3. It is difficult to seal.

3.3 Bamboo structure

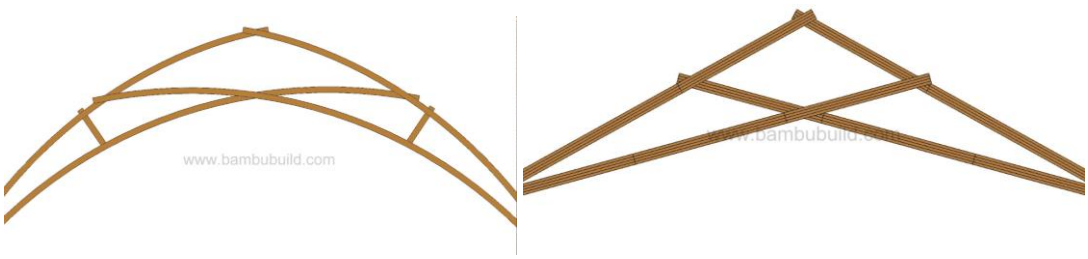
Bamboo truss construction are very similar to the construction of wood. The difference consists only in connections. This construction is very important, because when using bamboo, the trusses can be used as the main supporting elements, columns and roofs.

3.3.1 Truss structure

Truss construction are widely used in modern construction, mainly to cover large spans in order to reduce the consumption of materials used and to facilitate the construction, for example - in building large-span constructions, such as bridges, rafters of industrial buildings, sports facilities, as well as the construction of small lightweight building and decorative constructions: pavilions, stage constructions, awnings and podiums. People use truss construction for roof.

(a) Type of truss construction (b) View of truss construction in building

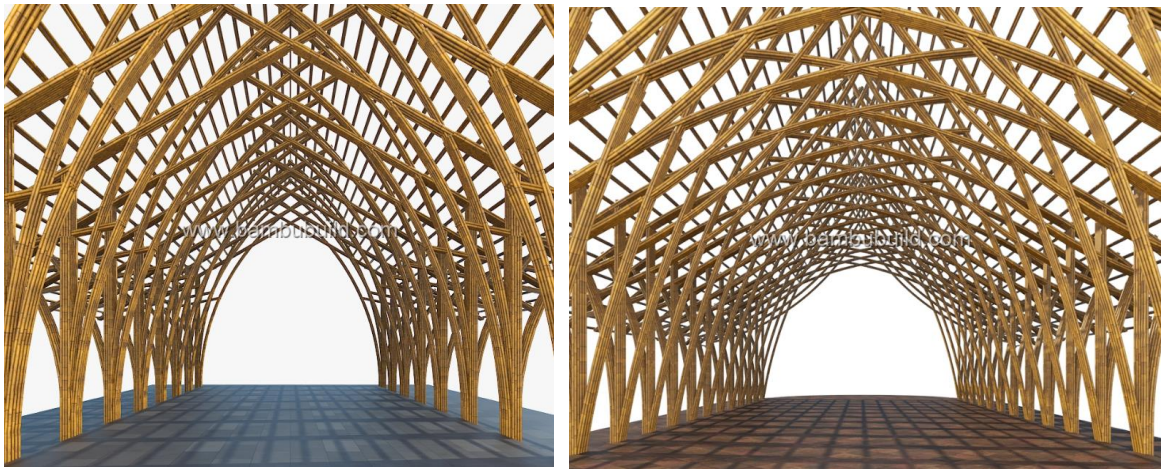
Figure 29: Truss construction for roof (BambuBuild, 2016)



(a) Type of truss construction (b) Type of truss construction

Figure 30: Different types of roof construction (BambuBuild, 2016)

3.3.2 Portal frame structure



(a) Type of portal frame structure (b) Type of portal frame structure

Figure 31: Portal frame structure (BambuBuild, 2016)

(a) Upper view of truss construction (b) Lower view of truss construction

Figure 32: Bamboo pavilion "The Asian Everyday: Possibilities in the Shifting World" at TOTO GALLERY MA (VTN Architects, 2015)

Pavilion consisting of three elements: portal frame structure, grid structure and box elements. The intersection of two grids creates a loudness. Eleven portal frames are inserted into the

grid to create an open space for walks through the pavilion. Thirty boxes have been installed to harden the entire structure.

3.3.3 Grid and Hybrid structure

Figure 33: Grid structure (BambuBuild, 2016)

Figure 34: Hybrid structure (BambuBuild, 2016)

Figure 35: Eco-resort Pavilion in La Vong, Hanoi, Vietnam, by VTN Architects. (VTN Architects, 2016)

Eco-resort Pavilion in La Vong, Hanoi it is 38 prefabricated bamboo arches were installed in a 22-meter-diameter circular form, aligned concentrically around the center axis. Combination of hybrid structure with grid and using several types of connection.

For architects, who are working with bamboo, they do not stop on one structure if it comes to this material. Bamboo material for which architects create a structure that may not exist; the material gives the right to implement ideas that go beyond the ordinary.

3.4 Foundation

Bamboo is a material that is used for building above the ground, since there is a possibility that the bamboo will germinate underground. However, if you observe certain significant rules and do not put bamboo on the straight to the ground, then the use of bamboo as a foundation material is possible.

Bamboo's several regulations for foundation:

- Bamboo and soil should not come in contact there is a risk that bamboo can take root,
- The plinth in which the bamboo is installed should exceed 350 mm above the ground water or above the hot water line (Krawczuk, 2013),
- Diameter of bamboo should not exceed 70 mm (Krawczuk, 2013),
- If post it exceeds three permissible meters, then connecting beams should support the column.

3.4.1 Foundation plinth

Before using bamboo, it must be treated with tare or creosote, for additional protection. The depth of the pits to establish the bamboo should be 300 mm and a diameter of 100 mm, but if the diameter of the bamboo is greater than 100 mm, the pit size need to change. After installing the culm in the pit, the spaces between the walls of bamboo and cement should be filled with sand (Krawczuk, 2013).

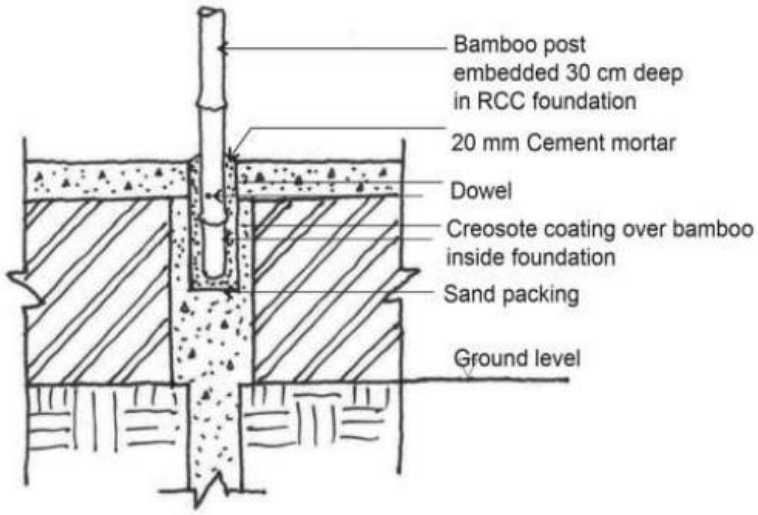


Figure 36: Fixing detail of bamboo post into plinth masonry (Krawczuk, 2013)

Figure 37: Filling the space between the walls of bamboo and cement with sand (Krawczuk, 2013)

3.4.2 Foundation plinth with anchor bolts

Bamboo and foundation are fixed with bolts and steel brackets and anchor bolts.

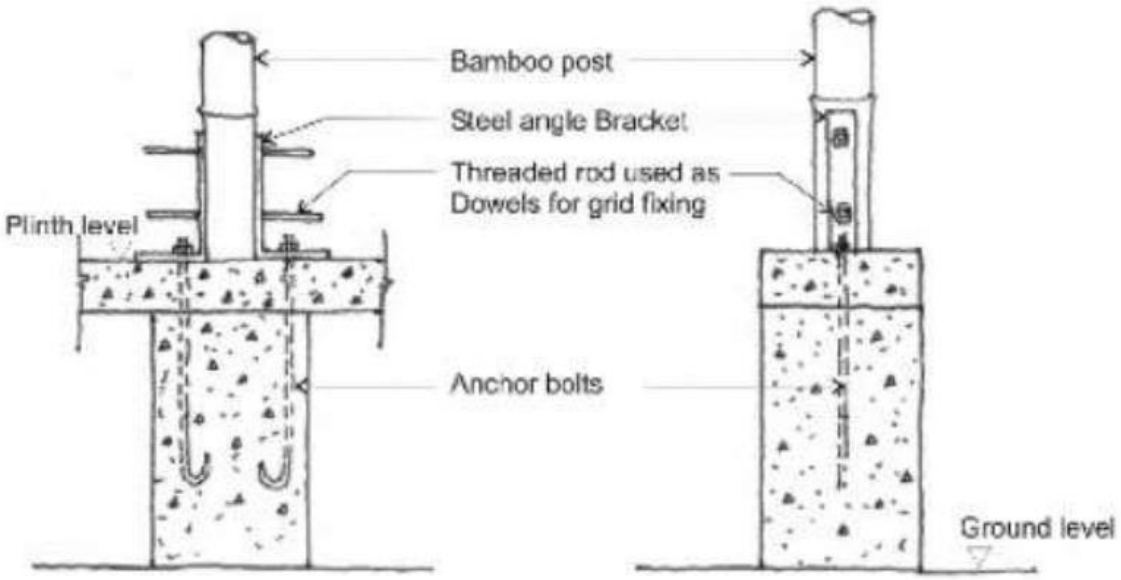


Figure 38: Fixing detail of bamboo to plinth using bolted connection (Krawczuk, 2013)

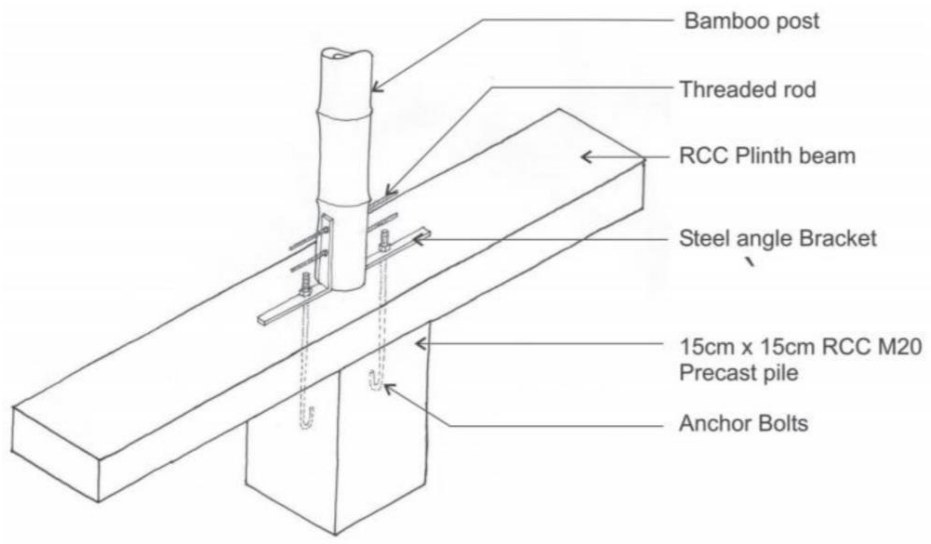


Figure 39: Fixing detail of bamboo to plinth using anchor bolts (Community Architects Network, 2013)

Figure 40: Fixing detail of bamboo to plinth using anchor bolts **(**Estudio Damgo, 2013)

3.5 Wall

The wall is a vertical enclosing structure that separates the room from the surrounding space or adjacent room. People in search of comfort, increasing mood and looking for a cozy atmosphere are beginning to turn to environmentally friendly materials - Bamboo was no exception.

3.5.1 Whole or halved bamboo

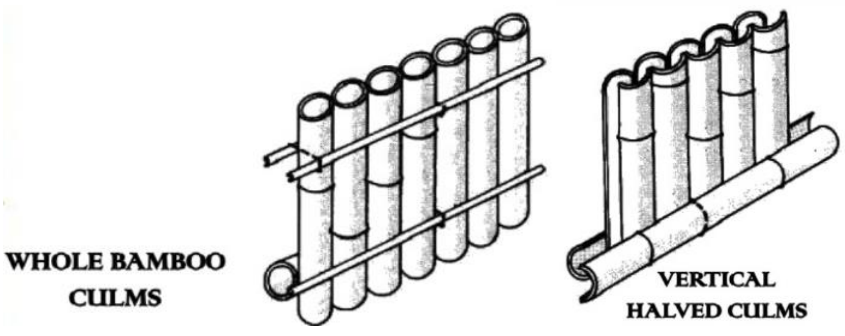


Figure 41: Whole bamboo culms and vertical halved culms (Choudhari, Kolamkar, 2012)

Figure 42: Wall for outside shower (Bees and Roses, 2016)

For frequent installation of vertical beams, as this contributes to the resistance of the shear of the beams. Beams can be install directly into the ground using floorboards or without.

3.5.2 Split or Flattened Bamboo

Figure 43: Split Bamboo (Mr.East, 2017)

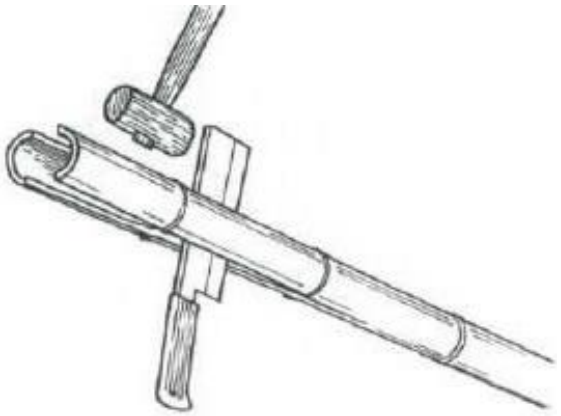


Figure 44: How to split bamboo (Guadua Bamboo, 2007-2017)

Begin to separate bamboo from the thin end. By hitting the hammer on the blade, you need to separate the reed. The splitting line will leave the center to prevent it. It is necessary to keep the expanded part of the cane by pressing it, and the smaller part to pull down. Be sure to check the thickness of the upper and lower parts, the thin part always points downwards.

Remember, bamboo has two different sides; straight side and curved side.

Figure 45: Flattened bamboo (Guadua Bamboo, 2007-20017)

By dividing the green bamboo stems into parts without breaking them into pieces, afterwards the diaphragms are removed, then unfold the bamboo and smooth it. The result is a board that is laid on the beams and fixed with nails or tied.

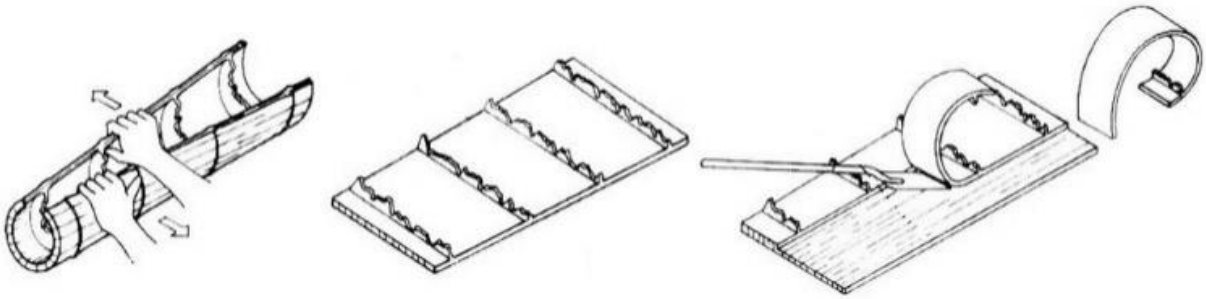


Figure 46: How to flatten bamboo poles (Guadua Bamboo, 2007-2017)

3.4.3 Bajareque

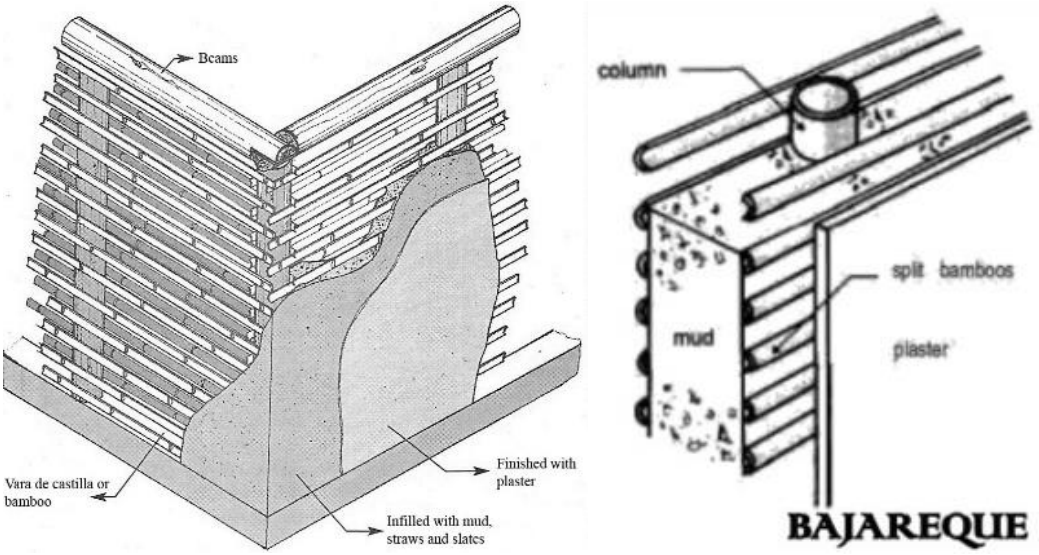


Figure 47: Bajareque (Choudhari, Kolamkar, 2012)

A strong and massive construction is often used in Latin America. Horizontal bamboo strips, connected together or nailed, covered with mud and stones, thereby filling the free space.

3.5.4 Wattle bamboo

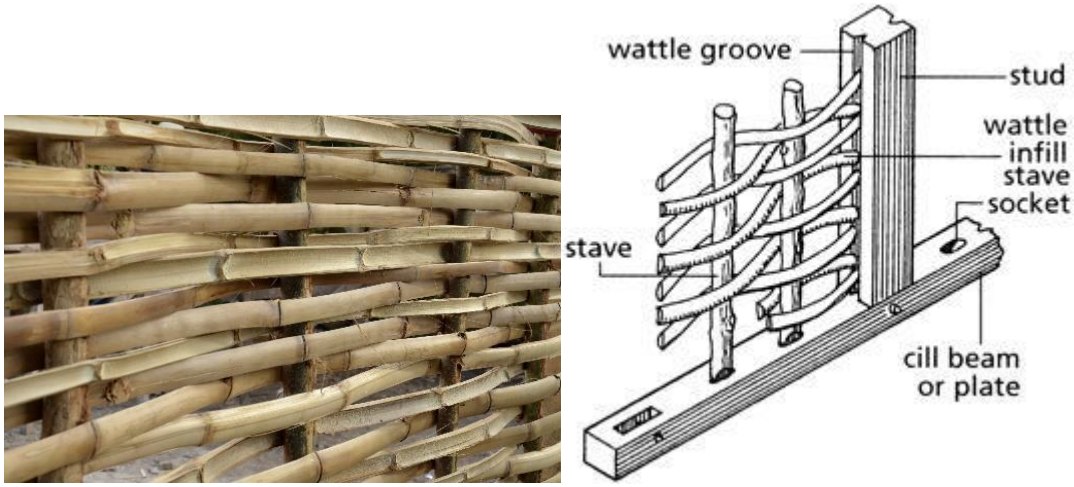


Figure 48: Wattle bamboo (Choudhari, Kolamkar, 2012)

Thick panels of bamboo strips are intertwined around the bearing beam of bamboo. It is commonly used in India, Peru and Chile.

3.5.5 Woven bamboo

The technique is similar to wattle bamboo, but the bamboo strips are denser to each other, this technique does not require external additional coating.

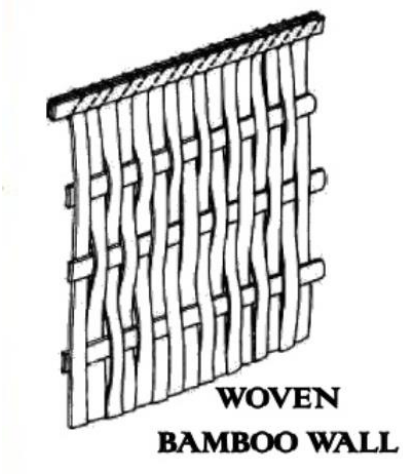


Figure 49: Woven bamboo wall (Choudhari, Kolamkar, 2012)

3.6 Roof

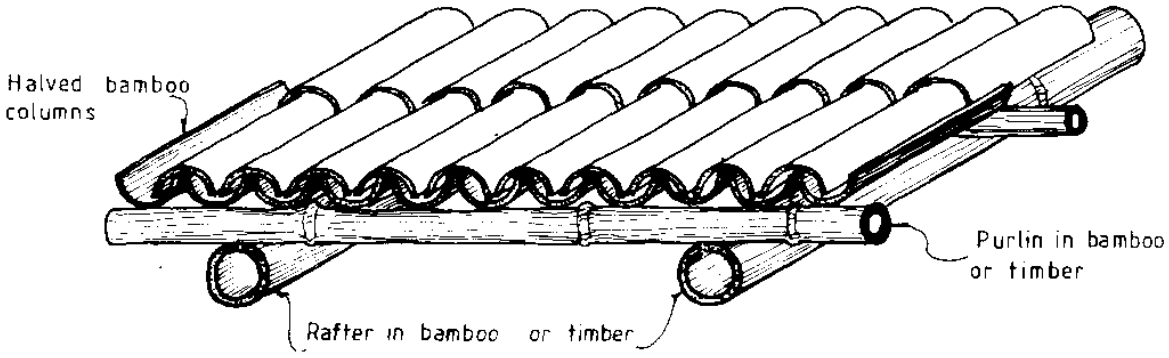


Figure 50: Roof with halved bamboo culms (Petehathaway, 2010)

Bamboo processing for construction

One of the best roofing methods of using bamboo is one that uses prefabricated bamboo farms, as well as bamboo boards. Farms are usually built in the form of a triangle, which gives the roof a completely different look than most western styles of houses. Sometimes bamboo is used with a coating of astringent materials after the construction is completed. This not only helps protect bamboo fibers, but also helps to create fireproof structures. Clay tiles can be placed in the upper part of the roof to prevent moisture penetration.When used as a building material, bamboo must be processed to prevent it from rotting or infecting insects. Although there are many different ways of preparing bamboo, the simplest and most effective is to simply allow it to air dry in an upright position. After the bamboo has been dried, a combination of chemicals is selected, for example, boric acid and borax for its processing. The entire process can take several months, but in the end, bamboo can be used in construction (Bengtsson and Whitaker, 2010).

The disadvantages of using bamboo for a roofing device. Unlike traditional wooden roofs, bamboo roofing can be quite expensive compared to other types of roofs. Bamboo is environmentally friendly and sustainable, but requires care and money investment. Although roofing bamboo can often be found on roofs in the traditionally western type of roof, it is mainly used when used with a triangular truss. If the appearance of the triangular roof does

not satisfy you, you can always choose your own version. Investing in the bamboo roof structure is a big deal. For confidence in the right choice, consider all the pros and cons associated with the material, its stability and its durability in your particular area (Bengtsson and Whitaker, 2010).

3.7 Bamboo reinforcement

Researchers from the BRE Centre of the University of Innovative Building Materials, in collaboration with a team from Coventry University and the University of Cambridge, are studying the use of bamboo for mass housing construction.

The research team develops an understanding of the properties and structure of bamboo fibers, in order to reduce its weaknesses, while retaining its unique mechanical properties. "As part of this project, we explored various options for obtaining high building strength composites, including combining bamboo fibers with bio-polymer materials or strengthening bamboo with other fiber composites." The first publication, a research project was published in 'Low Carbon' Building of Bamboo Guadua, 2016.

The design concept has undergone serious changes, boldly violating the traditional notions of form. With the help of the computer-aided design system, which carries out the most complicated computing functions, it became possible to exercise much more freedom in creating the project. After the constructive solutions of the structures have overcome the established architectural patterns of the past, the original designs have undoubtedly found their vivid embodiment in modern buildings of bamboo and interior spaces of their premises. At the World Architecture Festival in 2016, scientist Dirk Hebel presented bamboo fiber as a more solid and cheaper alternative to steel.

Figure 51: Scientist Dirk Hebel presented bamboo fiber as a more solid and cheaper alternative to steel. (Hebel,2016)

The team, led by a German architect from the Zurich Institute of Technology (ETH Zurich), is working on a composite material based on bamboo fiber with the addition of organic resins, which in the future can change the technology of reinforced concrete construction. From the new material, you can do any forms. For example, as twigs, it can replace the reinforcing mesh without any loss in bearing capacity. At the same time, such a bamboo composite works better for stretching but weighs four times less.

Now, together with the University of Berkeley, the scientist is developing a new concrete, where instead of cement, a material based on mycelium (mycelium) would be used.

The scientific laboratory from Singapore Future Cities Laboratory suggested using simple bamboo instead of reinforcement.

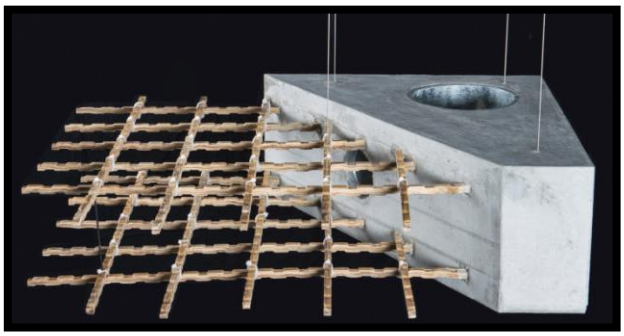


Figure 52: Bamboo Reinforced Concrete" / Future Cities Laboratory**,** Singapore / ETH Zurich (Hebel,2016)

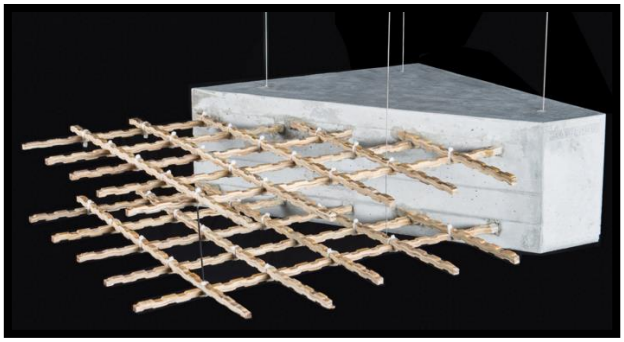


Figure 53: Bamboo Reinforced Concrete" / Future Cities Laboratory, Singapore / ETH Zurich (Hebel,2016)

In developing countries, steel reinforcement is very in demand. During the experiments, bamboo has outstripped the strength of many materials - including steel reinforcement. This stability is provided by the tubular structure of the bamboo stems, formed during the evolution under the influence of winds. Another undoubted advantage of bamboo is its low weight - it is easy to assemble and transport. In addition, the cultivation of bamboo as a building material will positively affect the environment - during growth, it absorbs a large amount of carbon dioxide.

3.8 Other building elements

3.8.1 Door

Figure 54: Sliding door (izbambuka, 2018)

From bamboo, processed by special technologies, door leaves are manufactured, which are produced as one-piece, and with inserts of glass, mosaic and pieces of mirrors. The resulting products will be an excellent element of finishing the room in the popular recently "Chinese" and "Japanese" styles.

It is possible to color this natural material in different colors - from light to dark. The surface of the canvas is varnished, giving them a shine. These products, thanks to processing by modern technology, perfectly withstand temperature changes, high humidity and exposure to sunlight. Modern industry allows you to make of banal bamboo stylish and high-quality door leaves, which look great and do not require special care (izbambuka, 2018).

Figure 55: Doors (izbambuka, 2018)

Another advantage of such products is their low price. Such an original door can afford almost every buyer, buying a little affordable exotics.

Do not think that such lightweight and airy structures have a low resistance to burglary. In fact, bamboo is not inferior in strength to metal, and it is very difficult to crack such a door structure. "Sheathing" is made of strips of glued bamboo, laid on the fabric base, which gives them high wear resistance (izbambuka, 2018).

The basis for such door panels is made of strong steel, treated with an anti-corrosion compound. This allows similar products to withstand heavy loads and exposure to adverse weather conditions.

Bamboo doors of the “accordion”

Bamboo “accordion” gives the room a distinctive ethnic style, creating the effect of "mats", which are used in the countries of Indochina instead of the usual doors (izbambuka, 2018).

Figure 56: Bamboo “accordion” door (izbambuka, 2018)

Light and at the same time strong "harmonies" made of bamboo perfectly help to distinguish the rooms of any rooms, while serving as a kind of exotic element of decoration. On the surface of such structures are often painted and various elements of decoration, which gives them a unique charm. Especially effectively, such "door-mats" look when decorating dachas and country houses (izbambuka, 2018).

3.8.2 Bamboo as solar shading devices

External shading devices for windows are effective cooling measures, since they block both direct and indirect sunlight from outside. The shading screen is a dense weave that blocks up to 70% of all sunlight. With the proper use of mobile shading devices, you can gain advantages in the use of energy. In the daytime, the shading device is kept in the open state in winter; it does not reduce the supply of radiation energy in the room. In winter, at night, when closed, lowers the heat transfer coefficient, i.e., heat loss, and in summer it protects the room from overheating. Such screens absorb sunlight, so they should be installed from the outside of the window (Megaobuchalka, 2015).

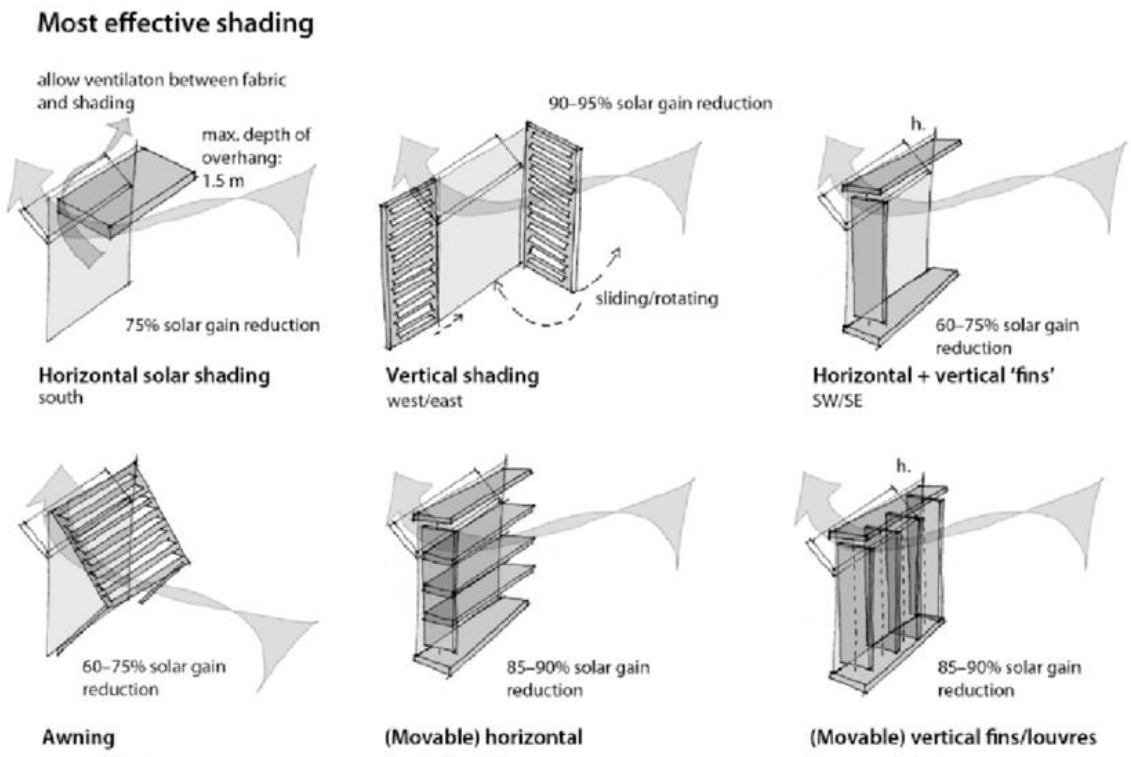


Figure 57: Types of most effective shading (Pelsmakers, 2012)

For example: Bamboo Passive House made by Karawitz architects in 2009, Bessancourt, France. This project was noted as the best performance of low consumption of a house in France and the first house in the Paris region to receive the European certification of PHI "Passiv Haus Institut" (ArchDaily, 2010).

Bamboo covers the windows in the North and continues to the roof. Identical blinds that close large windows with a picture in the south create light and shadow during the day or night. Also on the roof you can see photovoltaic panels (ArchDaily, 2010).

Figure 58: Bamboo Passive House (Photographs: Abbadie and Karawitz, 2009)

(a) Front view

(b) Close view to covers

Figure 59: Bamboo Passive House, close view to covers (Photographs: Abbadie and Karawitz, 2009)

Another example of building: Bamboo Housing in Carabanchel by Foreign Office Architects (FOA). One of the biggest social housing projects in Europe, 2007.

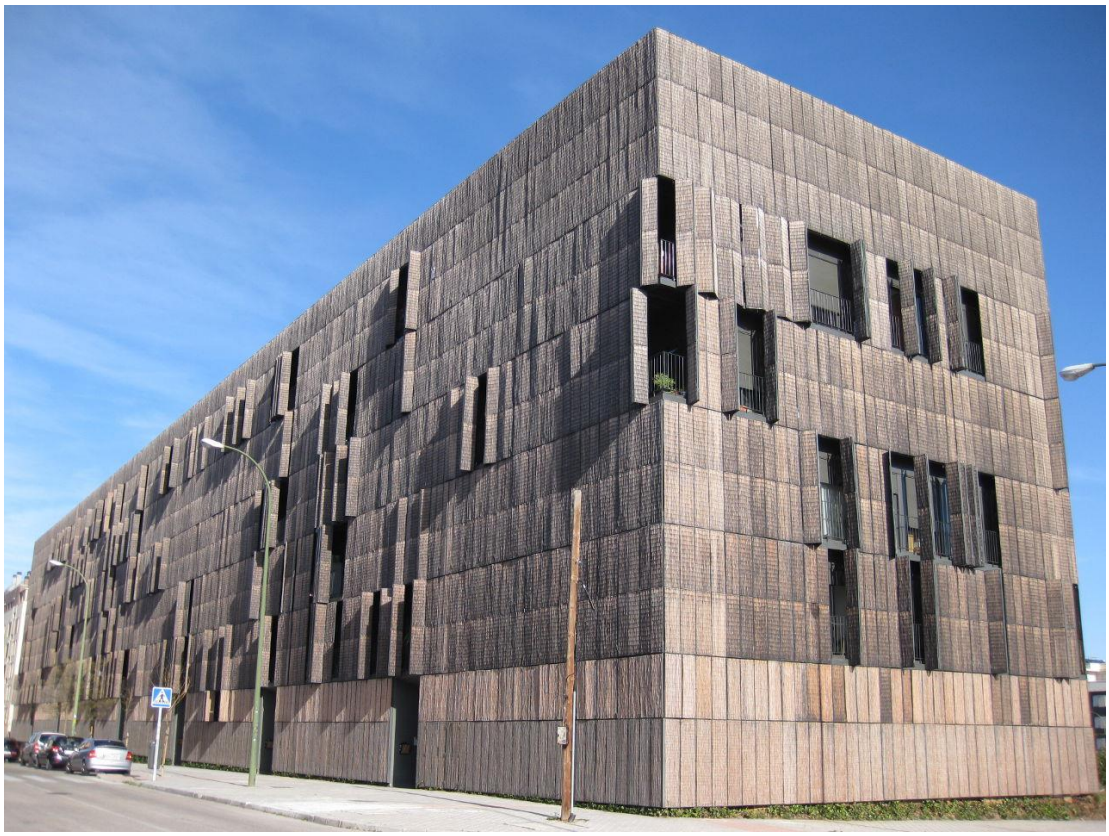
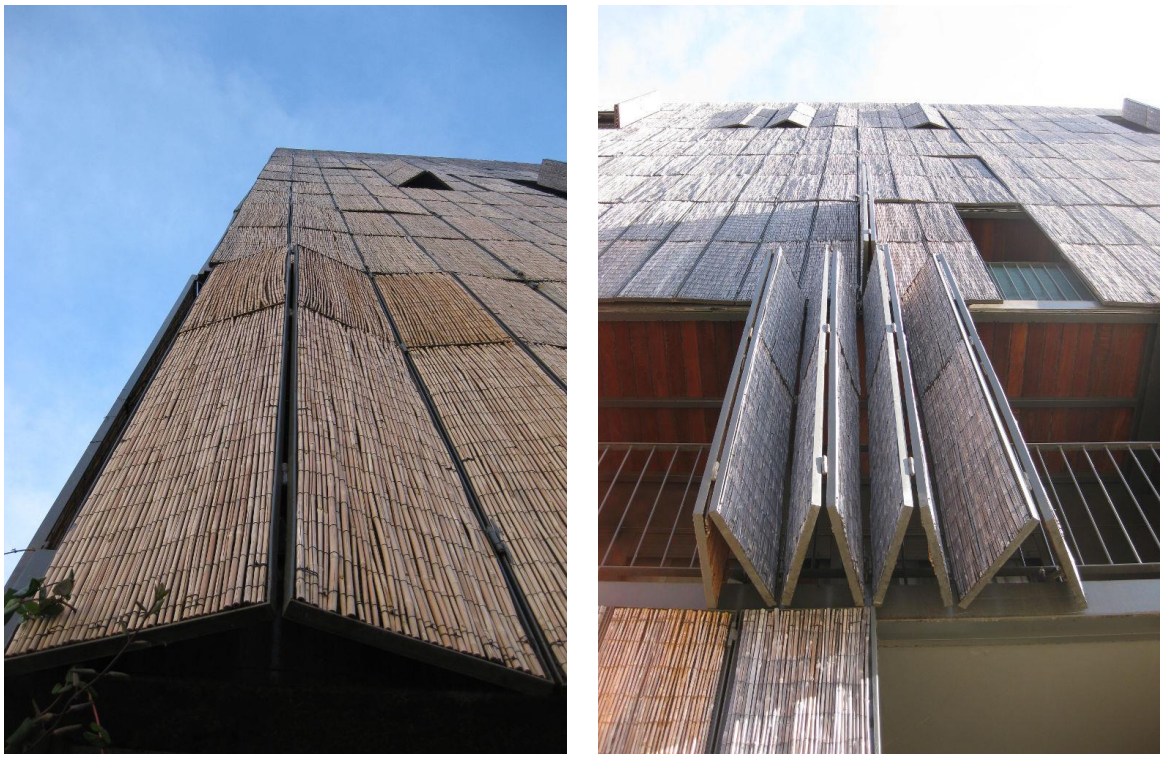


Figure 60: Bamboo Housing in Carabanchel (Jewell,2011)

This is a five-story residential building, covered with bamboo bars. The building itself does not consist of bamboo, but the first thing that rushes to the eye is bamboo. The purpose of this project was to offer inexpensive residences with the maximum amount of space and quality, as well as providing a facade that predicts the uniformity provided by bamboo blinds. They cover the whole structure, but with individual desire it is possible to push back the blinds, providing the ability of everyone to open or close the shutters (Jewell, 2011).

Bamboo - it saves energy in all aspects, here bamboo provides insulation in winter and provides a cool during the summer, as the natural canopy allows you to penetrate the light, but protects the interior from the scorching sun and heat. Bamboo is also a soundproof material, which is valuable in a busy city (Jewell, 2011).



(a) Upper view to covers (b) Upper view to moving covers

Figure 61: Bamboo Housing in Carabanchel, details (Jewell, 2011)

3.8.3 Stairs

In countries where bamboo grows, the trunks of this plant are often used to make ladders. The choice in favor of bamboo in the manufacture of stairs is completely justified: such simple designs are very convenient. Even with a long length, they are light enough, and they can be easily carried by one person.

Figure 62: Bamboo simple stair (bamboopro, 2010-2018)

According to the planned width of the stairs, the third bamboo is cut (the trunk is cut to the appropriate lengths). Next, take a long bamboo, in the trunk of which make holes. At the same time, the diameter of the holes must be such that they include previously cut pieces of bamboo stem. Holes can be made with one (internal) or two sides of bamboo (the trunk is cut through). If the holes are made only from the inside, the transverse sections of bamboo into the trunk are pushed to the stop so that it touches the opposite side of the support. Fasten the steps in any convenient way, for example, cutting bamboo to the trunk can be glued with a suitable glue for bamboo. In order not to allow the vertical stands of bamboo to disperse under load, the trunks in the top, bottom and middle should be tightened with threaded studs. In order not to spoil the appearance of the ladder and not to make extra holes in the bamboo, the trunks are pulled together by pins, passing them inside the transverse segments (bamboopro, 2010-2018).

3.8.4 Fence

Bamboo can be used as a frame for a balcony or a loggia, and it can also serve as a decoration for entering the house. And this is made possible by the fact that the bamboo has lush foliage, which makes it possible to create rapidly growing walls and a clever background for landscape compositions.

Figure 63: Bamboo fencing (ArtDecor, 2017)

3.8.5 Bamboo on construction sites

Builders work with some tools and devices made of bamboo. These are ladders, scaffolding, and supports (for example, for horizontal formwork).

Because of the relatively high cost of bamboo in the temperate countries in this capacity, it can be used where a small amount of material is required, for example in short ladders in the

backyard. Such a ladder with a sufficient diameter of the trunks will come out strong and light, which is important in its frequent transfers. You can also make an overhead staircase on the roof during its repair. It will also be easy to move it (Cancela, 2015).

(a) View of construction sites (b) View of construction sites

Figure 64: Bamboo for construction sites in Hong Kong (Cancela, 2015)

CHAPTER FOUR
USE OF BAMBOO

4.1 Examination of the Case Studies

Tables show an information about the buildings made of bamboo, the details of the performance tell about techniques that people use to this day. There are constructions that architects receive by mixing several joints and techniques.

Tables are based on the buildings type and type of structures, in search of various architecture of bamboo and various methods of building buildings, what kinds of buildings can be built with bamboo and what climate is needed for bamboo and what methods of construction are laid in the building.

4.1.1 Examination of the Children's Activity and Learning center

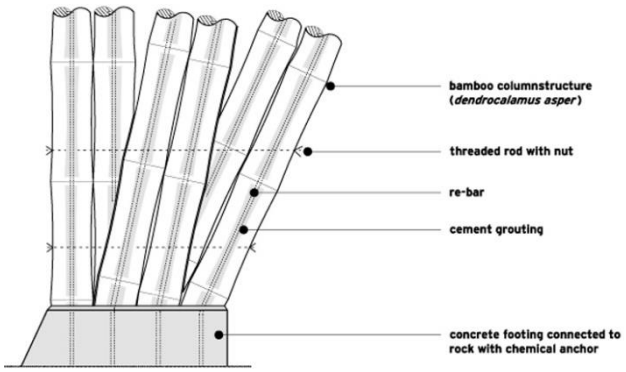
Table 4.1.1: Children's Activity and Learning Center

Name of the building	Children's Activity and Learning Center

Figure 65: Children's Activity and Learning center, night view
(Photo by Kiattipong Panchee and Boris Zeisser)

Location	Soneva Kiri Resort, Island of Koh Koodin, Thailand
Architect	24H-architecture
Year of construction	2008-2009
Type of bamboo	Bambusa Multiplex Dendrocalamus Asper
In witch climate	Tropical monsoon climate with little variation in temperature throughout the year

Construction of foundation



(a) Bamboo column structure

(b) View to Bamboo column

Figure 66: Bamboo columns anchor the structure and its view (Photos by Kiattipong Panchee and Boris Zeisser)

Construction of column

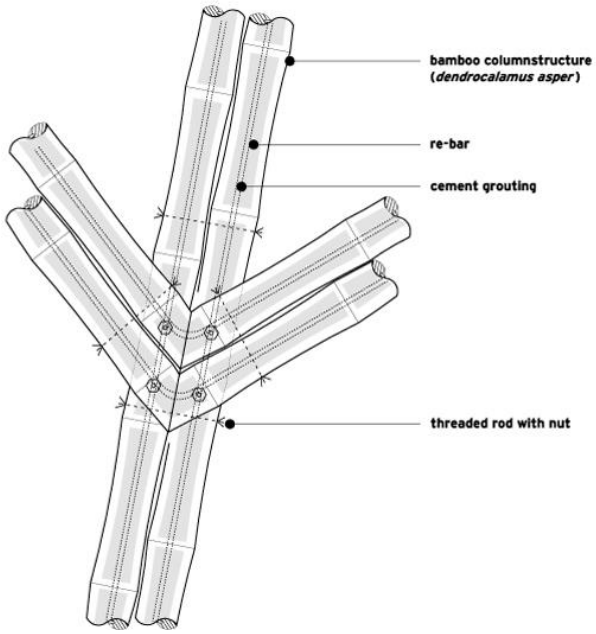


Figure 67: Bamboo column structure (Photo by Kiattipong Panchee and Boris Zeisser)

Construction of joints

Figure 68: Grouped members create flexible composite beams (Photo by Kiattipong Panchee and Boris Zeisser)

Figure 69: Pinned together with nut, bolt and washer (Photo by Kiattipong Panchee and Boris Zeisser)

Construction of roof

Figure 70: Split bamboo on top of roof (Photo by Kiattipong Panchee and Boris Zeisser)

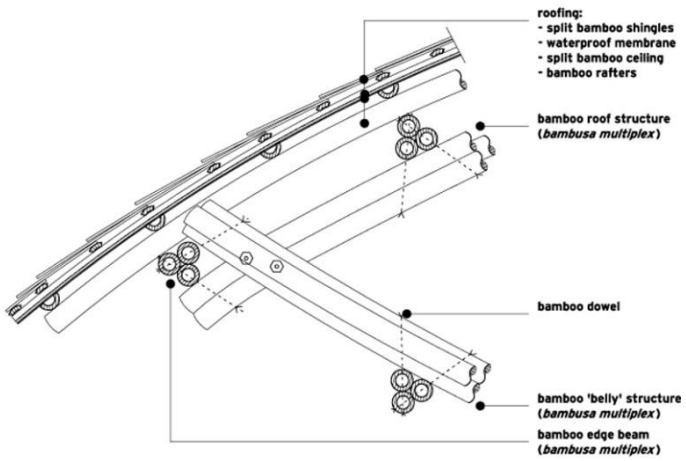


Figure 71: Roof, construction part (Photo by Kiattipong Panchee and Boris Zeisser)

Education Centre provides an Auditorium / Cinema for films, lectures and plays, a library with books on permaculture and local traditions, an Art room, a Music room and a Fashion room, thus giving children both creative and ecological education while playing.

The design adopts all bioclimatic aspects to suits it's humid tropical environment. The roof cantilevers up to 8m acting like a big umbrella providing shade and protection from the heavy rains. The open design with the translucent elevated rooftop and setback floors allow a natural airflow inside and the use of natural daylight, limiting the building's energy consumption.

Figure 72: Children's Activity and Learning center, design inside of center (Photo by Kiattipong Panchee and Boris Zeisser)

4.1.2 Examination of the Sharma Springs Residence

Table 4.1.2: Sharma Springs Residence

Name of the building	Sharma Springs Residence  **Figure 73:** Sharma Springs Residence, facade view (Photo by Rio Helmi)
Location	Sibang Gede, Abiansemal, Badung Regency, Bali, Indonesia
Architect	IBUKU Bamboo Engineer AsharSaputra, PhD
Year of construction	2012
Area	750.0 m2

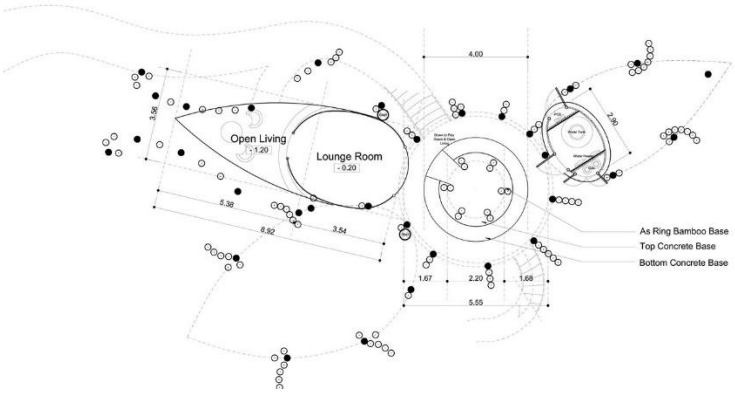
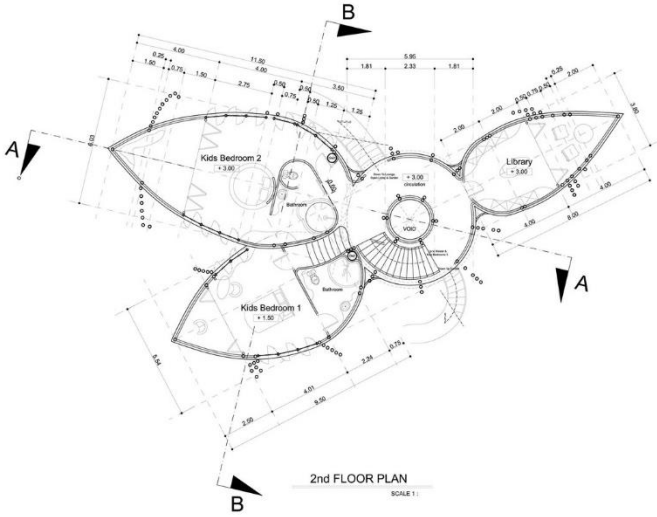


Figure 74: Plan of first floor (ArchDaily, 2012)



Construction

Figure 75: Plan of second floor (ArchDaily, 2012)

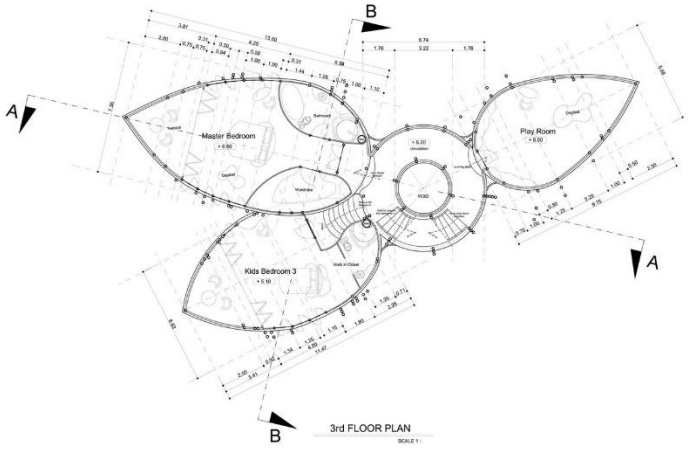


Figure 76: Plan of third floor (ArchDaily, 2012)

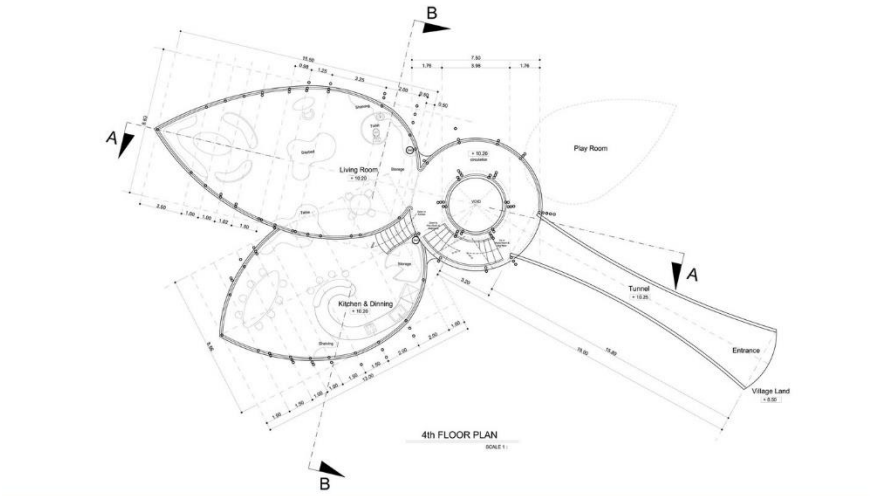


Figure 77: Plan of 4th floor (ArchDaily, 2012)

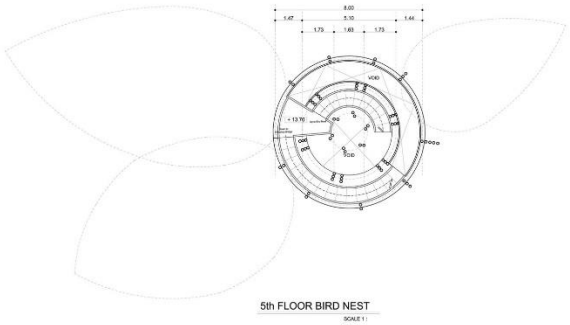


Figure 78: Plan of 5th floor (ArchDaily, 2012)

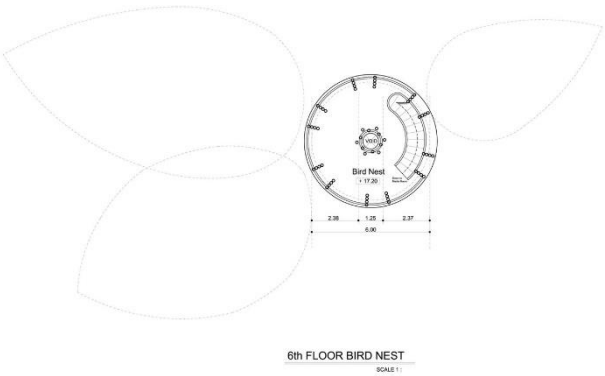


Figure 79: Plan of 6th floor (ArchDaily, 2012)

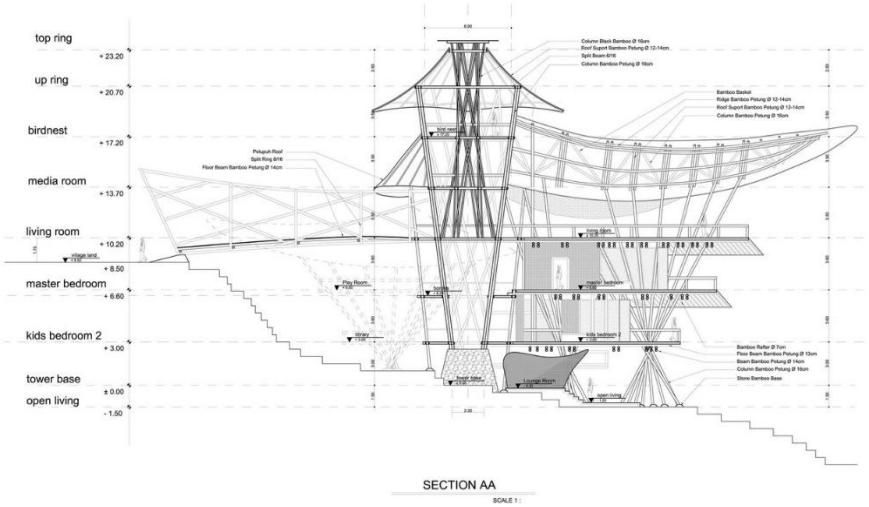


Figure 80: All details IBUKU made by bamboo, 100% bamboo house. (ArchDaily, 2012)

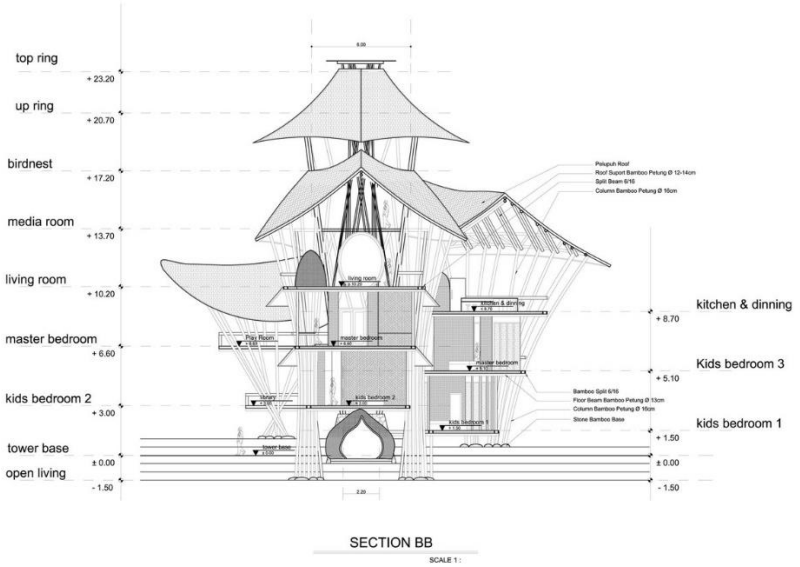


Figure 81: All details IBUKU made by bamboo, 100% bamboo house. (ArchDaily, 2012)

Construction of door	

Figure 82: Doors in Sharma Springs Residence (Photo by Rio Helmi)

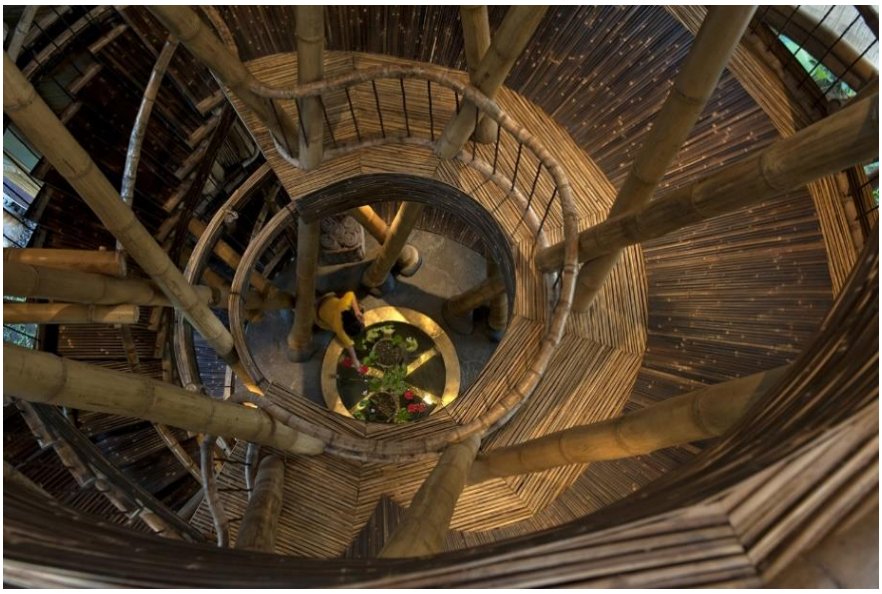


Figure 83: View from third floor to second and first floor (Photo by Rio Helmi)

Each room is equipped with full-sized straight glass windows and doors made of bamboo.

This is a 6-storey house with 4 bedrooms with an area of 750 sq.m. overlooking the valley of the river Ayung built almost entirely of bamboo. Entrance to the house is through a tunnel-bridge, also made of bamboo, which delivers you to living, dining and kitchen facilities in the open air on the 4th level.

(a) View of the living room

(b) View of the entrance group

Figure 84: View of the living room and entrance group (Photo by Rio Helmi)

Stairs are located around the central tower to the lower levels: a games room, four bedrooms, and a library; Full-sized spinning windows and doors do not let stagnate air. On the 6th floor, an observation deck with a stunning sunset over the Ayung river valley and a green village.

4.1.3 Examination of the Bamboo Sports Hall Panyaden International School

Table 4.1.3: Bamboo Sports Hall Panyaden International School

Name of the building	Bamboo Sports Hall Panyaden International School  **Figure 85:** Bamboo Sports Hall Panyaden International School, Entrance view (Photo by Alberto Cosi, Markus Roselieb)
Location	218 Moo 2, Namprae, Hang Dong district, Chiang Mai 50230, Thailand
Architect	Chiangmai Life Construction, Markus Roselieb, Tosapon Sittiwong Engineers: Phuong Nguyen, Esteban Morales Montoya
Year of construction	2017
Area	782 sqm

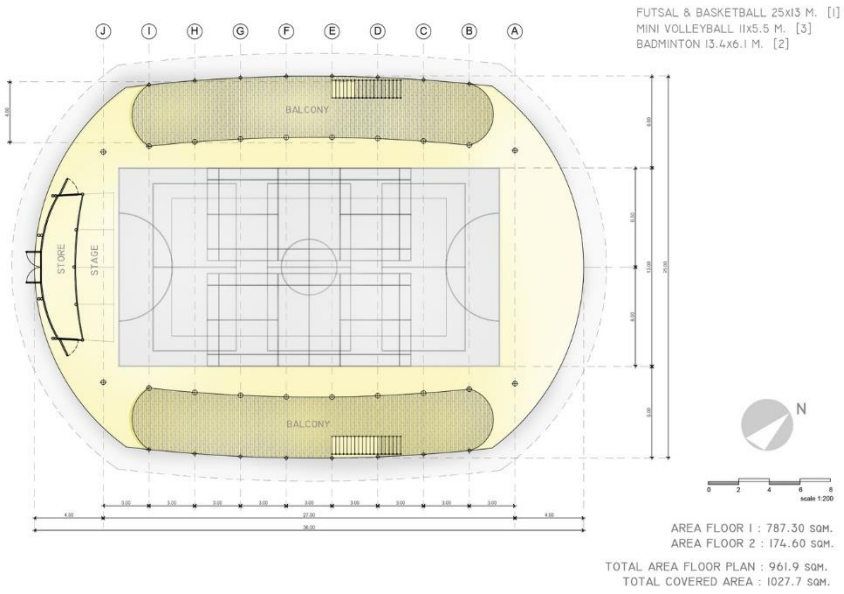


Figure 86: Plan of the sport hall

Type / size of elements

Figure 87: Inside of the sport hall (Photo by Alberto Cosi, Markus Roselieb)

Figure 88: Truss construction, details view (Photo by Alberto Cosi, Markus Roselieb)

Truss construction

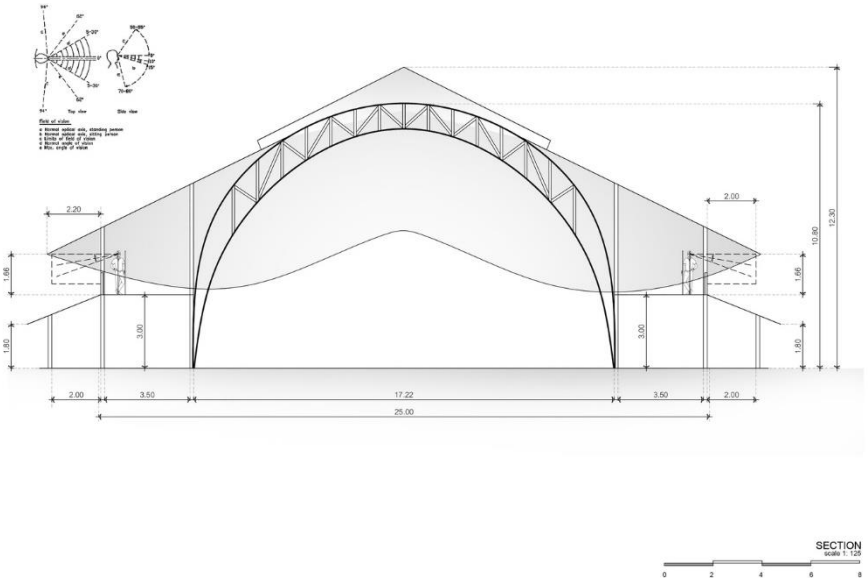


Figure 89: Section of the sport hall

The design of truss construction is based on newly developed prefabricated bamboo farms with a width of more than 17 meters without steel fittings or joints. These trusses were pre-built on site and raised to the site using a crane (Michael, 2017).

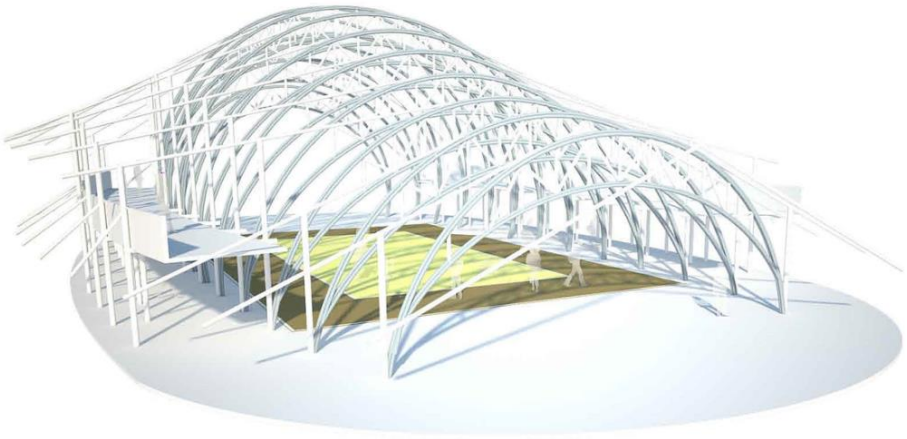


Figure 90: 3D model of sport hall, truss construction (Chiangmai Life Construction, 2017)

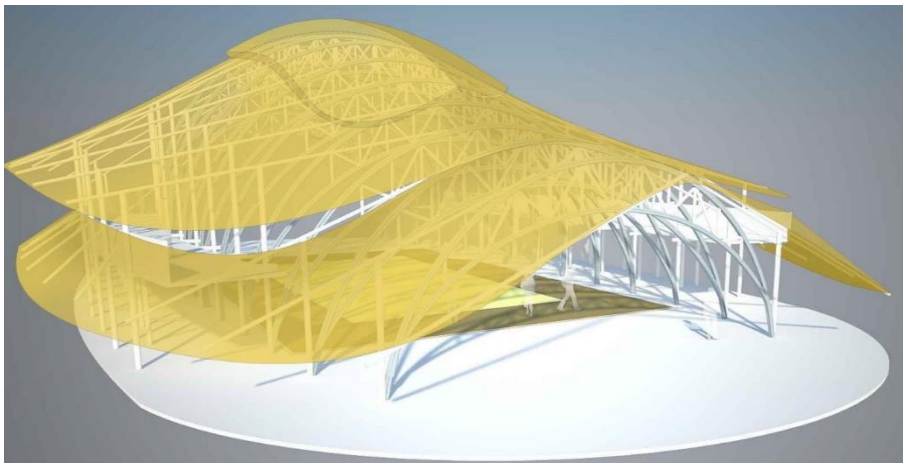


Figure 91: 3D model with roof and truss construction (Chiangmai Life Construction, 2017)

The construction of the entire building starts from the foundation to the roof automatically creating both walls and columns and a roof for the building.(Michael, 2017)

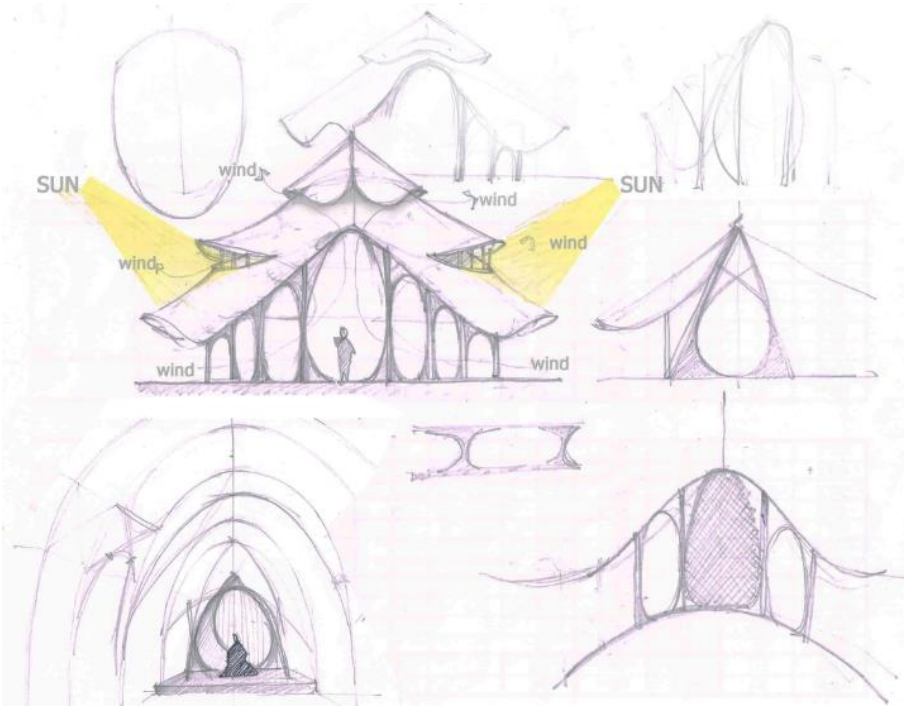


Figure 92: Scetch of sport hall construction (Chiangmai Life Construction, 2017)

A sports facility that accommodates 300 students, while at the same time approaches the natural hilly landscape of this area. There are grounds for basketball, volleyball, football and badminton, as well as a stage that can be removed automatically. On both sides there are balconies that provide space for parents and other visitors to watch sports events or shows (Michael, 2017).

In this area the climate is hot and humid, thanks to the natural ventilation the structure maintains a cool and pleasant climate all year round. High-speed winds, earthquakes and other natural forces will not subject the building to destruction, as it was designed according to modern standards of safety loads, shear forces, etc. Bamboo was treated with borax salt and was not subject to chemical treatment. The life span of the bamboo hall was calculated for at least 50 years (Michael, 2017).

4.1.4 Examination of the Restaurant in the Kontum Indochine Hotel

Table 4.1.4: Restaurant in the Kontum Indochine Hotel

Name of the building	Restaurant in the Kontum Indochine Hotel

Figure 93: Restaurant in the Kontum Indochine Hotel (Photo by Hiroyuki Oki)

Location	Kon Tum Province, Vietnam
Architect	Vo Trong Nghia Architects
Year of construction	2013
Area	551.0 sqm
Type / size of elements	

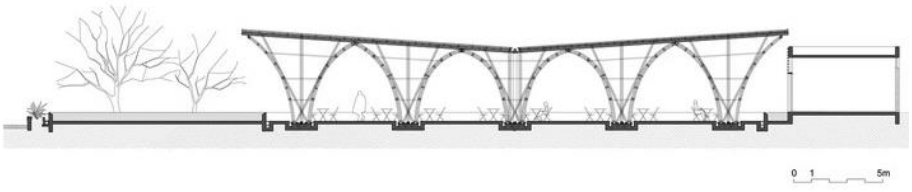


Figure 94: Section Architect in Charge (Vo Trong Nghia, 2013)

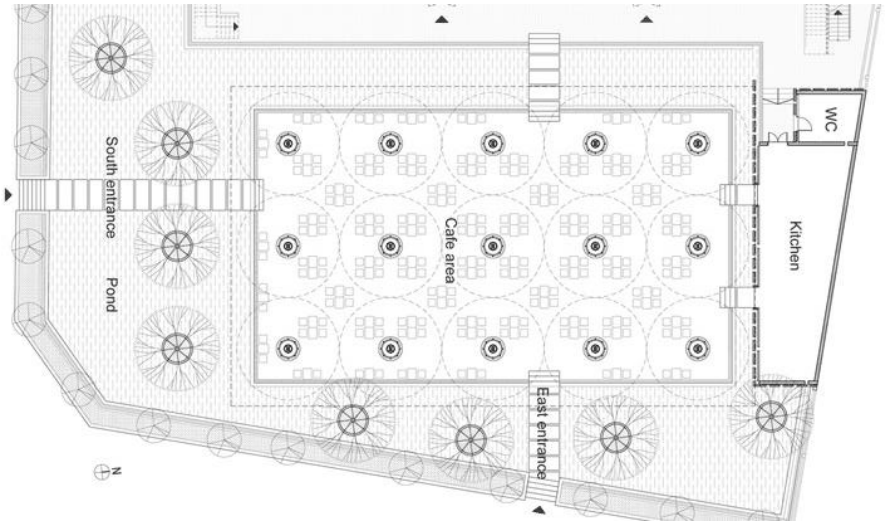


Figure 95: Plan (Vo Trong Nghia, 2013)

Construction of column

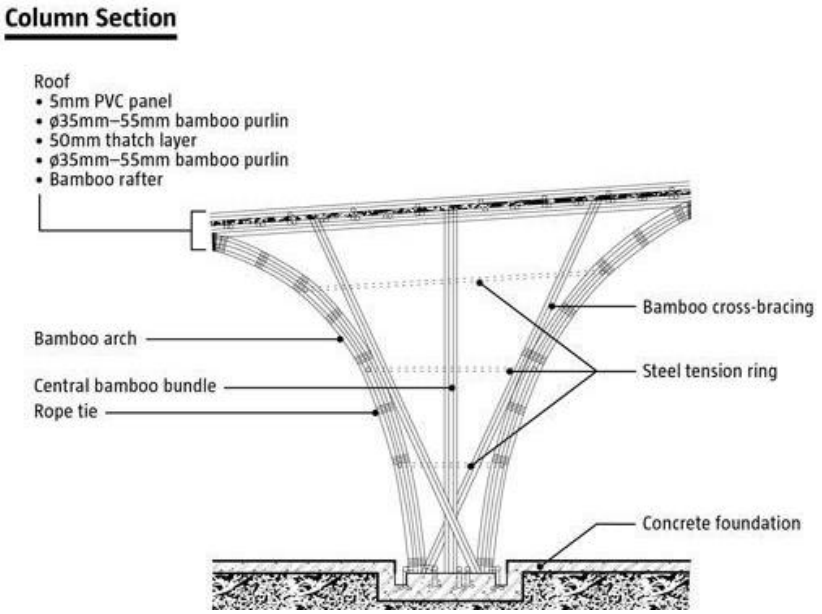


Figure 96: Bamboo roof, which is supported by 15 bamboo columns of conical shape (Vo Trong Nghia, 2013)

Figure 97: Inside view of the restaurant (Photo by Hiroyuki Oki)

The main building of the restaurant is covered with a bamboo roof, which is supported by 15 bamboo columns of conical shape. The reason for the creation of columns of this form was the inspiration of the architect of the Vietnamese basket for fishing, which gradually narrows from top to bottom (Frearson, 2013).

4.1.5 Examination of the Roc Von Restaurant

Table 4.1.5: Roc Von Restaurant

Name of the building	Roc Von Restaurant  **Figure 98:** Front view to Roc Von Restaurant (Photo by Hoang Le Photography)
Location	Xa Phu Cat, Huyen Quoc Oai, Hanoi, Vietnam
Architect	Project Architects: Vo Trong Nghia, Takashi Niwa Bamboo Construction: Vo Trong Nghia Architects
Year of construction	2015
Type of bamboo	Dendrocalamus barbatus, Dendrocalamus strictus
Type / size of elements	For the dining area, 12 columns of bamboo were used, rushing up the supporting roof (ArchDaily, 2018).

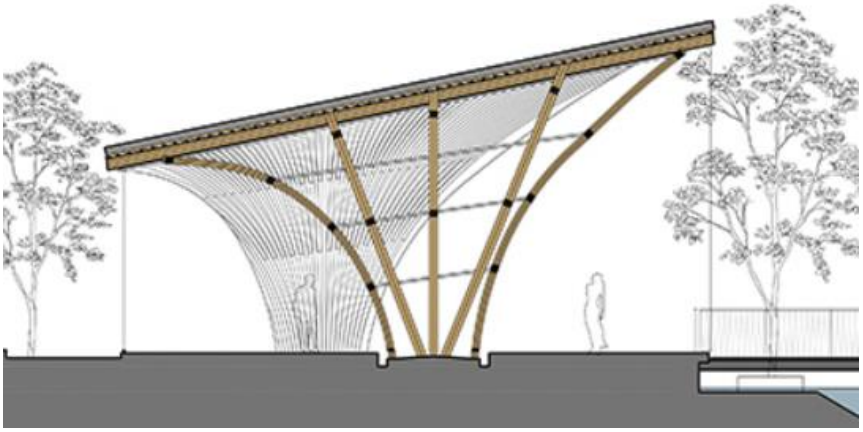


Figure 99: Section of first type column (Takashi Niwa, 2015)

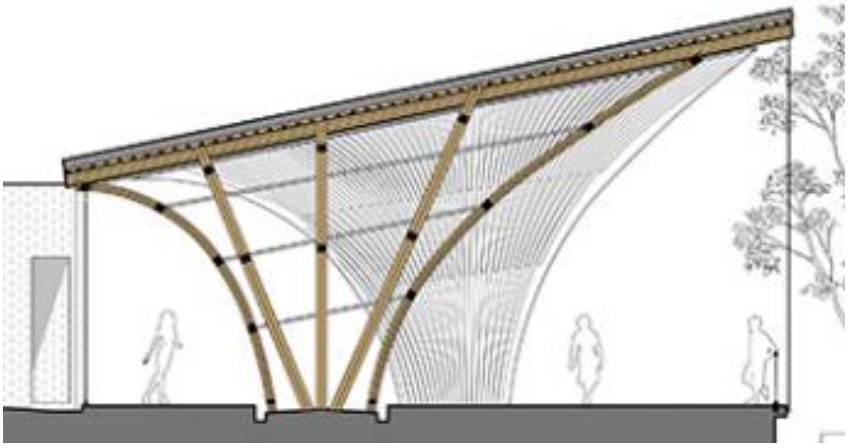


Figure 100: Section of second type of column (Takashi Niwa, 2015)

Figure 101: Joining of two columns (Photo by Hoang Le Photography)

Figure 102: View of three column (Photo by Hoang Le Photography)

The use of natural material in combination with open space creates a connection between restaurant and the culture of North Vietnam.
By evaporation of water from a neighboring lake, the space under the columns is cooled, creating a natural air-conditioning of the restaurant. The reference zone is separated by larenite blocks, which are often used in Thailand (Megson, 2016).

There Tam Vong bamboo (Dendrocalamus strictus) and Luong (Dendrocalamus barbatus) are two kinds of bamboo that were used to erect columns. Both types are important because they carry different, but necessary properties for fastening. For long use and quality, bamboo has been processed according to Vietnamese traditional techniques (ArchDaily, 2018).

4.1.6 Examination of the The ZCB Bamboo Pavilion

Table 4.1.6: The ZCB Bamboo Pavilion

Name of the building	The ZCB Bamboo Pavilion. Public event space built for the Construction Industry Council's Zero Carbon Building (ZCB)  **Figure 103:** The ZCB Bamboo Pavilion (Photo by Michael Law, 2016)
Location	8 Sheung Yuet Rd, Kowloon Bay, Kowloon, Hong Kong
Architect	The Chinese University of Hong Kong School of Architecture Sun Hip Scaffolding Eng. Co., Ltd., Dr. Goman Ho & Dr. Alfred Fong
Year of construction	2015, project construction period 3.5 month
Bamboo	• Length : 2956m (Gibson, 2016), • Pole ø: Base: 12-15cm, top: 8-12cm (Gibson, 2016), • Pole length: ≈ 7.2m (Gibson, 2016), • Total weight: 6,350kg after complete drying of bamboo. (7,100kg in wet state) (Gibson, 2016), • Species: Phyllostachys edulis (moso bamboo, mao zhu, 毛竹) (Gibson, 2016), • Age: Average age is 4 years (between 3 and 5 year old bamboo is used) (Gibson, 2016).

A large diagrid skeleton is crossed into 3 columns, which is a form. Also there are three concrete round columns on which hollow columns are based (Gibson, 2016).

Figure 104: Close look to pavilion's detail (Photo by Michael Law, 2016)

Construction of joints

Figure 105: Construction proces of building (Photo by Ramon Van Der Heijden, 2016)

It is built from 475 large bamboo poles that are bent onsite to shape the structure and that are hand-tied together with metal wire using techniques based on Cantonese bamboo scaffolding craftsmanship. The shape is a large diagrid shell structure that is folded down into three hollow columns. These columns rest on three circular concrete footings. A tailor-made white tensile fabric is stretched over the structure and is brightly lit from inside the three legs (Gibson, 2016).

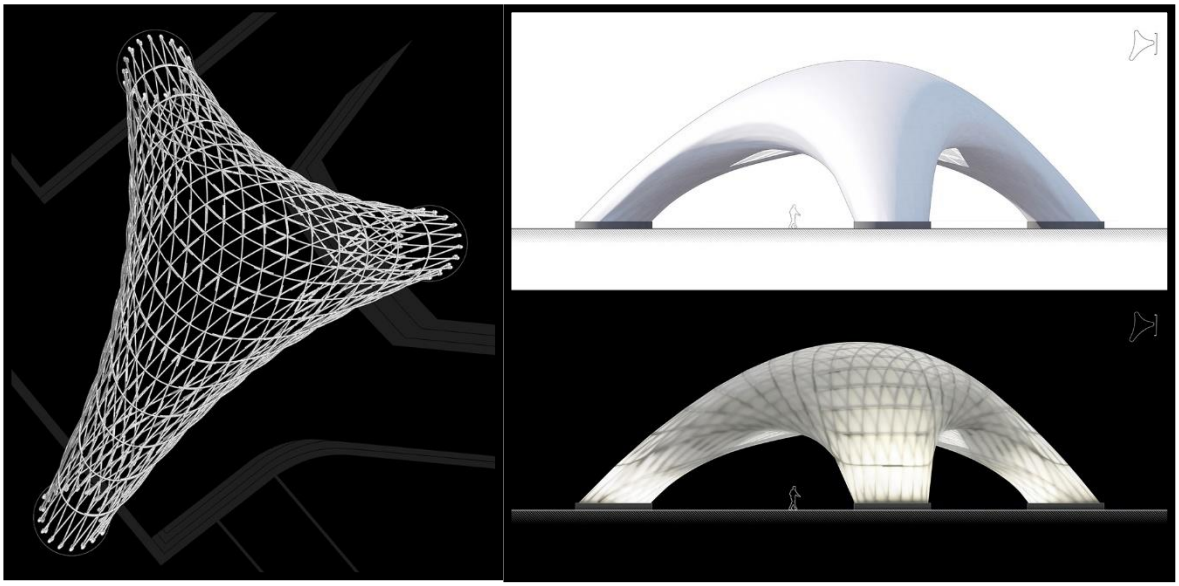


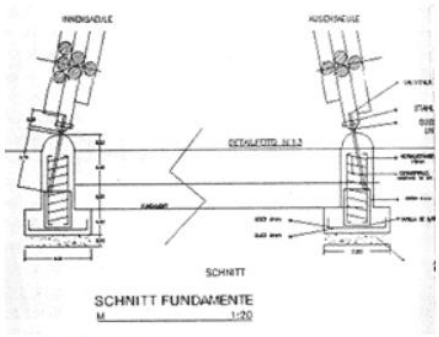
Figure 106: Top view of pavilion and side view (Gibson, 2016)

4.1.7 Examination of the ZERI Pavilion on the EXPO 2000

Table 4.1.7: ZERI Pavillion on the EXPO 2000

Name of the building	ZERI Pavillion on the EXPO 2000  **Figure 107:** Front view of pavilion (Rohrbach, Gillmann, 2001)
Architect	The ZERI organisation (Zero Emission Research Initiative) Simon Veléz
Location	Manizales, Columbia.
Year of construction	2000
Bamboo type	Guadua angustifolia; Different types of bamboo from China for the parquet, bamboo from Bali and Columbia for the interior
Type / size of elements	 **Figure 108:** Skeleton construction (Rohrbach, Gillmann, 2001)

Construction of foundation



detail section foundation

detail foot

(a) Detail section foundation (b) Detail foot

Figure 109: Foundation elements and process of working (Rohrbach, Gillmann, 2001)

Construction of roof

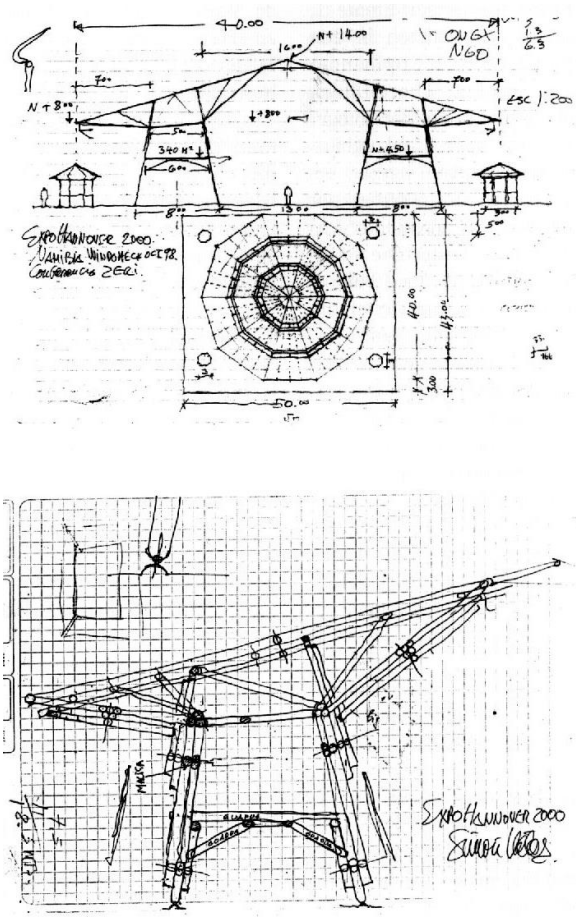


Figure 110: Sketch of the architect (Rohrbach, Gillmann, 2001)

Decagonal roof diameter 40m, height 7m.

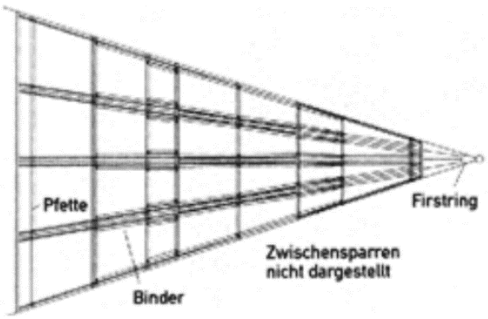


Figure 111: Roof structure (Rohrbach, Gillmann, 2001)

(a) View under the gallery (b) Detail view to construction

Figure 112: View under the gallery (Rohrbach, Gillmann, 2001)

"The ZERI Pavilion is a circular construction, thus one without a beginning, without an end, open in design as to invite everyone to participate without obstacles. It is open and unobstructed. It symbolises a universally accessible organisation which embodies concepts

and technologies which are applicable anywhere and accessible to everyone" (Marshall McLuhan).

The interior of the pavilion and its construction are protected from rain by a ten-faced polygon, 40 meters in diameter with a peripheral canopy seven meters wide. The building consists of 20 supporting wooden pylons with a height of 8 to 14 meters (Rohrbach, Gillmann, 2001).

External pillars are installed on a single base, which are connected by fundamental beams. On the foundation ring there are internal pillars. The roof has got a diameter of 40m and is at the ridge 14,5m and at the gutter 7m high. The roofing is made of 9mm thick cement tile, which are strengthened with bamboo and lying in a 3cm thick mortar layer (Rohrbach, Gillmann, 2001).

4.1.8 Examination of the Kim Boi Bamboo Restaurant

Table 4.1.8: Kim Boi Bamboo Restaurant

Name of the building	Kim Boi Bamboo Restaurant  **Figure 113:** Kim Boi Bamboo Restaurant (Photo by Hoang Le Photography)
Location	Kim Bôi District, Hoa Binh, Vietnam
Architect	Tran Ba Tiep
Year of construction	2016
Type of bamboo	Thyrsostachys siamensis
Construction technique	First, the bamboo is connected to the fastening and bamboo bolt to form the frame on the floor, and then it is installed by the crane. A stable structure is made by iron pins and a bamboo frame connected with concrete, foundation beams with metal pipes (ArchDaily, 2016).

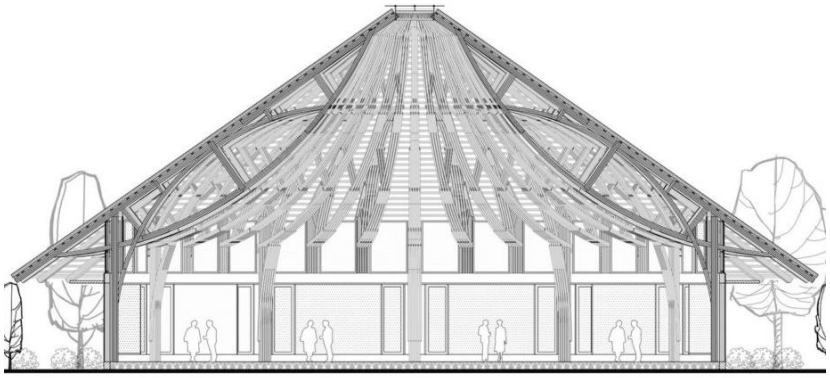


Figure 114: Section of restaurant (Tran Ba Tiep, 2016)

Figure 115: Detail view (Photo by Hoang Le Photography)

The project, abandoned for a long time, with a foundation in the form of a twelve-sided polygon was changed. The idea of the restaurant was taken from the image of a traditional conical hat, closely related to the beauty of Vietnamese women.

Figure 116: Detail view on bamboo and concrete construction (Photo by Hoang Le Photography)

The restaurant in the form of a conical hat has an area of more than 700 m2 and a height of 15 meters. The roof is made of natural leaves. In the middle of the roof there is a clearance of 1.56 meters in diameter, in order to pass natural light. The widest span of two columns is 24.6 meters, and the largest diameter of a conical hat-like restaurant is 32 meters (ArchDaily, 2016).

Figure 117: 3D interior design (Photo by Hoang Le Photography)

4.1.9 Examination of the wNw Bar

Table 4.1.9: wNw Bar

Name of the building	wNw Bar
	
	Figure 118: Front view (Photo by Phan Quang)
Location	Phu Tho district, Thu Dau Mot Town, Binh Duong, Vietnam
Architect	Vo Trong Nghia Architects
Year of construction	The WNW bar was built by local workers in duration of 3 months (from October 2007 to January 2008).

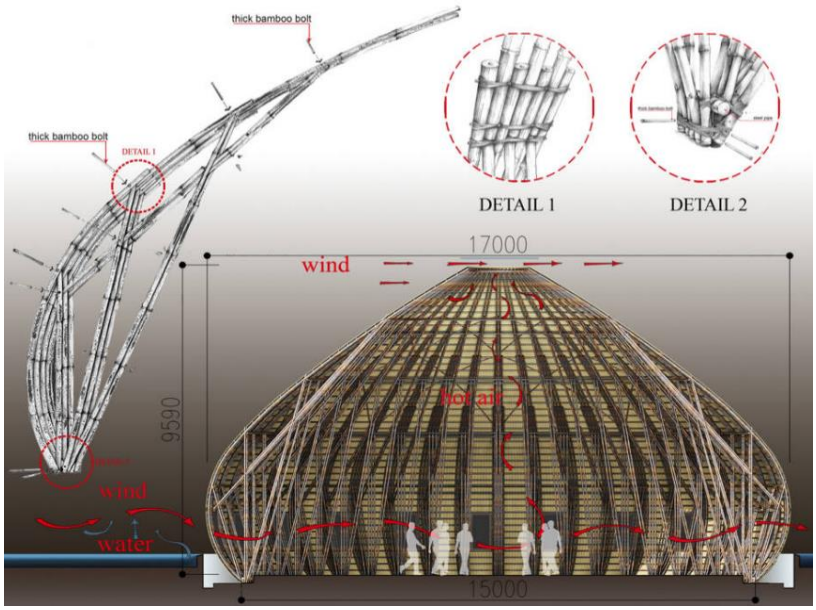


Figure 119: Conceptual diagram (VTN Architects, 2008)

Construction technique

A structural bamboo arch system was designed for this dome; 10m high and spanning 15m across. The main frame is made by 48 prefabricated units, each of them is made of several bamboo elements bound together (ArchDaily, 2012).

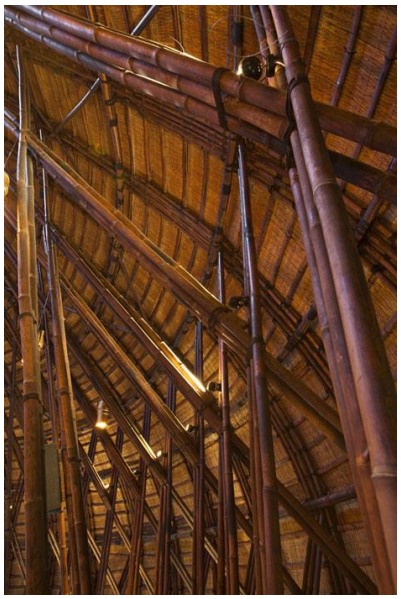


Figure 120: Detail view (Photo by Phan Quang)

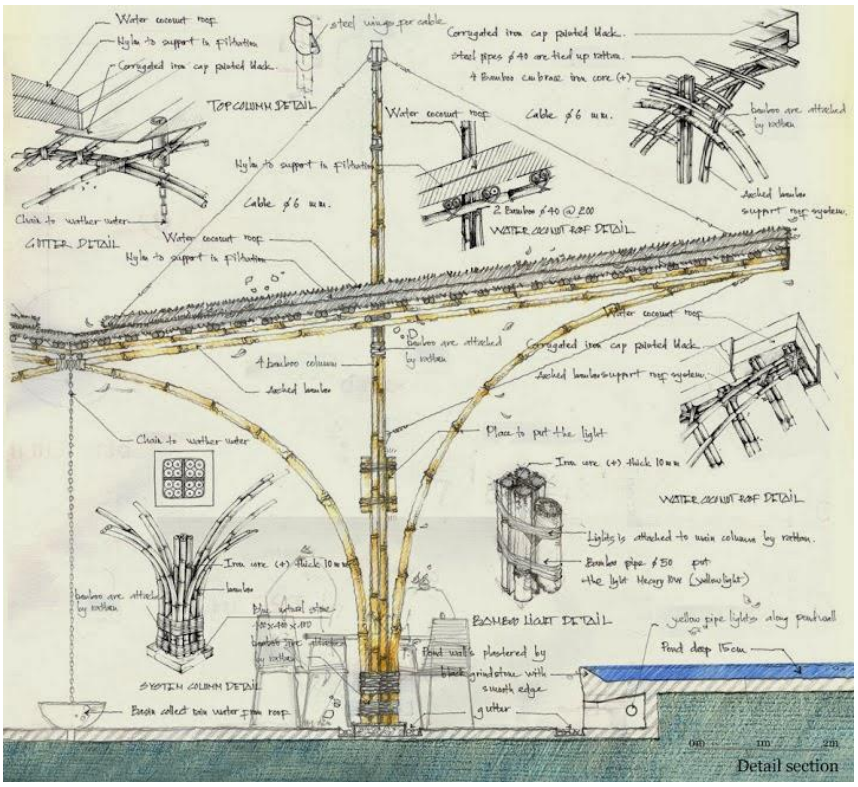


Figure 121: Detail section (VTN Architects, 2008)

Figure 122: Design of roof (Photo by Phan Quang)

The building of the bar is designed as a confined space, which can be used for ceremonies, music concerts and shows. But is now used for city meetings and other social events.

The basic frame consists of 48 prefabricated blocks, each of which is made of several bamboo elements connected together. Structural bamboo arch 10 m high and 15 m wide. The wind and cool water from the lake creates natural ventilation. On the roof of the roof there is a 1.5 m diameter hole for the acacia of the hot air outlet from the inside (Naidoo, 2009).

4.2 Comparison and discussion

Comparison of case studies prepared for understanding the difference of bamboo buildings, it also shows people types of bamboo and their building details properly. Discussion of table and case studies will help people understand how they can work with bamboo in a better way for them, how to choose good environ and how to take care of bamboo.

4.2.1 Table: Comparison of case studies

№	1	2	3	4
Name of building	Children's activity and learning center	Sharma Springs Residence	Bamboo sports hall Panyaden international school	Restaurant in the Kontum Indochine Hotel
Location	Soneva Kiri Resort, Island of Koh Koodin, Thailand	Sibang Gede, Abiansemal, Badung Regency, Bali, Indonesia	218 Moo 2, Namprae, Hang Dong district, Chiang Mai 50230, Thailand	30 Bạch Đằng, Phwờng Quyết Thắng, Kon Tum Province, Vietnam
Year of construction	2008-2009	2012	2017	2013
Area	165.0 sqm	750.0 sqm	782 sqm	551 sqm
Height	13 m (appr.)	23.20 m	13 m	6 m (appr.)
Span	-	-	-	-
Number of floors	2	6	1 – sport hall, 2 – balconies	1

Climate	Tropical monsoon climate with little variation in temperature throughout the year	All year round tropical, warm and humid climate	In this area the climate is hot and humid	The climate here is tropical. There is significant rainfall in most months of the year.	
Type of bamboo	Bambusa multiplex, Dendrocalamus asper	Dendrocalamus Asper) bamboo comes locally from Bali and Java		Dendrocalamus strictus (appr.)	
Methods for the treatment of bamboo		Treated with a boron solution that suppresses glucose inside, and renders it inedible for insects.	Borax/boric acid treated bamboo	Used traditional methods, soaking in mud and smoking out.	

№	5	6	7	8	9
Name of building	Roc Von Restaurant	The ZCB Bamboo Pavilion	ZERI Pavillion on the EXPO 2000	Kim Boi Bamboo Restaurant	wNw Bar (wind and water)
Location	Xa Phu Cat, Huyen Quoc Oai, Hanoi, Vietnam	8 Sheung Yuet Rd, Kowloon Bay, Kowloon, Hong Kong	Manizales, Columbia. The Zeri Pavilion was built for Expo Hannover	Kim Bôi District, Hoa Binh, Vietnam	Phu Tho district, Thu Dau Mot Town, Binh Duong, Vietnam
Year of construction	2015	2015, project construction period 3.5 month	2000	2016	From October 2007 to January 2008
Area	1100.0 sqm	910 sqm	1,650 m² at ground level and 500m² on first floor galery	770 sqm	250.0 sqm (spanning 15m across)

Height		12.30 m	14 m	15 m	10m
Span	-	-	40 m in diameter	17 m in diameter	15m across
Number of floors	1	1	2	1	1
Climate	The climate is subequatorial. It is characterized by a hot rainy season from April to November and a cool dry season from December to March.	The climate in Hong Kong is subtropical with cool dry winters and hot, humid summers.	In this area the climate is hot and humid.	The climate of this district is representative for tropical monsoon, which is pretty cold and less rain in winter and hot and rainy in summer, between 15 to 29 Celsius Degrees, depending on seasons.	Climate - is hot and rainy, with high humidity. It is a tropical monsoon climate, divided into two distinct dry and wet seasons.
Type of bamboo	Dendrocalamus barbatus, Dendrocalamus strictus	Phyllostachys edulis	Guadua angustifolia, Different types of bamboo from China for the parquet, bamboo from Bali and Columbia for the interior	Thyrsostachys siamensis	Dendrocalamus barbatus, Dendrocalamus strictus (appr.)
Methods for the treatment of bamboo	Traditional Vietnamese method, water soaking in running water 90 – 100 days.		The smoking of the guadua is a sustainable and productive alternative to chemicals which used today.	Water soaking in running water 90 – 100 days. (appr.)	Soaking and smoking out

4.2.2 Discussion of case studies

Comparison of the nine buildings made of bamboo, in Table 4.2, the buildings are designed for different activities (sports hall, training center, restaurants, pavilions, etc.) however there are similarities of these buildings. The construction of buildings does not take a long time to build a pavilion for 3 months, and for a year to build a 6-storey building, and this is taking into account the time of bamboo preparation for construction. Each country and each architect has his own approach to protecting bamboo from external factors; they are similar, each designer is trying to find a different approach to bamboo and then the imagination of the architect may not go out. His unusually shaped bamboo can be taken by surprise, but people who already know how to handle it see it as their highlight and the cylindrical shape of the plant does not frighten them.

As shown in the comparison table, you can see that the climate is tropical, the terrain where the buildings are built is mostly 35 degrees Celsius with frequent rains, and this is not because bamboo can stand only in this climate. The birthplace of bamboo is hot countries, so bamboo is easily available in tropical countries. The material is preferred because it is easy for them to build small houses for the local population, however architects find new ways and new techniques for using bamboo in construction, often they are based on the main joints and fastenings. However, the unusualness of the material gives a chance for fantasy and not ordinary use of bamboo, although this is the old material.

Buildings of bamboo may not have certain boundaries on the area, it all depends on the idea of the building, in the table you can see that in a single-story building the area can be 1100 square meters, and a two-story building can be 165 sq.m. When it comes to bamboo, you cannot accurately say its dimensions, as many buildings can be built in different ways and to each element of the building will be selected a certain bamboo. Unfortunately, bamboo is difficult to make the same for a large batch, so builders and engineers should select bamboo separately for each element of the building. However, this is also fascinating, as it makes the building unusual in appearance.

The plus is that there is no non-replaceable part of the building made of bamboo. Local residents of tropical countries know that when building houses from bamboo is not an irreplaceable part, bamboo is unique in that the part of the building can be easily replaced if damaged, and the whole building will not be affected.

The methods of protecting bamboo basically use soaking and smoking out with boron solution, which destroys glucose in bamboo by this making the plant not edible for insects. Since this is one of the most environmentally friendly methods of processing bamboo. The boron solution does not contain chemical elements that can harm the environment or a person.

Renewable material:
Bamboo can be harvested from three to four years after ripening, in contrast to coniferous and deciduous plants that grow for 40 years. Yield at a bamboo is about 25 times above in difference from trees. Almost a thousand hectares of forests are cut down every week around the world, but using bamboo instead of wood makes it possible to cut this figure and protect forests.

Bamboo Absorbs greenhouse gases:
Bamboo absorbs carbon dioxide, and also releases 35% more oxygen than most deciduous trees.

Fast Growth Rate:
Some varieties of bamboo can grow from 40 to 120 cm per day. After harvesting, a new shoot from the root system grows, so there is no need for additional planting or cultivation, this saves time.

Few wastes:
Each part of bamboo is used to produce different products. People use the roots of bamboo as food, as well as enrich the soil with mulch, from furniture to chopsticks and textiles.

Versatility:

Since bamboo fibers are stronger than wood, the replacement of wood is quite possible for our world. At the moment, paper, charcoal, textiles, flooring, furniture are produced from bamboo, and this is only the beginning of the list. Similarly, unlike other materials such as cotton, which requires frequent spraying with chemicals, bamboo does not require any fertilizers, pesticides or herbicides in the process of growth.

4.3 Table : Types of Bamboo That Are Used in Construction

The table is designed to understand what kinds of bamboo can be used as a building material, and in which part of the building is mainly used. The bamboo shown in the table comes from the dimensions in the green state of bamboo, after careful treatment and drying of the bamboo, the dimensions change. The change in size depends on what type of treatment will be chosen for bamboo. For frequent bamboo sizes change after treatment within 10% -15%

For architects who work on building bamboo buildings, the table will be useful, since it indicates the size of the bamboo, where it grows and where it can be used.

Table 4.3: Types of Bamboo That Are Used in Construction

(Reference for table: https://www.guaduabamboo.com/ , http://tropical.theferns.info/ , http://e-monocot.org/, https://sites.google.com/site/bamboosthailand/, https://www.kew.org/, http://www.efloras.org/, https://uses.plantnet-project.org/en/)

No	Scientific Name	Location	Height	Diameter	Wall Thickness	Internode length	Construction uses
1	Arundinaria alpina	South East Asia; Africa; Madagascar.	8–25 m	7–10 cm			Furniture, poles
2	Bambusa arundinacea	India, Bangladesh, Myanmar, Thailand and China;	Up to 30m	Up to 18 cm	Up to 15cm	up to 40 cm	handicrafts and low-value construction

		Indonesia, Vietnam, Philippines.					
3	Bambusa balcooa	North-Eastern India (including the eastern Himalayas), Nepal; Bangladesh; South-East and East Asia; Africa and Australia.	12-24 m	6-15 cm	Up to 2.5cm	20-40 cm	building material for houses, temporary fishing floats, bridges, frames of rickshaw hoods
4	Bambusa blumeana	Indonesia – Malaysia; Southeast Asia; Thailand - Philippines - Vietnam - China - Japan	15-25 m	8-20 cm	2-3 cm	25-60 cm	parquets, concrete reinforcements, furniture, basketry,
5	Bambusa dolichoclada	China and Eastern Asia, Taiwan	6-20 m	4-11 cm	Up to 2 cm	30–45 cm	building material for houses, framing
6	Bambusa khasiana	Indian Subcontinent Assam	10-15 m	25-30 mm		13-38 cm	Framing, walls, sheathing, matting, concrete formwork.
7	Bambusa multiplex	E. Asia - Eastern Himalayas to southern China.	2-7 m	15-25mm	10-30mm	20-40cm	Walls, sheathing.
8	Bambusa nutans	Asia-Tropical, Indian Subcontinent Assam, East Himalaya, Bangladesh, Nepal, Indo-China Laos, Thailand, West Himalaya, Vietnam	6-12 m	40-70 mm	thick-walled	35-45 cm	Framing, walls, floor, sheathing, concrete formwork, scaffolding

9	Bambusa pallida	Bangladesh, India, Myanmar, Thailand	15 – 20 m	5.5–7.5 cm		30–57 cm	General use, Framing
10	Bambusa polymorpha	Myanmar, Thailand and Bangladesh	15-25 m	7-15 cm	1-2 cm	40-60 cm	house construction, baskets, furniture, handicrafts, woven matting, landscaping
11	Bambusa textilis	China	6-15 m	3–5 cm	0,2-0,5 cm	up to 60 cm	Wall, matting, landscaping, sheathing
12	Bambusa tulda	E. Asia - northern India to Myanmar and Thailand	6 - 30 m	5–10 cm	50 - 100mm	36 - 70cm	construction, furniture, boxes, scaffolding,
13	Bambusa tuldoides	E. Asia - southern China, Vietnam	6–10 m	3–5 cm	50mm	30–36 cm	farm equipment and as punting poles and scaffolding
14	Bambusa vulgaris	Southern China and Madagascar	10-20 m	4-10 cm	7-15 mm	25-35 cm	light construction such as houses, huts, boats, scaffolding, furniture, fences
15	Cephalostachyum pergracile	The Indochinese Region; The province of Yunnan, China, Java	7-30 m	2.5-7.5 cm	0.003-0.006 mm	20-45 cm	light construction, house posts, walling mats, shingles
16	Dendrocalamus asper	Southeast Asia, Malaysia, near Cameron Highlands	20-30 m	8-20 cm	11-20 mm	20-45 cm	building material, structural timber for heavy construction such as houses and bridges,

							furniture, laminated boards
17	Dendrocalamus barbatus	North Thailand: Doi Inthanon, Chiang Mai, Thung Luang	15–20m	10–15 cm	8-15 mm	26–32 cm	building construction, furniture, farm implements, basketry, handicrafts
18	Dendrocalamus brandisii	Southeast Asia, India: north-eastern part (Manipur), and Andaman Islands; Burma: from the Kachin hills to Tavoy (Tenasserim); Thailand; Laos; Vietnam: Tonkin; China: Yunnan	19-33 m	13-20 cm	25 - 50mm	30-38 cm	building construction, boat masts, farm implements, furniture
19	Dendrocalamus giganteus	Myanmar (Burma), Bhutan, China and Thailand	25-35 m	15-30 cm	2-2.5 cm	35-45 cm long	scaffolding, boards and parquet, boat masts, rural housing, water pipes, furniture, water pots, buckets, matting
20	Dendrocalamus hamiltonii	E. Asia - southern China, Indian subcontinent, Myanmar, Thailand, Laos, Vietnam.	12–20 m	9–20 cm	1.2–2 cm	30–50 cm	houses, floor, roof, wall, sheathing, trough, bridges and various household utensils
21	Dendrocalamus hookerii	East Asia - northeast India, Bhutan, Nepal and Myanmar.	15 - 20 m	10 - 15cm	25mm	40 - 50cm	house construction, particularly roofing,

							framing, floor strips, concrete formwork – boards, sheathing-strips
22	Dendrocalamus latiflorus	Southern China and Taiwan	14-25 m	8-20 cm	5-30 mm	20-70 cm	for structural timber (of medium quality) for house and temporary construction, agricultural implements, water pipes, basketry, furniture
23	Dendrocalamus longispathus	E. Asia - India, Bangladesh, Myanmar, Thailand	10 - 20 m	6 - 12cm	12mm	25 - 60cm	constructions, baskets, furniture, mats and containers
24	Dendrocalamus membranaceus	E. Asia - China, Bangladesh, Myanmar, Thailand, Cambodia, Laos, Vietnam	10 - 24 m	6 - 10cm	6-10 mm	22 - 42cm	building purposes, bamboo board, furniture, basketry, matting
25	Dendrocalamus merrillianus	Southeast Asia - Philippines	10 – 25 m	4 - 12cm	25-30mm	150-210mm	house construction, wall, framing, as strips for floor and sheathing, concrete formwork, scaffolding, furniture,

26	Dendrocalamus sikkimensis	India: Sikkim, West Bengal; Bhutan; China: Southern Yunnan	17-20 m	1.2-2 cm	1–2.5 cm	30-45 cm	General construction, framing, walls, strips floor, sheathing strips, shoring concrete frame work, scaffolding
27	Dendrocalamus strictus	India; Nepal, Bangladesh, Myanmar and Thailand. Southeast Asia: China, Sri Lanka, Malaysia, Indonesia, Philippines and Vietnam.	6-20 m	2.5-8 cm	25 - 75mm	30-45 cm	light construction, furniture
28	Gigantochloa albosiliata	E. Asia - Myanmar, Thailand.	6 - 16 m	15 - 70mm	0.8—1.2 cm	15 - 60cm	light construction, cottage walls, frames of thatched roofs
29	Gigantochloa apus	Asia-Tropical, Indian Subcontinent Assam, Bangladesh, Indo-China Laos, Myanmar, Thailand, Malesia Borneo, Jawa, Malaya, Soutern America, Brazil.	8 - 22 m	4 - 13 cm	6-13 mm	20-70cm	to construct roofing, scaffolding, bridges, walls, fences
30	Gigantochloa levis	Philippines, Eastern Indonesia, Northern and Western Kalimantan, east Malaysia, China and Vietnam	Up to 30 m	5–16 cm	1–1.2 cm	up to 45 cm	structural, furniture, fencing

31	Gigantochloa macrostachya	E. Asia - northeast India, Bangladesh, Myanmar	10 - 16 m	6 - 10mm	-	40 - 80cm	Framing, wall, roof, strips- sheathing and floor, scaffolding
32	Gigantochloa verticillata	Indonesia, Java, Bali, Sumatra, Mentawai Islands; Peninsular Malaysia	7 - 30 m	5 - 13 cm	2 cm	40 - 60cm	building material, water pipes, furniture, floor and sheathing – strips, concrete formwork, framing, wall, roof, scaffolding
33	Guadua aculeata	Mexico to Central America; Thailand	15 - 30m	15 - 22cm			
34	Guadua amplexifolia	Venezuela to Peru, Central and Southern America; Thailand	7 - 25 m	7 - 15 cm			
35	Guadua angustifolia	extending from Mexico to Argentina; India, Bangladesh, China	15 - 30 m	11- 20 cm	30 - 35mm	20 cm	Alternative to wood for production of laminated and agglomerate wood (columns, beams, girders, planks, panels, etc.)
36	Guadua superba	Northen and Western South America and Brazil.	80-20 m	10-15 cm			General using, framing, wall, roof-tiles, floor, sheathing-strips, concrete formwork,

							scaffolding, troughs, pipes
37	Melocanna baccifera	Northeast India, Bangladesh, Myanmar	10 - 20 m	5–9 cm	0.5–1.2 cm	20 - 60cm	Building, framing, wall, floor strips, sheathing, matting, troughs, pipes
38	Oxytenanthera nigrociliata	E. Asia - southern China. India, Myanmar, Thailand, Indonesia	15-20 m	30-60 mm	6 mm	20-35 cm	construction of rafters, fences and watch houses, wall, floor and sheathing-strips, concrete formwork-shoring, scaffolding
39	Phyllostachys aurea	E. Asia - southeast China (Fujian, Zhejiang), Vietnam	2 - 8 m	20 - 30mm		8 - 10cm	furniture and construction, wall, sheathing
40	Phyllostachys bambusoides	Japan, Thailand, Doi Ang Khang, Chiang Mai province,Taiwan, China.	15 - 24m	12 – 16 cm	5 mm	40 cm	General construction, framing, wall, roof, floor, sheathing, matting, lashing, concrete formwork, scaffolding, troughs, pipes
41	Phyllostachys edulis	Asia-temperate: Caucasus, China, and eastern Asia. Asia-tropical: Indo-China	10-35m	18 -20 cm	1 cm	35-50 cm	General construction, scaffolding

42	Pseudostachyum polymorphum	E. Asia - southern China, northeast India, Bhutan, Myanmar, Vietnam	15 - 20 m	30 - 35mm		20 - 23cm	for weaving into paneling, wall, roofing or fencing, sheathing,
43	Schizostachyum hainanense	E. Asia - southern China, Vietnam	8 - 30 m	2 - 4cm	1.5–2 mm	35 - 75cm	Wall, roof-shingles, sheathing, matting
44	Thyrsostachys oliverii	E. Asia - southern China, India, Myanmar, Thailand	15 - 25 m	50 - 70mm	0.5 – 1 cm	40 - 60cm	construction purposes, the culms are also used for reinforcing concrete blocks, framing, wall, sheathing, concrete formwork, scaffolding
39	Thvrsostachvs siamensis	E. Asia - southern China, Myanmar, Thailand	7 - 13 m	20-60 mm	0.5 – 1 cm	15-30 cm	house construction, general household uses, for cottage industries, wall, sheathing, concrete formwork, scaffolding

CHAPTER FIVE
CONCLUSION

5.1 Conclusion

After a long study of environmental materials and looking for answers to the question "What materials can be used without harming the environment?", people can understand that mass cutting of trees will not lead the future of construction to good ecology. But after a thorough study of bamboo as a building material, one can come to the conclusion that this is exactly one of the most worthy materials that does not harm the environment. Surprisingly it was that this herb can grow over a day by several meters and after three or four years it can be cut down and used as a material for construction. . People have used bamboo for centuries in their lives. Today, bamboo is used in many areas of activity, from food and reaching construction, textiles and high technologies.

Bamboo, despite its light weight, is very flexible and hardy. There are minuses, it is cylindrical and hollow inside. Bamboo does not always grow straight, and working with a curved plant is quite difficult. With the right approach and processing of this material, you can build a house from the foundation to the roof. One of the most basic and difficult parts is the bamboo joints, they are not typical and the methods of joining the tree or any other material will not fit in any way to the bamboo. For the bamboo mastered their own special techniques, and many architects will improve them making the design of the building exotic. Familiar homes, we begin to build with the laying of the foundation, the construction of columns, walls and finish the roof. In the case of bamboo, the foundation can flow into the supporting column, which is a wall and this structure can end as a dome-roof. Do not forget that it is durable, now scientists have studied bamboo and the mix of cement with bamboo gives a double strength, so the benefit of bamboo in subsequent years is that it can replace iron and steel in the reinforcement of buildings.

Having considered bamboo from the outside and inside, it seems that this is an ecological product that people still do not know how to use. Protection from pests always comes first

in people who build bamboo. Boron solution is considered to be the best protection and the most ecological, without harming the environment. For example, Ibuku House is a company that built a village of 100% bamboo. If in the architecture of the 21st century there are already buildings that consist of 100% of bamboo, why not go further and not think about an ecological multifunctional building that is without harm to the environment.

Bamboo releases 35% more oxygen than coniferous trees, while absorbing carbon dioxide. Since bamboo is a 100% natural product, energy is not expended on production, making bamboo already ready for use. For local residents of countries where bamboo is grown, this is work, in various industries providing jobs and eliminating poverty in developing countries. Cultivation of bamboo gives people building material, textiles, food and work. Economically, ecologically and socially the life of people will be in stability.

Bamboo, a unique material from which you can build houses, schools, restaurants, church pavilions, bridges and a list on this just begins. Properties of bamboo can be both a finishing material and the basis of a building's construction.

In the future, the bamboo sector should be brought to the forefront as a sustainable material; bamboo is not well represented to the public, as it has just begun to gain the attention of architects and investors. With a good contribution to bamboo, its use can significantly increase and many countries in Europe and nearby countries in the tropical and subtropical regions can learn more about bamboo. Bamboo can play an important role in the future of mankind, the human need for wood can be replaced with bamboo, while wood will be protected from frequent deforestation, due to the growing demand for raw materials for housing and construction. In addition, a big plus of bamboo, this is the secondary use of the material.

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