State of the Art on Bamboo- A Viable Tool in Construction

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Abstract

The present work investigates on use of bamboo and its application in the field of construction. Across the world, people have been using bamboo in construction for millennia. Its strong and lightweight characteristic gives an easy to build option in bamboo construction. Moreover it is resilient to wind, earthquake forces and readily repairable in the event of damage. This paper lays down emphasis on key parameters of viable use of bamboo in construction such as housing, protection of bamboo components, it's associated products (bamboo based panels and bamboo reinforced concrete) and various jointing techniques. As a renewable material, with incredibly fast growth rate and properties similar to wood, bamboo has the potential to play an important role in meeting construction needs for a rapidly urbanizing world in an environmentally sustainable way. Therefore constructive improvisation needs to be done in order to exploit bamboo as a construction material and further burgeoning effort should be made in areas of structural design, preservation, jointing and codification.

Keywords: Bamboo, Construction, Design, Joints, Prevention

I. INTRODUCTION

The world is divided into various climatic zones mainly tropical, temperate, cold, polar and dry. Bamboo has a long and well established tradition for being used as a construction material throughout the tropical and sub-tropical regions of the world. There are over thousand species of bamboo each with their own individual properties [9].Bamboo is the fastest growing plant on the planet and has been measured to grow as fast as 1.2 metres in a single day [5]. It is widely used for many forms of construction, in particular for housing in rural areas. Bamboo is a renewable and versatile resource, characterized by high strength and low weight, and is easily worked using simple tools. As such, bamboo constructions are easy to build, resilient to wind and even earthquake forces (given the correct detailing) and readily repairable in the event of damage. Associated products (bamboo based panels and bamboo reinforced concrete, for example) also find applications in the construction process. Modern studies find bamboo can be excellent structural option when compared to modern materials. Therefore this had lead to use of bamboo as a judiciously applicable construction material:

1) Bamboo Buildings: Bamboo's easy availability, workability and low cost have lead to its use in foundations, floors, walls, roofs, doors and windows.
2) Protection: To provide a safe and sustainable design suitable designing of structure and chemical treatments need to be implemented.
3) Construction applications: Bamboo reinforced concrete, panels and scaffolding are one of the major applications in bamboo construction.
4) Jointing: Various traditional as well as other jointing techniques have been used keeping in mind the cost effectiveness.

Varied uses and applications in building construction have established bamboo as an environment-friendly, energy-efficient and cost-effective construction material. With the rise in need for housing, buildings and roads, variety of alternate building materials and construction systems and advancements in bamboo technology offer several cost effective and environment friendly options.

II. BAMBOO BUILDINGS

Bamboo has been important organic building material in South, East and Southeast Asia. It is used in over 70% of rural houses and extensively employed in rural areas [33]. Due to urbanization and rapid population growth, some researchers have attempted to find new low-cost construction material to substitute steel [7, 8]. According to [24], bamboo building construction is characterized by a structural frame approach similar to that applied in timber frame construction. The floor, wall and roof elements are interconnected and often one dependent on the other for overall stability. Bamboo has a great economic potential, its adequacy and suitability depends on good detailing and its resistance from moisture ingress and fungal attack. All the above features are dealt with in following sections.

A. Foundations:

The types of bamboo foundation in common use are:

1) Bamboo in direct contact
2) Bamboo on rock or preformed concrete footings
3) Bamboo incorporated into concrete footings
4) Bamboo on steel shoes
5) Bamboo reinforced concrete
6) In general, it is best to keep bamboo clear of the ground, since untreated material can decay very quickly in ground contact.

B. Flooring:

The initial step for flooring in a bamboo building is the construction of plinth area with damp soil or mud in 6 inch layer. Once the plinth has been built and thoroughly compacted to the desired height, a final coat of clay-rich mud plaster with straw or cow dung should be applied to the floor of the plinth to achieve a smooth, final surface. The final floor plaster should also be dampened and compacted. Keeping in mind the economic aspect of construction, turfing with Hessian cloth and grass, clay and dung mixture can be used as erosion-prevention technique. Eventually bamboo boards, bamboo mats, culms and panels can be used for floor decking.

C. Walls:

The most extensive use of bamboo in construction is for walls and partitions. For bamboo wall construction, a basic skeleton is provided which consist of wood poles or wood framework, or rounded bamboo posts which serve as support for wall in the form of infill or cladding [6]. Infill between framing members is required to complete the wall. The purpose of the infill is to protect against rain, wind and animals, to offer privacy and to provide in-plane bracing to ensure the overall stability of the structure when subjected to horizontal forces. The infill should also be designed to allow for light and ventilation. Not least is its architectural and aesthetic function [22].

D. Roofing:

A number of cultures have used bamboo for roofing materials. The Chinese used bamboo for roofs with the ends covered with round tiles. In the Philippines, roofs of interlocking split bamboo are created with the part receiving the water being the soft inner surface of the bamboo. Corrugated sheet made from bamboo mats by IPIRTI, India has great potential for bamboo roofing. A bituminous or rubberized weatherproof coating can be used as finishing coat for the roof. Also a cement plaster, with or without the addition of organic fibers, is traditionally applied to bamboo roofs, to get stronger roof coverings.

E. Doors and Windows:

In traditional types of bamboo building, doors and windows are usually very simple in form of operation. Shutters for doors and windows are also made of bamboo. These are of three basic types: shutters that slide across the opening hinged shutters or pivoted shutters. Bamboo windows are generally left unglazed and can have bamboo bars, or a sash with woven bamboo infill. Various products from different bamboo panel manufacture technologies could be applied for doors and windows. According to [39], the main materials are bamboo square boards in different sizes or panels in different thickness. The panels can be made from plybamboo, particle board and bamboo-based medium density fireboard (MDF) process.

III. PROTECTION OF BAMBOO COMPONENTS

To provide safe and sustainable design various structural shapes and connection as well as necessary chemical treatments have to be implemented from the laboratory level to actual construction practice, particularly in housing projects. Protection is therefore essential to ensure longest possible life of material and the building in which it is used.

A. Protection by Design:

Protection of design is related to a sustainable design strategy which includes durability and green life cycle evaluation (short term strategy), satisfying demands and principle of technological feasibility (middle term strategy), behavioral change in bamboo and services provided to it is the long term strategy. Keeping in mind the above design strategy, there are some design aspects to be followed:

1) Keeping Dry:
Extended roof eaves are used to prevent direct wetting of walls during rain. Rainwater gutters can be used to discharge water away from the house.
2) Avoiding Ground Contact:
Concrete stump or if affordable, brick plinth should be used to support bamboo posts. Resting bamboo walls on the plinth should be avoided. Better to have a small gap (around 1 inch) between wall bottom and floor.
3) Ventilation:
Roof space should be left exposed to allow better airflow and ventilation. If ceiling is used, it should allow ventilation and should be accessible for maintenance. Adequate number and size of windows should be built, oriented along the prevailing wind flow direction to allow cross ventilation.
4) Protection from Insects and Vermin:
Termite shield of galvanized MS sheet or cheaper polythene sheet should be used between bottom of bamboo post and its support, such as concrete stump or masonry plinth. Open ends of bamboo posts should be plugged to protect from rodent infestation.
5) Good Visibility:
Where possible, the roof space should be left exposed to improve both visibility and airflow, and aid routine maintenance.

B. Protection by Preservation:

Natural but low durability of bamboo is the major drawback of it in structural use. Several methods have been developed to remedy this. Soaking bamboo in water is a traditional method widely practiced in Indonesia, Vietnam, Bangladesh and other countries [38]. Steeping, sap-displacement, diffusion, hot-cold bath and pressure processes are some treatment methods adapted in India [27]. The diffusion process and the Boucheri process are suitable for the treatment of green bamboos [1, 30 and 35]. The performance of treated bamboo depends mainly on location of use and preservative employed. Bamboo treated with copper-chrome-arsenic (CCA) shows some decay after 15 years in exposed conditions. The performance is partially exposed or covered conditions are much better. A CCA- treated low cost bamboo house in India was found intact without any damage even after forty years of service [27]. In Columbia, a bamboo house with ceiling and walls plastered with cement mortar is reported to have lasted more than 90 years [11]. Also the Costa Rican National Bamboo Project (CRNBP) describes the technical and economic aspects of bamboo preservation. According to [32], treated and used properly, bamboo construction long last compared to any modern house. Preservatives can thus impart longevity to bamboo and thereby improve its performance in housing.

IV. OTHER TYPES OF CONSTRUCTION AND ITS APPLICATIONS

A. Scaffolding:

Bamboo scaffolding was first introduced to the building industry in Hong Kong immediately after colonization in the 1800s. This method was widely used in the building of houses and multi-story buildings (of up to four stories high) prior to the development of metal scaffolding in the last 100 years. The main advantages of bamboo scaffolding when compared with steel are its lightness and low cost. According to [23], if bamboo is to be used as a serious building material then it is encouraging that the work is being done to turn specification into an ISO code from which builders can be taught how to practice safe construction for multi storey buildings with the help of lashed joints. This is the only way safe construction practice can occur in multistory bamboo scaffolding. Also the Hong Kong Building Department (2002) code specifies every aspect of scaffolding construction including maintenance and bracing required.

B. Bamboo Based Panels:

The first recorded production of bamboo-based panels was in China during World War II. Since then, some 28 panel products have been developed. Among the technologies developed, only a few, like bamboo mat board and bamboo strip board, are the outcome of detailed investigations and industry-scale trials. As bamboo has the advantages of straight grain, beautiful color, high strength and toughness, and excellent abrasion resistance, bamboo-based panels have been widely used in the fields of vehicle, construction, ship building, furniture, and decoration to partly take the place of wood, steel, plastic etc in Asia, specially China. The various types of panel product can be broadly classified as follows:

1) Processed from slivers, strips or laths
2) Processed, peeled veneers
3) Reconstituted particles, strands or fibers.

C. Bamboo Reinforced Concrete:

Many steel and concrete structures built in the past reveal serious deterioration caused mainly by the corrosion of the steel reinforcement. Similar to reinforcement, bamboo mesh has been used to reinforce cement mortar under the name 'Bamboocrete' [29, 37]. According to [26], a steel reinforced concrete column after 10 service years and the first bamboo reinforced concrete beam tested at PUC-Rio in 1979 were presented and compared. It was observed that the bamboo segment of the beam reinforcement, treated against insects as well as for bonding with concrete, was still in satisfactory condition after 15 years. The fundamental aspects of stabilizing bamboo, the nature of bond between bamboo and concrete and the durability of bamboo in a matrix of concrete needs to be studied at length.

V. JOINTING TECHNIQUES

The jointing of bamboo is very different to any other materials and requires an understanding of how materials act under loading. Traditional wood jointing techniques are generally not applicable because of hollow and cylindrical nature of bamboo. The tapered nature of bamboo is very important to consider as the jointing techniques need to accommodate a range of diameters. [28] reports that, when comparing both ends, a three metre length of bamboo could easily vary in diameter by over twenty millimetres. Bamboo construction techniques do not have the standardized design and construction codes, but there are some basic rules to be followed. [4] published basic guidelines to be followed in bamboo joint construction. However, building of structurally efficient, more durable and possibly larger and more economic bamboo structures will depend on new improved and developed jointing technology.

A. Traditional Jointing Techniques:

1) Lashing:
It is the basic relying principle adopted in traditional jointing techniques. According to [5], it is the most common method of jointing bamboo. Lashing is found in construction across the world and can be traced back over thousand years. Lashing bamboo with steel wire is used in scaffolding to create structures up to forty storeys high [12] in China.
2) Butt Joints:
[24] looks into other common jointing techniques that only use natural materials. In bamboo structures the most common joint needed is when two bamboo culms run perpendicular to each other. They are commonly joined through a butt joint.
3) Splice Joints:
They are necessary in bamboo construction either to extend a culm to span between two points or to create a stronger beam by tying culms together. They following variations of the splice joint were collected by [24]:

1) Lapped Splice Joint
2) Side Plate Splice Joint
3) Sleeves and Insert Splice Joint

B. Other Techniques:

1) In formal Construction (such of multi storey buildings), lashing does not produce enough stiffness in connection and better options are needed. An alternative is to clamp the culm between pieces of wood or plywood connected with bolts as rigidity can be improved by making use of moment of the plane moment of inertia of the pieces of plywood.
2) A different proposal by [36],in which bamboo elements are lashed to a steel plate. The author reports that a full-scale dome was constructed in India using this joint with good results. The advantage of the design is that advantage is taken of the rigidity of the plate, but that damage to the culms is avoided. No report was made on the rigidity of the joint itself, but it is very likely that this characteristic largely depends on the quality of lashing.
3) A system has been developed by the Costa Rican Bamboo National Project in which steel bars run inside the culm. The bar is welded at the extremes to the steel plates. The extreme internodes are filled with mortar to prevent insects from entering and to keep the bar in position.
4) According [24], preservative treatment of the bamboo and protection from wetting by good detailing will increase the life of the joint. The use of wire is in many cases preferable to bamboo lashings or rope as it is not subject to insect attack.

C. Cost Effectiveness:

Taking the interests of bamboo users into account, any submission or proposal must fulfil requirements of cost-effectiveness. In themselves joints are one of the highest components of structural costs in a building. But it is common knowledge that joints affect the overall structural costs as well, because they change the amount of structural material needed, construction time, labour

needs, and architectural design possibilities. The real impact on joints to the total cost is not a simple matter to determine, and it certainly would be a mistake to simply compare joint to joint by the cost of material involved.

VI. CONCLUSION

In this investigation, use of bamboo as an engineering material is limited from the point of view of design and safety factors by several major considerations:

1) The reason for its non-popularity can be attributed to the precautions that have to be taken during the design and construction of the structural elements. Therefore further analysis is required on how to simplify its treatment and eliminate operational problems in making bamboo one of the key structural materials.
2) The formulation of structural design guidance is governed largely by practical, engineering experience. In the case of bamboo, information from this source is somewhat limited.
3) Basic mechanical properties have been dealt with by many authors, but, unlike timber, bamboo properties do not relate well to species because of the dependency on other factors, such as geographical location and age.
4) Bamboo's behaviour towards water adsorption is a major area of research.
5) Behaviour of bamboo against flammability and its cost of treatment being high is a major concern.
6) Bamboo joints behaviour when subjected to fluctuating wind pressures is also a major area of research.

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