International Journal of Advanced Science and Technology
Vol.72 (2014), pp.49-62
http://dx.doi.org/10.14257/ijast.2014.72.05

Investigation on the Physical Properties and Use of Lumampao Bamboo Species as Wood Construction Material

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Abstract

This study focuses on investigating the physical properties and use of lumampao bamboo as a substitute to wood constructional material. The development of lumampao bamboo may potentially bring some positive outcomes and contribute to relieving the deforestation issue. To be able to develop the lumampao bamboo potential either in Philippines or other countries, some tasks are still needed to do beforehand. One of the interesting insights in the study shows that the physical properties of lumampao bamboo may potentially become an alternative to wood constructional material under certain circumstances.

Keywords: *Construction materials, indigenous materials, lumampao bamboo, wood materials*

1. Introduction

Bamboo is a native product common used as primary construction material in Asian countries prior to the introduction of steel alloy and concrete.

Since the introduction of the composite materials (steel and concrete), bamboo has been neglected because may be of its inadequate stiffness than other construction material.

Similarly, bamboo has also a long and well established tradition for being used as a construction material throughout the tropical and sub-tropical regions of the world. With the rising global concern, bamboo is a critical resource as it is very efficient in sequestering carbon and helps in reduction of greenhouse gas emissions. In the modern context when forest cover leaves fast depleting and availability of wood is increasingly becoming scarce, the research and development undertaken in past few decades have established and amply demonstrated that bamboo could be a viable substitute of wood and several other traditional materials for housing and building construction sector and several infrastructure works. Its use through industrial processing have shown a high potential for production of composite materials and components which are cost-effective and can be successfully utilized for structural and non-structural applications in construction of housing and buildings. Main characteristic features which make bamboo as a potential building material are its high tensile strength and very good weight to strength ratio. It can withstand up to 3656 Kg/cm^2 of pressure. It can be easily worked upon by simple tools and machines. The strength-weight ratio of bamboo also supports its use as a highly resilient material against forces created by high velocity winds and earthquakes. Above all bamboo is renewable raw material resource from agro-forestry and if properly treated and industrially processed, components made by bamboo can have a reasonable life of 30 to 40 years. Varied uses and applications in

ISSN: 2005-4238 IJAST

building construction have established bamboo as an environment-friendly, energy-efficient and cost-effective construction material. With the rising need of housing, buildings and roads the country requires a variety of alternate building materials and construction systems and advancements in bamboo technology offer several cost-effective and environment friendly options.

Bamboo is a highly versatile resource and widely available needs to be adopted as an engineering material for construction of houses and other buildings. In order to propagate these for wider application, awareness and confidence building amongst professionals and householders is required. This calls for organized action on prototyping, demonstration, standardization aimed at improving acceptance levels and promoting appropriate construction practices. One of the key objectives of the proposed National Mission on bamboo is to promote value added products which are being commercially and industrially produced. Demonstration projects based on bamboo applications will help in creating high visibility for use of bamboo as a material for housing construction. Once the demand is built up, investment from entrepreneurs will be automatically flow to enhance availability of bamboo based materials and components.

Several manufacturing units are already engaged in production and marketing of bamboo based building materials (boards, panels, composites, laminates, roofing sheets) Variety of industrially produced products and elements are being used in building construction besides hundreds of traditional systems and types where bamboo is predominantly used for house/building construction.

Philippines currently relies on imported wood for most of its wood domestic consumption. Philippines has considerable amount of wood stock but less accessible. While in the future, the domestic demand of wood in Philippines is likely to increase. Constructional wood accounts for over 30% of total wood consumed in Philippines. Approximately 70% of that constructional wood comes from imported wood and mostly are designated for structural purposes. Considering the above situation, it will be helpful if there is an alternative material that can replace constructional wood material.

Among many possible alternative materials, bamboo which is available .However, since in order to be able to substitute wood construction material there are many requirements should be fulfilled; whether bamboo can really serve as an alternative to constructional wood material in Philippines is still questionable.

In order to be able to substitute wood constructional material, a material must be able to function as wood constructional material. It requires the material to be able to perform at least the same or better than wood constructional material; address the regulation restrictions in using wood constructional material; be economically competitive; be accepted by the consumers and so on.

Even though, there are many requirements should be fulfilled, this study will only investigate two preliminary and very important premises. These are the physical properties and the availability of material .The physical properties are investigated to have insight whether bamboo can perform as well as wood which is required for safety assurance. While the availability of the material is investigated to address and avoid the problem which is currently faced by wood constructional material, import dependency.

2. Literature Review

Bamboo, like true wood, is a natural composite material with a high strength-to-weight ratio useful for structures [1].

In its natural form, bamboo as a construction material is traditionally associated with the cultures of South Asia, East Asia and the South Pacific, to some extent in Central and South America, and by extension in the aesthetic of Tiki culture. In China and India, bamboo was used to hold up simple suspension bridges, either by making cables of split bamboo or twisting whole culms of sufficiently pliable bamboo together. One such bridge in the area of Qian-Xian is referenced in writings dating back to 960 AD and may have stood since as far back as the third century BC, due largely to continuous maintenance.

Bamboo has also long been used as scaffolding shown in figure 1; the practice has been banned in China for buildings over six stories, but is still in continuous use for skyscrapers in Hong Kong [2].

Figure 1. Bamboo used as Scaffolding

In the Philippines, the nipa hut is a fairly typical example of the most basic sort of housing where bamboo is used; the walls are split and woven bamboo, and bamboo slats and poles may be used as its support shown in Figure 2.

Figure 2. Nipa Hut in the Philippines

In Japanese architecture, bamboo is used primarily as a supplemental and/or decorative element in buildings such as fencing, fountains, grates and gutters, largely due to the ready abundance of quality timber shown in Figure 3[3].

Figure 3. Japanese Architecture Using Bamboo

Various structural shapes may be made by training the bamboo to assume them as it grows. Squared sections of bamboo are created by compressing the growing stalk within a square form. Arches may similarly be created by forcing the bamboo's growth into the desired form, costing much less than it would to obtain the same shape with regular wood timber. More traditional forming methods, such as the application of heat and pressure, may also be used to curve or flatten the cut stalks [4].

Bamboo can be cut and laminated into sheets and planks. This process involves cutting stalks into thin strips, planning them flat, and boiling and drying the strips; they are then glued, pressed and finished [7]. Long used in China and Japan, entrepreneurs started developing and selling laminated bamboo flooring in the West during the mid-1990s; [6] products made from bamboo laminate, including flooring, cabinetry, furniture and even decorations, are currently surging in popularity, transitioning from the boutique market to mainstream providers such as Home Depot. The bamboo goods industry (which also includes small goods, fabric, etc.) is expected to be worth $25 billion by 2012 [5]. The quality of bamboo laminate varies among manufacturers and varies according to the maturity of the plant from which it was harvested (six years being considered the optimum); the sturdiest products fulfill their claims of being up to three times harder than oak hardwood while others may be softer than standard hardwood [7].

Bamboo intended for use in construction should be treated to resist insects and rot. The most common solution for this purpose is a mixture of borax and boric acid. Another process involves boiling cut bamboo to remove the starches that attract insects.

Bamboo has been used as reinforcement for concrete in those areas where it is plentiful, though dispute exists over its effectiveness in the various studies done on the subject. Bamboo does have the necessary strength to fulfill this function, but untreated bamboo will swell with water absorbed from the concrete, causing it to crack. Several procedures must be followed to overcome this shortcoming [7].

Several institutes, businesses, and universities are researching the use of bamboo as an ecological construction material. In the United States and France, it is possible to get houses made entirely of bamboo, which are earthquake- and cyclone-resistant and internationally certified. In Bali, Indonesia, an international K-12 school, the Green School, is constructed entirely of bamboo, for its beauty and advantages as a sustainable resource. There are three ISO standards for bamboo as a construction material [8].

In parts of India, bamboo is used for drying clothes indoors, both as a rod high up near the ceiling to hang clothes on, and as a stick wielded with acquired expert skill to hoist, spread, and to take down the clothes when dry. It is also commonly used to make ladders, which apart from their normal function, are also used for carrying bodies in funerals. In Maharashtra, the bamboo groves and forests are called Veluvana, the name velu for bamboo is most likely from Sanskrit, while vana means forest.

Furthermore, bamboo is also used to create flagpoles for saffron-colored, Hindu religious flags, which can be seen fluttering across India, especially in Bihar and Uttar Pradesh, as well as in Guyana and Suriname in South America.

Bamboo was used for the structural members of the India pavilion at Expo 2010 in Shanghai shown in Figure 4. The pavilion is the world's largest bamboo dome, about 34 m (112 ft) in diameter, with bamboo beams/members overlaid with a ferro-concrete slab, waterproofing, copper plate, solar PV panels, a small windmill, and live plants. A total of 30 km (19mi) of bamboo was used. The dome is supported on 18-m-long steel piles and a series of steel ring beams. The bamboo was treated with borax and boric acid as a fire retardant and insecticide and bent in the required shape. The bamboo sections were joined with reinforcement bars and concrete mortar to achieve the necessary lengths [9].

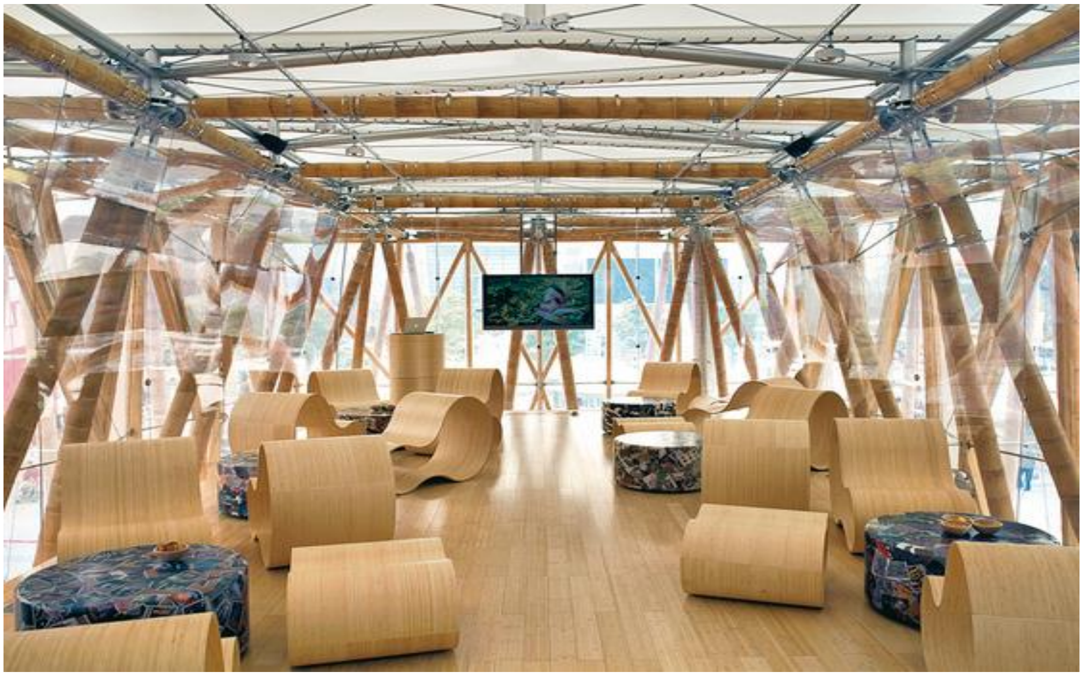

Figure 4. India Pavilion Using Bamboo

Jörg Stamm most impressive bamboo construction is the Tiga Gunung (three mountains) in Bali, Indonesia shown in figure 5. Built as a workshop and event building that covers 1200 square meters [5, 9]. Three about 15 meters high towers carry a suspended roof construction and at the same time form three skylights to give the interior its significant and unique architectural expression. The famous and iconic building is used as event location and showroom of an international jewelry. This is an example of architectural design in promoting a building material, that is locally despised as “poor man‘s timber” to the highest acceptance and most representative use. But the building also shows the most obvious problems in building with natural bamboo poles. Mostly because of its joints construction is hardly statically calculable. In the case of the Tiga Gunung building, the construction proofed to be not braced enough and undulates under the load of strong wind. By far most bamboo structures are designed just by the experience of the architect and not calculated according to standard specifications. That‘s why in many constructions structural elements are by far over-designed and therefore disproportionate. For simple and repeating building tasks that procedure might be suitable. But even in China, India and South East Asia, where there is a tradition of building sophisticated bamboo constructions with a great variety of well elaborated joints for thousands of years, the designing and planning process has not yet caught up with methods used in every day‘s practice constructing with timber, steel, or concrete work [4, 9].

Figure 5. Tiga Gunung Building (Interior) in Bali Indonesia

In some cases, like the ZERI-Pavilion, stability is determined by mechanical load tests, an appropriate, but expensive way of designing structural elements [9.10]. That method of defining structural elements is the most promising in constructions of a high quantity of repeating elements and without complex dependencies. Markus Heinsdorff took a very different approach designing the German-Chinese House at the Expo 2010 in Shanghai, China as shown in Figure 6. His design combines primarily structural elements of natural bamboo poles and of laminated bamboo trusses, frames and panels. To pass German as well as Chinese building regulations, all parts of the structure had to be verified for its stability by calculation. The laminated structural elements produced in China were of very homogeneous quality, could be tested at the Tongji University in Shanghai and calculated in the manner of timber constructions, even though for the first time laminated bamboo trusses with a span of seven meters were produced. The harder part was to deal with the structural elements made of natural bamboo poles. In order to create a reliable and rather invisible joint between two poles, the common technique of steel connections implemented in concrete fillings of the outer internodiums of the bamboo canes were chosen. To optimize the compound properties between bamboo and concrete, the Technische Universität Darmstadt made an innovative concrete mix formula aside from avoided shrinking of the concrete filling, but also improved adhesion between both of the compounds. Material testing of the connections generated reliable values for static calculations.

Figure 6. German-Chinese House at the Expo 2010 in Shanghai, China

Like timber, bamboo is an in homogeneous and ansiotropic material. Analogous to wood products like cross laminated panels, the strategy of producing a rather homogenous material by cutting and reassembling is adapted to bamboo. Cross lamination of layers reduces its anisotropic qualities. With laminated bamboo is already an elaborate bamboo material are available in many regions and can be used in the same way as timber products. An example for that possible substitution is the project of a restaurant building in Zhoushan, China designed by Hermann Kaufmann, Wolfgang Huss and Stefan Krötsch shown in Figure 7 [10].

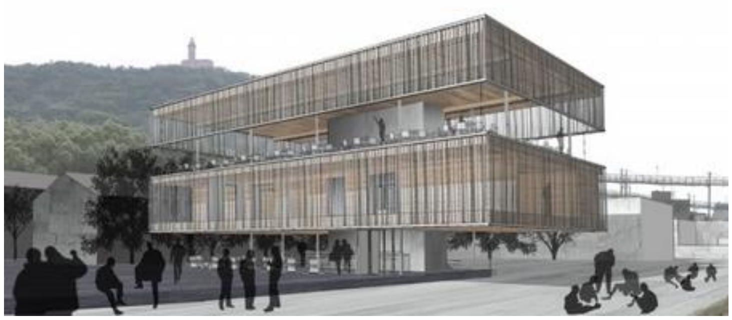

Figure 7. Restaurant Building in Zhoushan, China

Designed as a timber construction in the first place, it was changed into a construction of laminated bamboo since high quality timber was locally not available. That change of material had almost no altering impact to the structural design.

Bamboo symphony is an office building in Bangalore that promotes the use of more natural building material like bamboo shown in Figure 8 [1,6]. The curvilinear office building extensively made use of locally sourced, recycled and natural building material like Bamboo, fly ash, recycled wood, metal and stone. Bamboo symphony is basically open air structure is built out of mud blocks made on site with locally available material and concrete shell roof over a lattice grid of bamboo provides shade and thermal mass. This office building attempts to use bamboo in place of wood or steel and even reduces the weight of the concrete by adding bamboo fibers in to the concrete mix. For walls Bamboo Crete precast wall panels are used. The office floors are made from bamboo.

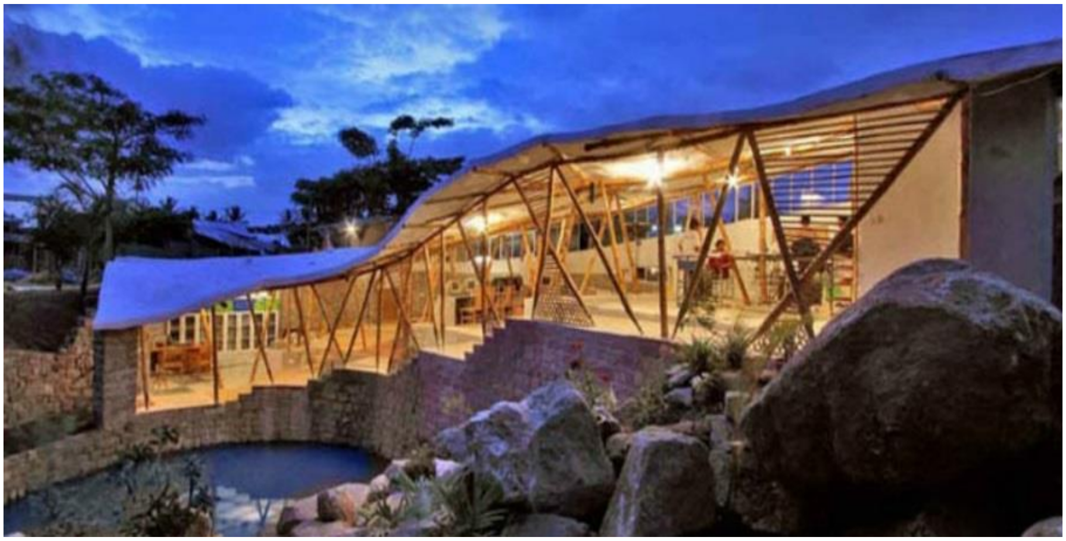

Figure 8. Bamboo Symphony Office Building

Some ambitious students at the Indian Institute of Technology in Bombay, India have constructed this bamboo bus stop for commuters shown in Figure 9 [4.6].

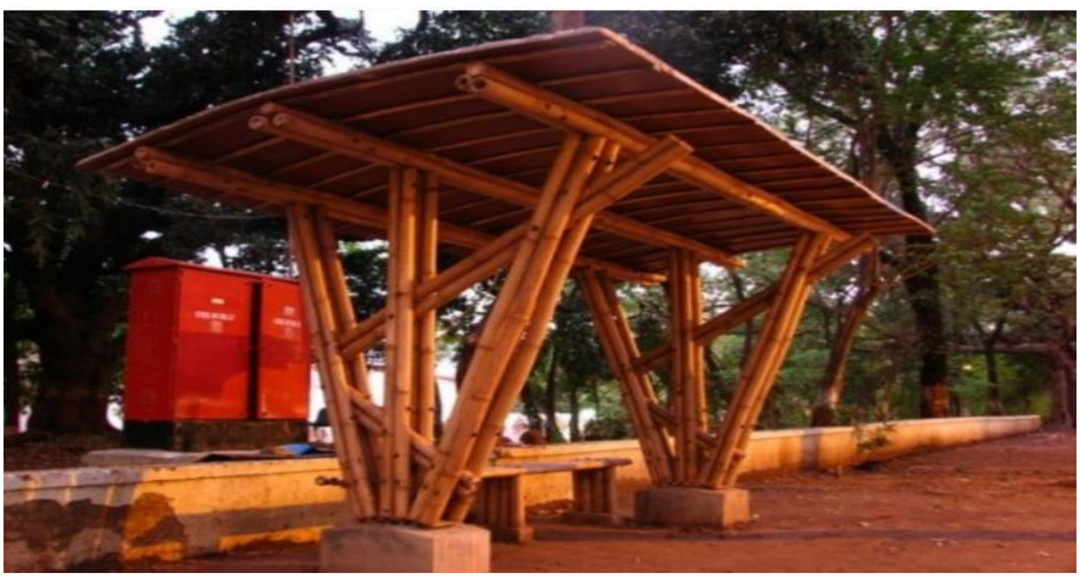

Figure 9. Bamboo Bus Stop

The structure is intended to demonstrate the structural efficiency of bamboo and raise awareness of it as a strong, versatile building material.

Simplicity infused with a traditionalistic virtue defines this interesting design concept of a housing project shown in Figure 10 [6,9]. This was proposed for Port au Prince, Haiti St Val Architect studio have supposedly been inspired by the prevalent traditional art of making cocoon-shaped baskets, composed from weaving natural plant fibers available from the local habitat. The buildings will maintain a vertical alignment so as not to increase the overall structural density of the area.

Figure 10. Vernacular Bamboo Housing Project in Haiti

Looking like voluptuous petals of a grandiose lotus about to unfurl upon a tree, this stunning treehouse restaurant shown in Figure 11 [10]. This was designed by Pacific Environments Architects Ltd. (PEL) in New Zealand.

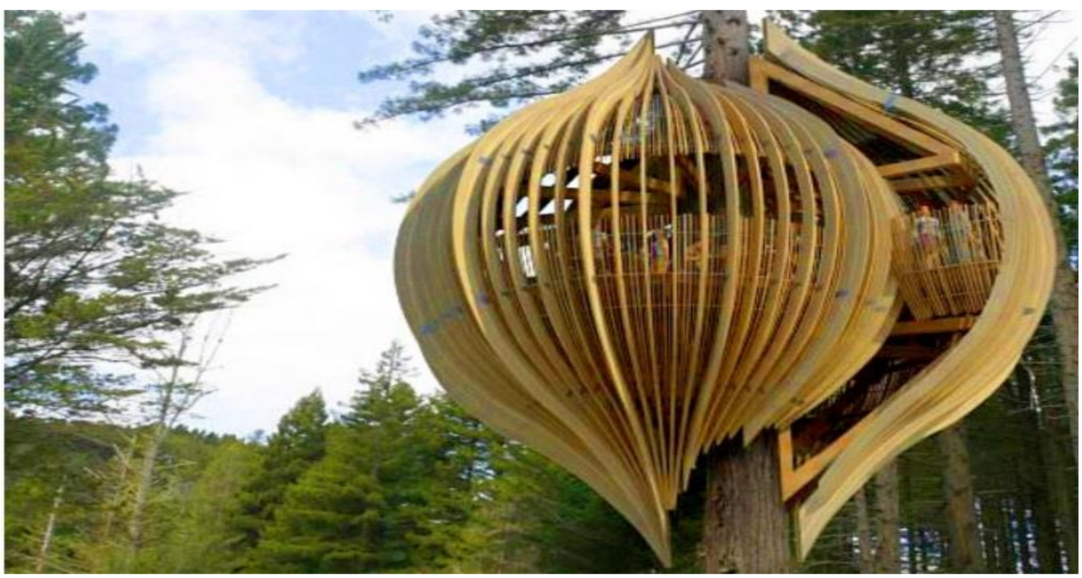

Figure 11. Tree house Restaurant in New Zealand

Though not strictly using bamboo, the conception does incorporate plantation poplar slats with redwood balustrading. Moreover it uses natural daylighting techniques to accentuate upon its naturalistic bearing.

3. Methodology

The physical properties of lumampao bamboo are compared to the requirement standard for structural lumber in order to understand the lumampao bamboo substitution potential. Since the requirement standard is varied depended on the species of wood, the type and function of the building, the location of the building etc.; this study adopts the physical properties of the most commonly used domestic wood for building material as the benchmark. In shorts, this study uses a comparative analysis method in order to examine the potential of bamboo to substitute structural lumber. Therefore, the physical properties of lumampao bamboo to the physical properties of the most commonly used domestic wood for building material are compared.

4. Results and Discussion

4.1. Physical Properties of Philippines Cedar and Lumampao Bamboo

As shown in Table 1, the specific gravity of lumampao bamboo 0.80; this is higher to the specific gravity of Philippine cedar. This proves that the specific gravity of different woody materials under the same condition in most cases can be used as an index for the strength of the materials and shows a positive relationship with the strength. This also confirmed that all bamboo culms ‘physical strengths shown in the table are greater than the physical strengths of the Philippines cedar.

The compression strength parallel to the grain of the lumampao is 45.6MPa. The compression strength parallel to the grain obtained from the study is considerably low compared to results from other studies. It might be caused by the higher moisture content of the specimens compared to moisture content of other studies specimens. On the other hand, compression strength parallel to the grain obtained shows the highest value among others. It might be because the specimen used in this experiment was said to be 6 years old where the bamboo culms are about the mature age with optimum strength.

In the case of the bending strength, the result is lower compared to the result. It might be because of the different age of the culms samples their use and the moisture content of the specimen.

Even though the values indicating the physical strengths of the lumampao bamboo shown in table 1 are varied; in overall, the physical strengths of the lumampao bamboo are superior compared to the physical strengths of Philippines cedar. In other words, if the physical strengths of bamboo is assumed to be same as the physical strengths of its raw material and only the physical strengths which taken into consideration to determine the possibility of using bamboo as alternative building material; bamboo can be considered one possible option.

However, in terms of the dimensional stability, the shrinkage rate indicates that bamboo seems to be more easily affected by the changes in the environment especially moisture compared to Philippine cedar. Since the physical strength and moisture content of the material are in general negatively related; this physical property of bamboo may restrict potential as alternative building material regardless its strength performance. Further, considering the production of bamboo which includes so many processes; the bamboo is expected to have different physical properties to its raw material.

Table 1. Physical Properties of Philippines Cedar and Lumampao Bamboo

Physical Properties	Philippines Cedar	Lumampao Bamboo
Specific gravity	0.67	0.80
Tensile strength parallel to the grain (MPa)	56.7	145.6
Compression strength parallel to the grain (MPa)	23.6	45.6
Compression strength perpendicular to the grain (MPa)	-	32.6
Bending strength (MPa)	45.7	100.3
Shear strength (MPa)	5.9	11.2
Tangential shrinkage rate for every 1% change in moisture change (%)	0.21	0.23
Radial shrinkage rate for every 1% change in moisture change (%)	0.16	0.29

4.2. Availability of Lumampao Bamboo

The availability of bamboo resources in a region can be considered as the amount of bamboo material that can be used in manufacturing bamboo-based products. This bamboo resources availability mainly depends on the available production area (bamboo plantation area) and the productivity of that bamboo production area. The larger the production area and the higher the productivity of a unit production area, the more bamboo resources can be produced and available for bamboo –based products manufacturing. The extent of bamboo cover in a region naturally depends on the adaptability of bamboo to the environmental condition. However, the available area for bamboo production is in general the outcome of the decision made in designating land use which is influenced by the ownership of the land, socio-economic development plan, political factor, etc. This makes increasing availability of bamboo resources by expanding bamboo production area may require complicated legal processes. On the other hand, increasing bamboo resources availability by improving the productivity of the bamboo plantation is considered to be more relevant given that the production area is limited and sufficient information related to the bamboo plantation productivity is available.

The productivity of bamboo plantation is also affected by the age structure of the bamboo culms in the plantation. A plantation with high proportion of productive culms tends to grow exponentially if there is no limiting factor. On the other hand, a plantation with high proportion of old culms tends to diminish since old culm is relatively low in productivity. Old culm is also weaker compared to young culm which causes them easily attacked by insects or pests. Since plantation is a limited area and yield is expected, maintaining an equilibrium stock to produce sustain optimum yield is desired. For this reason, studies related to age structure of bamboo plantation have been done. Those studies came out with some hypothetical optimum age structure ratio, such as equal ratio for all age structure or equal ratio for even and odd age structure. But because the yield from a plantation is also influenced by many other factors, the optimum age structure for every plantation is different among each other.

Temperature is one important factor to the growth of bamboo particularly during the shoots development. Warm temperature is needed for lumampao bamboo to grow well;

regions in which the minimum summer temperature goes below 15 degree Celsius are not suitable. Lumampao bamboo is better grown in the area where the temperature is never lower than 3.7 degree Celsius and never higher than 30 degree Celsius. Water availability is another important growth factor to bamboo and the demand of water is different depends on the growth stage of the culms. In terms of precipitation, the optimum rainfall for the lumampao bamboo growth is around 500-500mm during the shooting time. Further, since the root systems of lumampao bamboo is relatively shallow, mostly concentrated up to 30 cm below ground; lumampao bamboo growths are prone to wind storm.

Even though, lumampao bamboo is believed to be able to grow well even on poor soil condition; suitable soil condition results in better productivity of the bamboo plantation. For example, the number of new shoots emergence increased with the application of fertilizer. Fertilizer application may be needed when the natural nutrient supply by soil and precipitation is not enough. Further, the most suitable soil conditions for lumampao bamboo is over 60cm deep fertile loam; pH = 3.5 to 6.0; moist but not soaked.

5. Conclusion

The physical properties of lumampao bamboo are still considerably stronger than those of Philippines cedar. The dimensional stability of lumampao bamboo is also comparable to the Philippines cedars. Therefore, if the requirement taken into consideration is only the mentioned physical properties; it can be simply said that lumampao bamboo has the potential to substitute Philippines cedar. In terms of constrains in the development of lumampao bamboo potential; the location of bamboo plantation, the availability of labor force to restore the bamboo plantation and engage in the production activities, way to motivate people to engage in bamboo related industry and the cost-benefit analysis of lumampao bamboo development are some factors should be clarified to address the constraints.

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