

Bamboo Structures for Modern Sustainable Architecture

Solanilla Medina Yor Maikol¹, Shuvalov Vasily Maksimovich¹,
Bykova Galina Ivanovna¹ and Sultanova Ainur²

¹Department of Architecture, Academy of Engineering,
RUDN University, Moscow,
Russia

²Department of Rural Architecture,
Moscow Architectural Institute (State Academy), Moscow,
Russia

Email: sultanovs36@mail.ru

Abstract

Bamboo is an old and traditional building material throughout the world's tropical and sub-tropical regions. Considered a renewable and versatile resource, bamboo has gained popularity over the years. Although not many architects use it as the main construction material in bearing structures, it is frequently highlighted in research. New technologies combined with innovated traditional techniques enable its use in structural applications in regions with a hot-humid climate. All this significant development is not only because of engineering advances, but also reckoning the capabilities of bamboo.

Many specialists are developing new technologies, some of which are already used in construction. Bamboo fibers are longer and more flexible than wood, so they are often used in the construction of earthquake-resistant buildings. Innovations in the field of bamboo constructions allow us to expand the capabilities of this natural material, making it more stable in structures with large spans. This paper presents the case for promoting bamboo structures in the modern world.

The paper uses the following research methods; study of literary and online sources, abstraction, analysis and comparison. It argues that in the 21st century, bamboo structures are becoming more in demand due to the increasing environmental problems in the cities. Natural origin, rapid production, construction and recycling of bamboo structures are very good reasons for promoting bamboo as a versatile material.

Keywords: Bamboo constructions, Bamboo structures, Guadua Bamboo, Modern constructions, Sustainable architecture.

Introduction

Sustainability includes taking into account local conditions and taking advantage of the site's location; multi-functionality of the interior space; attention to open planning elements and application of high technologies of construction. The principle of sustainable development is considered as a direction of ecological energy efficient architecture, the main task of which is to conserve resources and to maintain the sustainability of the environment.

“While designing for sustainability, emphasis should be laid on compatibility with regional context, finding local solutions from local resources, finding ways of decreasing high energy consumption levels and learning from our own traditional wisdom for simple cost effective solutions”

(Wahid, 2012;84).

Bamboo is one of the renewable natural resources that meet the principles of sustainability in modern architecture. Bamboo is more environmentally friendly than other building materials such as concrete and steel because during the production of concrete and steel structures, huge amounts of carbon dioxide and heat and dust are emitted into the atmosphere. Bamboo is a unique multifunctional material deeply rooted in the history, culture and life of people around the world (Figure 1).

This study refers to a hot-humid climate. According to the Keppen climate classification, the hot-humid climate of a given region is determined by the following features: 1) moisture is a significant problem in a hot-humid climate, more so in those areas that receive more than 40 inches of annual precipitation; 2) the intense solar radiation in this climate also imposes a large thermal load on an architectural project that can increase the cooling costs and affect comfort (Aronin, 1959).

There are many experiences in different countries that utilize bamboo for big financial returns, and environmental protection. It is understandable that sustainable bamboo utilisation is a function of bamboo resource development, availability of new technologies and scientific information, production of bamboo products using the technologies, and marketing. For these to happen, availability of appropriate institutions, supporting policies, strategies and legislatives and their implementation is essential. Bamboo is an important material for architectural projects and houses in the regions with hot-humid climates.

Bamboo is an old and traditional building material throughout the world's tropical and sub-tropical regions. Bamboo is considered a new, able and versatile resource, with a high strength and low weight. That's why it is widely used in different forms of construction (Raj and Agarwal, 2014).

History shows us that in ancient times, bamboo was widely used in construction by muddling with other natural renewable materials. Currently, this cultural heritage is being used in different parts of the world. Its construction reliability has been tested and evaluated by the experience of our ancestors. Bamboo ('Bahareque' or 'bajareque') is designed for building low-rise structures, from bearing vertical racks connected through walls from intertwined stems of bamboo and clay. This technique has been used for a long time to build houses for the indigenous people of America. For example, dwelling huts made of bamboo are often used by American Indians, especially in Colombia and Venezuela (Hidalgo, 2004). In some countries of South America, such structures are called 'Bareke'. Similar constructions are used in different countries in different types and forms but have the same characteristics. It is proved that the 'Bareke' and similar structures resist earthquakes well (for example, in Central America). Scientists have confirmed the effectiveness of this construction system.

The aim of the research is to study geometric structures using bamboo in the development of modern sustainable architecture; buildings and structures. The subject of research is architecture of buildings and construction using bamboo elements and structures.

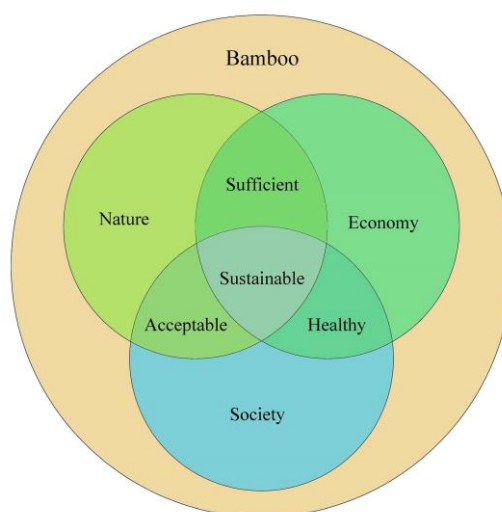


Fig. 1: The concept of sustainable architecture development with bamboo using
Source: Author.

Review of Literature

The use of bamboo for the formation of architectural objects have been insufficiently studied. However, there are scientific works in which the organization of architectural environments from bamboo have been considered.

Some architects such as Oscar Hidalgo López (Colombia) (Hidalgo, 2004), Simón Vélez (Colombia) (Velez, 2020), Simón José Samper (Colombia) (Aschner, 2016), Andrés Böppler Ramírez (Colombia / Germany) (Architecture in development, 2020), Jorge Morán Ubidia (Ecuador) (Lara and Espinosa, 2019), Khosrow Ghavami (Iraq / Brazil) (Eustáquio Moreira, L. et al, 2019), Elora Hardy (Indonesia / USA) (IBUKU, 2020), Richard Buckminster Fuller (USA) (Silva, J. et al, 2019), have carried out research on the possibility of using bamboo as a structural and finishing material, and finding new original design solutions for its use in modern architecture. They have confirmed with their works, the technical and aesthetic advantages of bamboo over other building materials. Research in the field of technical properties of bamboo have been carried out by Fedor Ivanovich Shimkin (Shimkin, 1987), Wang Xin Yu (Wang, 1998), Li Hui (Li, 2007), Jiang Jianxin (Jianxin, J. et al, 2008), Yang Zhongkai (Jianxin, J. et al, 2008), Zhu Liwei (Jianxin, J. et al, 2008), Shi Liming (Jianxin, J. et al, 2008), Yan Lijie (Jianxin, J. et al, 2008).

The connections of bamboo structures have been carried out by Zhang Nan (Zhang, 2008), and Vo Trong Nghia (Vo Trong, 2020). Construction solutions from bamboo knots are reflected in the monographs of Simón Vélez (Velez, 2020), Marcelo Villegas (Villegas, 2005), and Xiao Yang (Xiao, 2020).

The authors listed above however, did not consider the methods of architectural shaping of buildings and structures using bamboo to organize modern sustainable architecture.

Research Methodology

This study involved the examination of scientific papers, project documentation, and foreign and domestic literature on this topic in the works of Simón Vélez (Velez, 2020), Oscar Hidalgo López (Hidalgo, 2004), Anna Heringer (Heringer, 2020), Vo Trong Nghia (Vo Trong, 2020), and Elora Hardy (IBUKU, 2020). Field and visual survey of

buildings and structures made of bamboo were studied during expedition trips in 2017-2019 to the settlements of Colombia, Ecuador, Mexico and Indonesia. Analysis of existing objects using bamboo and graphic interpretation of buildings and structures by the following authors: Simón Vélez – Colombia (Velez, 2020), Jorge Moran Ubidia – Ecuador (Archivo Arquitectura Panamericana, 2020), Linda Garland – Indonesia (Mitchell, 2020).

Features of traditional architecture and construction using bamboo in different regions

Bamboo is one of the oldest construction materials used worldwide. The evolution of bamboo construction solutions has created a reliable system of structures. Evaluation of the material on the final states for strength and deflection has become the main criteria in the design of structures and joints of bamboo elements.

Asia

In most Asian countries, most of the buildings were made of bamboo, which was also used in the construction of roofs and interior and exterior walls. In India, bamboo was used to build arches and vaults in the construction of houses. It was used to make frames for various domes, which are still symbols of Hindu architecture today (Tadgell, 1990).

In China, small-diameter bamboo stalks were used to strengthen adobe walls and to build suspension bridges, where they were used as bamboo ‘cables’. The resistance of these cables was so great that they could span distances of over 75 meters. The first suspension bridges were built in China in 300 AD. The bridge in Colombia ‘la Plata’ was also built of bamboo in the 15th century (medieval period), destroyed and rebuilt in the 19th century. A bamboo bridge was built in Indonesia in 1893 (industrial period). In Peru, the ancient city of Chan Chan was famous for its buildings using bamboo, clay and stone.

In Japan, bamboo structures were used in homes and gardens as a decorative element, in window bars, barriers and fences (Hidalgo, 2004).

Africa



In Africa, many countries have huge reserves of largely untapped indigenous bamboo and excellent conditions for growing cultivated species. With careful management, both natural and cultivated bamboo can provide valuable resources for sustainable rural development (INBAR, 1999). We can mention countries like Nigeria, Ethiopia, Kenya, Madagascar, Rwanda and others (Yigardu, 2010). As an example in Ethiopia, the bamboo utilization has been customary and limited mainly to hut construction, fencing and to a lesser extent production of handicrafts, furniture, containers for water transport, and storage, baskets, beehive, firewood, fodder, house utensils, various arte-facts, and walking sticks (Yigardu, 2010)





Latin America

In Venezuela, Colombia, Peru and Ecuador, bamboo is used as a construction material for residential buildings, bridges, galleries and other structures. As bamboo grows in these countries, architects and designers are aware of the strength, durability and reliability of bamboo although different varieties of bamboo are specially grown in nurseries. In Peru, the city of Chiang Chan was the most notable due to its buildings made from bamboo, clay and stone (Solanilla, 2019).

With the arrival of the Spaniards new construction techniques, Spain gradually began to introduce bamboo in the construction of buildings and structures. In Latin America during the pre-colonial period, weaving bamboo was used in different designs and is still being used nowadays. Although the construction of houses with weaving structures is old, it is unlikely that modern architects will use this method. In the middle of the 19th century, the introduction of new forms of farming and cultivation aimed at growing export trade led to a massive transformation of Latin America in many regions. Those regions were growing bamboo in its natural environment. Unfortunately, they were destroyed because they were not considered as a cost-effective and profitable resource. Despite all the drawbacks, a sudden attention towards bamboo is increasing in recent decades. It has the ability to replace wood, finishing materials, and other materials used in furniture.

Thanks to the influence of Latin America, scientific conferences and congresses were held, where well-known architects and designers showed the advantages of bamboo designs and paid more attention to the potential of bamboo as a modern building material; not just to its crafting but also cultivation and distribution of local species. The notion of the use of such materials in Latin America is still developing and it is important to consider issues related to the environment and conservation (table 1).

Country/ Year	Illustration	Technology	Structure's weaknesses
Guiaquil, Ecuador 1736		<ul style="list-style-type: none"> - handcrafted from local material; - bamboo flooring and supporting elements; - roof - purlin bamboo with palm leaf; - it is being built by a family of 3-4 people; 	<p>A private house and outbuilding is protected from flooding when the water level rises. The piles are made of moisture resistant solid wood. The structures are not durable and flammable.</p> <p>Woven bamboo walls are laborious to manufacture. The structures are individual, the construction technology is primitive, typical.</p>
Neiva, Colombia 1853		<ul style="list-style-type: none"> -manual individual assembly; - supporting arches, bridge deck, purlins are made from local bamboo; 	<p>The shroud is woven of bamboo plates. The structures are not durable, time-consuming to manufacture. Erected by the forces of a brigade of 8-10 people.</p> <p>The structures are individual, the construction technology is primitive, typical.</p>

Colima, Mexico 1905		<ul style="list-style-type: none"> - handcrafted from local material; - bamboo roof frame and rafters, vertical bamboo trunks walls, bamboo top and bottom rail; - roofing palm leaf, bamboo beams; 	Private houses and outbuildings of forest dwellers. The structures are not durable, flammable, labor intensive. The structures are individual, the construction technology is primitive, typical. The floors are unpaved.
Amapa, Brazil 1922		<ul style="list-style-type: none"> -handcrafted from bamboo; -the walls are made of woven bamboo with a coating of soil mixture; -the roof is made of bamboo, the purlins are bamboo with bamboo leaf weaving; 	Private houses and outbuildings of the inhabitants of the steppe zone. The structures are not durable, flammable, labor intensive. The structures are individual, the construction technology is primitive, typical.
Tarija, Bolivia 1937		<ul style="list-style-type: none"> - handcrafted from local material; - the supporting elements of the frame and the roof are made of bamboo, the walls are made of vertical bamboo trunks; - the roof is made of bamboo purlin with palm leaf weaving; 	Private houses and outbuildings of forest dwellers. The structures are not durable and flammable. laborious. The structures are individual, the construction technology is primitive, typical.
Cojedes, Venezuela 1954		<ul style="list-style-type: none"> -handcrafted from local material; -the posts are made of moisture-resistant solid wood, the flooring and load-bearing elements of the building are made of bamboo, the walls are wicker bamboo coated with clay mortar. 	Private houses and outbuildings of forest dwellers. The structures are not durable, flammable, labor intensive. The roof is made of bamboo purlin with palm leaf weave. The structures are individual, the construction technology is primitive, typical.



Tumbes, Peru 1961		<ul style="list-style-type: none"> -handcrafted from local material; - bamboo decking and supporting elements, braided bamboo walls; - the roof is made of bamboo purlin with palm leaf; 	Private houses and outbuildings of forest dwellers. The structures are not durable, flammable, labor intensive. Roof and walls are woven bamboo. The structures are individual, the construction technology is primitive, typical.
Guanacast, Costa Rica 1968		<ul style="list-style-type: none"> -handcrafted from local material; -the piles and frame of the building are made of bamboo, the deck and roof structures are made of bamboo, the walls are made of woven bamboo. 	Private houses of residents on the banks of rivers and lakes. The structures are not durable, flammable, labor intensive. The roof is made of bamboo girders with weaving of palm leaves, coated with clay. The structures are individual, the construction technology is primitive, typical.

Table 1. Analysis of the technology and weaknesses of bamboo structures in 18th - 20th centuries

Source: Author.

Use of Bamboo as a Structural and Building Material.

Currently, there is a continuous expansion in the use of bamboo, not only as a construction material but also as a finishing material. Bamboo and its properties depend on the diversity of technology and storage methods. A number of available varieties, diversities and sparkling appearances make bamboo one of the best materials for decorative purposes and manufacturing of sculptures. Apart from construction, it is also used for the production of food, charcoal and textiles. Currently, this cultural heritage is being used in different parts of the world.

During the past, bamboo was one of the main building materials in countries with a hot-humid climate. There, bamboo can be used as the main supporting structural material because of its ability to withstand the loads acting on it. It is also used as a minor material being part of the structural elements that are not subjected to high loads for fencing and roofing materials.

The technique of making joints and constructions in bamboo structures are quite diverse. When constructing buildings and other objects from bamboo, as a construction material, we are talking about hollow tube joints, which are very specialized. The difficulty is that trunks have always different internal and external diameters and they are not perfectly round. In construction, it should be taken into account and predisposition to the formation of longitudinal cracks. Traditionally, bamboo trunks are connected by plug connections or ropes (Villegas, 2005).

The main advantages of bamboo as a construction material are low weight with high strength, the possibility to design curvilinear elements, high precision of structures for individual production, ease of machining, high speed of construction, effortlessness of assembly and processing of structures on the construction site, ecological purity, aesthetics of natural material, dielectric properties, seismic resistance, and durability.

Bamboo Structures: Projects and Innovations

The technology of creating ecologically friendly and harmless structures using bamboo as the main building material is one of the most advanced. Compared with traditional bamboo buildings, this technology has made a huge step in the field of creating structural elements and has significantly expanded the scope of bamboo as a construction material.

Among the architectural and urban applications, the bamboo openwork house Sharma Springs (Bali, Indonesia) stands out as one of the most interesting construction projects in the world. An amazing house hidden in the tropical jungle on the banks of the Ayung River, it consists of six levels with a total area of 750 m² and is the tallest bamboo building in Bali (23 m). The villa is built of local bamboo, the favorite material of Elora Hardy, the architect of the project and the head of the design bureau IBUKU¹. The main entrance is made in the form of a bridge; a covered tunnel that leads directly to the fourth level. Around the spiral staircase are arranged the ‘petals’ of the rooms, where four bedrooms, a games room, and a library are located. Elora Hardy believes that the design of Sharma Springs is consistent with perma-cultural principles; the surrounding space is based on interconnections from natural ecosystems (Figure 2).



Fig. 2: Bamboo openwork house Sharma Springs
(Bali, Indonesia, author: Elora Hardy, design bureau IBUKU, 2012)
Source: ibuku.com.

Attention should be paid to the work of the architect Simón Vélez² who belongs to the city of Manizales Colombia. He became one of the few architects in the world who viewed bamboo as a structural and bearing foundation of a building. Innovating architects are working on improving the design, systems and techniques which are being used in the construction of bamboo buildings. Some of the most famous projects are the ZERI Pavilion in Manizales (2000), the Cathedral of the Virgin Mary in Pereira (2002), the Jenny Garson Bridge in Bogotá (2003), and the Cardera Administrative Building in Pereira (2004).

¹IBUKU – Sharma Springs Residence. URL: <https://ibuku.com/sharma-springs-residence/>. Accessed 18th March 2020.

²Velez, S (2020) Simon Velez [Online]. Available at: <http://www.simonvelez.net/info.html> (Accessed 10th March 2020)

The architects of the studio Penda designed a whole bamboo city for 200,000 residents. The authors of the idea showed how structures built from interconnected horizontal and vertical bamboo trunks can be used for the sustainable construction of an entire city by 2023. To start with, the bureau developed a concept of a bamboo modular hotel. It included the connection of bamboo rods with X-shaped modules from the same material. In the process, the architects realized that the system could be expanded and used to create larger structures from housing to new urban centers. One of the main advantages of the system is that it will become more stable as more connections are added, which means that multi-level structures can be easily created. Structures can be dismantled with minimal loss, as components can be reused several times (Figure 3).

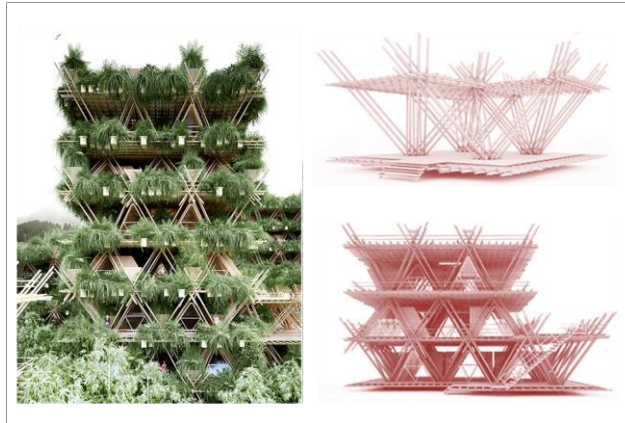


Fig. 3: Bamboo city (Author: arch. studio Penda)
Source: dezeen.com

The Gallery Project

All these significant developments are not only because of engineering with bamboo, but also reckoning the capabilities of the material. This has created conditions for the manifestation of new architectural solutions. Currently, constructions based on bamboo overlap the spans of 10, 20 and even sometimes 40 meters or more (Wirabuana, Maurina, 2017). Such spans can be made with other materials, but in developing countries, where the cost of steel or aluminum is high, the use of bamboo has become more affordable. Bamboo has shown the possibility of being used in the construction of stadium floors, circuses and other spatial elements.

The author's project in Columbia presented here also uses bamboo as the main structural material. Guadua' bamboo is one of the most suitable for constructions and it grows mainly in Latin America, Africa, and Asia. This type of bamboo, with a strong trunk and thick walls of rods has characteristics of high strength. In many other countries, the idea of building objects from bamboo is dictated by the massive growth of 'Guadua' bamboo. It also reduces labor costs because of the small number of workers involved in the construction process. This construction technology does not harm the environment preserving the forests. This is a very ecological, economical and rational choice at the present time (Raoa, 2014). Among the main factors that affect the quality of guadua bamboo are: the physical properties of bamboo (bulk weight, humidity); age and quality of the material (storage and drying conditions) (Figure 4).

Bamboo architecture is located at the initial stage of development. Specialists are developing new technologies, some of which are already used in the construction.

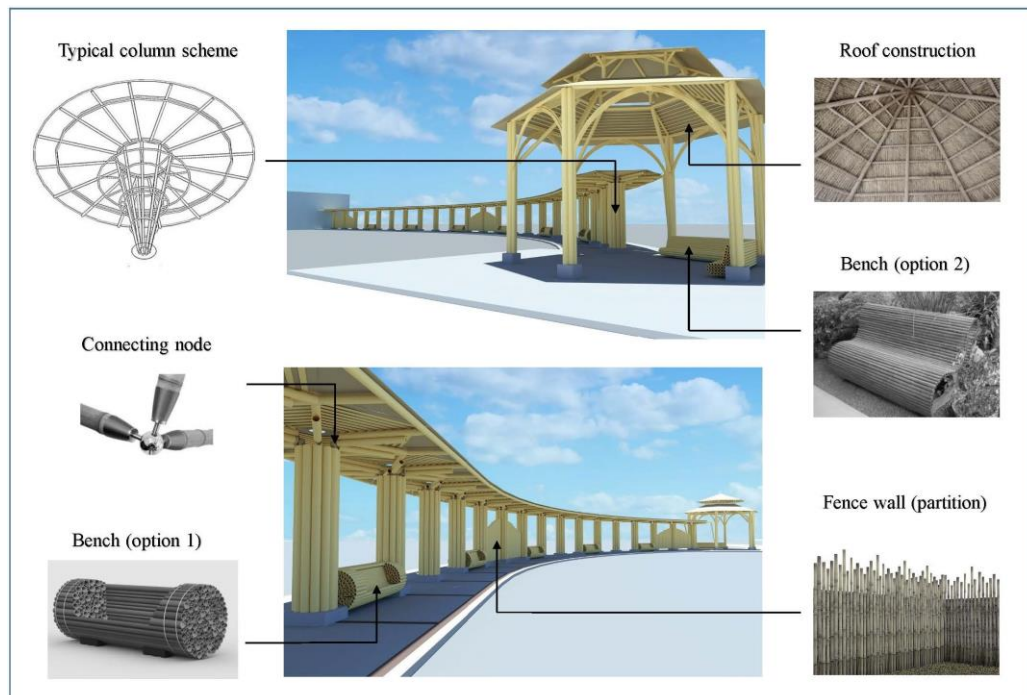


Fig. 4: Gallery made from "Guadua" Bamboo,
Source: Author.

Conclusion

The positive results of practical use in modern architectural practice have shown the practical benefits and design advantages of this material. With the advent of new technologies and methods for automated processing of bamboo trunks, bamboo use in construction is becoming more accessible and economically more profitable for the following factors:

- 1) Local material - reduces shipping costs;
- 2) Fast assembly of the frame - reduces building time;
- 3) Rapid restoration of the natural environment - saving costs for landscaping.

The design capabilities of bamboo make it possible to use it in the construction of large-span objects and pedestrian bridges, where bamboo structures become much more profitable due to the high cost of steel and aluminum, especially in developing countries, as can be seen in Fig. 4 'Gallery of bamboo Guadua'. The Sharma Springs Bamboo Trace House in Bali (architect Elora Hardy) has shown that bamboo elements are becoming an alternative to expensive building materials such as wood, steel and aluminum. Rapid renewability of raw materials is an important factor for modern construction, which reduces its cost. Bamboo is not a tree, but a perennial herb that matures for use in 3-4 years. The ecological value of bamboo also lies in the fact that it actively absorbs carbon dioxide.

There are several problems in the development and designing of buildings and structures from bamboo. The main task is to reduce the material intensity and lower the speed of erection in the objects, which is under consideration for many builders and architects. The search for reserves is aimed at reducing the weight of structures, reducing the costs of their manufacture, delivery and installation. Based on this, the task of intensive use of light materials is actualized. For this, the development of measurement methods, bamboo designs, and methods for constructing spatial systems from bamboo is

necessary. Constructions and building materials must meet the requirements of energy efficiency and resource-saving. Consequently, it is necessary for renewability and reasonable resources to employ local raw materials — reduce transportation cost, exercise suitable materials in the region and the recycling of materials.

In developing countries, bamboo is considered a common material, due to lack of resources, and it is also often used in rural communities. In recent years, there has been a change in this approach and today you can find bamboo as a noble material for a variety of uses. The use of advanced technologies in construction areas will contribute in the development and expansion of bamboo applications (buildings, structures, bridges and others). This will enable further possibilities of study of modern structural elements made by bamboo, the extension of the nomenclature, the typology of buildings and structures in which the use of this effective material is possible.

Bamboo ‘Guadua’ has become an excellent material for solving many problems in the construction for various segments of the population in different segments of the population. Bamboo has significant competitive advantages in comparison with other traditional materials. Sustainable architecture dictates new principles for the use of environmental materials in modern constructions. Bamboo designs have very good reasons for becoming the ideal in the 21st century. Bamboo has a low level of unfavorable effects on the environment. The use of bamboo structures has very good reasons for spreading it across the world where the material is available.

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