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DEVISE/FORMULATE AN APPROPRIATE DESIGN AND TECHNOLOGY TRANSFER PROCESS TO EXISTING BAMBOO PROCESSING CRAFTSMEN AND HANDICRAFTS INDUSTRY TO USE MODERN MANUFACTURING PROCESSES AND METHODOLOGY TO BE EFFECTIVE IN FORMING THE SUPPLY CHAIN FOR MASS MANUFACTURING OF BAMBOO BASED PRODUCTS IN CONSTRUCTION AND HOUSING AS WOOD SUBSTITUTE

PRANJAL KUMAR PHUKAN

Research Scholar, Department of Design, Indian Institute of Technology, Guwahati, Assam, India

ABSTRACT

Bamboo has for long been considered as one of the most important resources that can influence the state of society, as it is known to lessen rural poverty, empower women and rejuvenate the environment. Worldwide, especially in the tropical and sub-tropical regions, bamboo has been traditionally used as a building material. Bamboo has well established itself in the area of construction. Its usage is more prevalent in the rural areas. Roughly, 1200 species of bamboo grow in 14.5 million hectares of land, with the majority growing in Asia, Africa and Latin America. Approximately, bamboo grows at the rate of 7.5 to 40 cm a day, with the world record held by a bamboo shoot in Japan that grew at the rate of 1.2 m in just 24 hours. Bamboo is ready for harvest in about four to five years in the commercial varieties. Following their maturation, the wood can be harvested multiple times every second year; they continue to yield indefinitely in most of the species; however, in some, the yield is restricted to 120 years. In India, the use of bamboo in brick making provides an alternative source of income to those living in areas where the soil has been ravaged. The rural community primarily uses bamboo as its construction material, and as such, bamboo is essential in developing countries. In rural areas, mainly domestic houses are constructed, which are often simple in design. Traditional construction methods rely on local skills and methods. The other structures constructed in a rural area include farm and school buildings and bridges. In addition, bamboo is used for constructing scaffolds and water pipes, as well as for shuttering and reinforcement of concrete, in both rural and urban settings.

KEYWORDS: Flattened Bamboo, Composite Bamboo, Corrugated Sheets

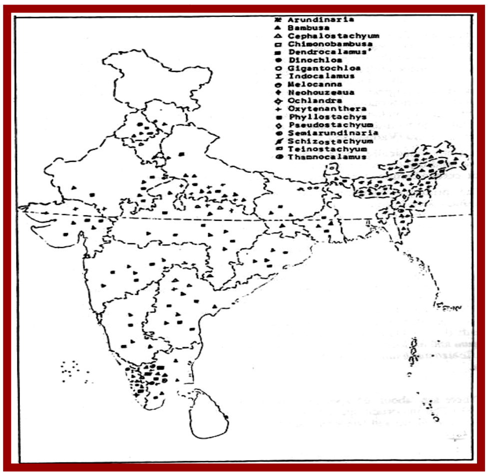
INTRODUCTION

BACKGROUND ON BAMBOO FOR CONSTRUCTION & HOUSING

Bamboo is the world's fastest growing woody plant, growing three-times faster than other plant species. It has wide applications as it can be easily worked on using simple tools. Its high strength and low weight makes it a versatile resource that is also renewable. Universally, bamboo-based products are profitable, non-timber forest resources, and therefore are socially and economically relevant. Bamboo is mainly used in housing, which is one of the priority items on the agenda of all governments in the world, i.e. to provide basic infrastructure for dwelling. Bamboo is the most promising material for this purpose. Traditional timber frame design and construction interconnects the wall, floor and roof elements, and they are dependent on each other for stability. Construction using bamboo is also known to have a similar approach, and so is suitable as an alternative, cheap construction resource. The use of bamboo for foundation is rather restricted. This could be because they deteriorate and decay quickly when in contact with the damp earth; however, this may be prevented by treating with some very effective preservatives. Consequently, they are primarily employed in constructing walls and partitions, and are an integral part of the structural framework. Bamboo is strong, resilient and lightweight, making it an ideal roofing material. In a rural atmosphere, bamboo use continues to transform villages by involving in the progress and expansion of enterprises.

Bamboo Diversity in India

India is the second richest country in bamboo genetic resources after China. These two countries together have more than half the total bamboo resources globally. Sharma (1987) reported 136 species of bamboos occurring in India. Fifty-eight species of bamboo belonging to 10 genera are distributed in the northeastern states alone. The forest area, over which bamboos occur in India, on a conservative estimate, is 9.57 million hectares, which constitutes about 12.8% of the total area under forests (Bahadur and Verma 1980). Out of the 22 genera in India, 19 are indigenous and three exotic.



MAJOR BAMBOO GROWING REGIONS / STATES

	AREA (%)	Gross Share
North East	28.0	66
Madhya Pradesh	20.3	12
Maharashtra	9.9	5
Orissa	8.7	7
Andhra Pradesh	7.4	2
Karnataka	5.5	3
Other States (Kerala, UP, Jharkhand, West Bengal)	20.2	5

Figure 1

Bamboo Resources in North East Region of India

In India, most species of bamboo are reported from the north-east region (Arunachal, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura and West Bengal – north Bengal Himalaya). Approximately, 115 species, i.e. 50% of the species, have been reported here. This region is considered as the centre of genetic diversity for *Arundinaria, Bambusa, Cephalostachyum* and *Dendrocalamus.* In addition, *Dinochloa, Melocanna* and *Thamnocalamus* are also predominantly found.

Table 1

State	Bamboo Growing Area (Sq. Km.)	Bamboo Stock (Million tons)
Mizoram	**9210**	**10.89**
Assam	**8213**	**13.41**
Arunachal Pradesh	**4590**	**9.84**
Manipur	**3692**	**11.47**
Meghalaya	**3102**	**4.41**
Tripura	**939**	**0.86**
Nagaland	**758**	**3.66**
Total	**30504**	**54.53**

Distribution of Main Species of Bamboo in India

India has one of the richest bamboo resources in the World, second only to China in Bamboo production. The annual bamboo production in the country is estimated at 3.23 million tons. According to Forest Survey of India (FSI), in India bamboo grows in 8.96 million hectares of forest area, which constitutes about 12.8% of total forest area of the country. Of this, nearly 28% occur in the North Eastern States, followed by 20.3% in Madhya Pradesh, 9.90% in Maharashtra, 8.7% in Orissa, 7.4% in Andhra Pradesh, 5.5% in Karnataka and the balance is spread over in other states.

Table 2

Species	States/UTs
Bambusa arundinacea	Arunachal Pradesh, Karnataka, Orissa, Maharashtra, Himachal Pradesh, Andhra Pradesh and Gujarat
Bambusa balcooa	Arunachal Pradesh, Mizoram
Bambusa pallida	Arunachal Pradesh, Nagaland, Mizoram, Tripura
Bambusa tulda	Arunachal Pradesh, Assam, Mizoram, Nagaland, Tripura
Bambusa polymorpha	Tripura
Dendrocalamus hamiltonii	Arunachal Pradesh, Assam, Mizoram, Nagaland
Dendrocalamus longispathus	Mizoram
Dendrocalamus strictus	Andhra Pradesh, Assam, Gujarat, Maharashtra, Himachal Pradesh, Madhya Pradesh, Manipur, Orissa, Karnataka, Uttar Pradesh, Rajasthan
Melocanna bambusoides	Assam, Mizoram, Nagaland, Tripura, Manipur, Meghalaya
Neebenzia balcooa	Nagaland
Oxytenanthera nigrociliata	Tripura, Assam
Oxytenanthera parviflora	Assam
Pseudostachyus polymorphium	Arunachal Pradesh
Polystachia pargracile	Orissa

Distribution of Bamboo Species in India

Species	Availability % Growing Stock	States
D. *strictus*	45	Meghalaya, Manipur, Nagaland, Orissa
M. *baccifera*	20	Assam, Manipur, Meghalaya, Mizoram, Tripura
B. *arundinacia*	13	Nagaland, Karnataka, Orissa
D. *hamiltonii*	7	Arunachal Pradesh, Assam, Nagaland
B. *tulda*	5	Arunachal Pradesh, Nagaland, Tripura
B. *pallida*	4	Arunachal Pradesh, Nagaland, Tripura
Rest	6	

Figure 2

Characteristics of Bamboo as Construction Materials

Bamboo is a grass common in tropical zones. Since time immemorial, it has been used for construction and for preparing artifacts. However, until recently, its usage was limited to small, poor establishments, despite having superior mechanical (tension and bending) and anatomical properties, as well as being lightweight, in comparison to timber. Its hollow, circular configuration differs from the regular, rectangular timber and presents both advantages and disadvantages. Further, its cellulosic fibers also pose several challenges in its suitability for construction.

The details as given in Table below with various tests for strength and mechanical properties and design rules which have been put forward by INBAR (ISO-22156, 22157, ISO/DTR-23157.2).

In areas prone to earthquakes, bamboo can be successfully used for housing. It is naturally highly resistant to earthquakes as it is both lightweight and hollow, thereby having high stiffness in relation to weight. Bamboo houses suffer relatively minor damages in an earthquake, and may provide shelter in the aftermath.

Comparison of Mechanical Properties between Bamboo and Rectangular Lumber

	Property	Bamboo	Rectangular Lumber	Assumptions
1.	Moment of Inertia, I	$I = 0.40A^2$	$I = 0.16A^2$	• For most bamboos, d = internal diameter = 0.82D • For timber, mostly h = 2 x b
2.	Optimum Material Use, EI	$4900A^2$	$2240A^2$	• Ecellulose = 70,000N/mm² • Efibre = 35,000N/mm² • 50% of cross-section of fibre is cellulose. • E≈350x% of fibres. • In bamboos, fibre is 60% on outside and 10% on inside, hence Eoutside = 350x60 = 21,000N/mm² and Einside = 350x10 = 3500N/mm² • Edahoma = 14,000N/mm²
	Bending	• Compression stress during bending may result in transverse strain in fibres of top face of culm. Lignin in fibres is weak in strain. Coherence in cross-section is lost and EI drops dramatically. • If load removed culm returns to original straight form.	• Timber will not regain original length when load is removed.	• Poisson coefficient for bamboo = 0.3.
4.	Shear	• Shear in neutral layer = 1.3x shear for timber • Smaller thickness to resist shear. • Larger forces on bolt fastnesrs at joints. • Advantage of not having a ray structure is nullified by hollow nature.	• Larger thickness to resist shear. • Has rays. Rays are mechanically weak. Hence, timber material is weaker in shear than bamboo material.	
5.	Torsion	• Better torsional resistance due to circular shape.	• Poorer torsional resistance because of sharp corners.	
6.	Wind Resistance	• Bending stress due to wind is constant over height of culm. • At top (near skin) vessels decrease and cellulose replaces vessels, leading to increase resistance to bending stress.		
7.	Compression	• Because of hollow nature and thus greater distance of solid mass from center, longitudinal shortening is greater and thus greater the likelihood of lateral strain in lignin. • Friction due to clamping at top and bottom of culm reduces lateral strain. • Amount of lignin deter-mines compressive strength not cellulose.	• Solid nature makes for better compres-sion resistance and reduced lateral strain.	
8.	Density	700 – 800kg/m³	850kg/m³	

Figure 3

Bamboo has varying specific gravity (0.5 to 0.79), and a density of about 648 kg/m3 (40.5 lb./ft3). Other article claimed that the average specific gravity of bamboo ranged from 0.3 to 0.8 [14]. Density is the major factor that influences the mechanical properties, and it is closely related to the proportion of vascular bundles. Shear, compression parallel to grain, bending at proportional limit and MOE are correlated with density and moisture content. The observation is that as moisture content decreases the mechanical properties increase, and as the density decreases the mechanical properties also decrease. This behavior is similar to mechanical properties of wood. Vascular bundle distribution is positively correlated with all the strength properties except for MOR. Vascular bundle size (radial/tangential ratio) and fiber length are positively correlated with compression strength, bending stress at proportional limit and MOE. The decrease in tangential size of the vascular bundle (mature stage or higher radial/tangential ratio) was accompanied by an increase in strength properties.

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 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. Though natural durability of bamboo varies according to species and the types of treatments, varied uses and applications in building construction have established bamboo as an environment-friendly, energy-efficient and cost-effective construction material.

Species Preferable for Construction in India

- Bambusa nutans
- Dendrocalamus brandisii
- Oxytenanthera stocksii
- Melocanna bambusoides
- Dendrocalamus strictus
- Dendrocalamus hamiltonii
- Dendrocalamus giganteus
- Bambusa bambos
- Bambusa polymorpha
- Bambusa balcooa

Figure 4

Fiber Texture and Mechanical Graded Structure of Bamboo

Among plants, bamboo has a unique structure which resembles that of a unidirectional, fiber-reinforced composite with many nodes along its length. Furthermore, bamboo's growth rate is very fast, producing an adult tree in only one year. This paper demonstrates that bamboo has a functionally graded and hierarchical structure. Bamboo's diameter, thickness and inter-nodal length have a macroscopically graded structure while the fiber distribution exhibits a microscopically graded architecture, which lead to smart properties of bamboo. The reinforcing fibers are oriented along the bamboo's culm (trunk), whereas in the nodes the fibers become entangled in a complicated manner to produce nodes with isotropic properties that provide additional reinforcement for the culm.

Grading is sorting out bamboo on the basis of characteristics important for structural utilization as under:

- Diameter and length of culm,
- Taper of culm,
- Straightness of culm,
- Inter nodal length,
- Wall thickness,
- Density and strength,

- Durability and seasoning.

One of the above characteristics or sometimes combination of 2 or 3 characteristics form the basis of grading. The culms shall be segregated species - wise.

Diameter and Length

Gradation according to the Mean Outer Diameter

- For structural Group A and Group B species, culms shall be segregated in steps of 10 mm of mean outer diameter as follows:

Special Grade 70mm <Diameter <100mm

Grade I 50mm < Diameter <70mm

Grade II 30mm < Diameter <50mm

Grade III Diameter <30mm

- For structural Group C species culms shall be segregated in steps of 20 mm of mean outer diameter:

Grade I 80 mm < Diameter <100 mm

Grade II 60 mm < Diameter< 80 mm

Grade III Diameter <60 mm

The minimum length of culms shall be preferably 6 m for facilitating close fittings at joints.

Taper

The taper shall not be more than 5.8 mm per meter length (or 0.58 percent) of bamboo in any grade of bamboo.

Curvature

The maximum curvature shall not be more than 75 mm in a length of 6 m of any grade of bamboo.

Wall Thickness

Preferably minimum wall thickness of 8 mm shall be used for load bearing members.

Defects and Permissible Characteristics

- Dead and immature bamboos, bore/GHOON holes, decay, collapse, checks more than 3 mm in depth, shall be avo ided.
- Protruded portion of the nodes shall be flushed smooth. Bamboo shall be used after at least six weeks of felling.
- Broken, damaged and discolored bamboo shall be rejected.
- Matured bamboo of at least 4 years of age shall be used.

Durability

The natural durability of bamboo is low and varies between 12 months and 36 months depending on the species and climatic conditions. In tropical countries the bio deterioration is very severe, Bamboos are generally destroyed in about one to two years' time when used in the open and in contact with ground while a service life of two to five years can be expected from bamboo when used under cover and out of contact with ground. The mechanical strength of bamboo deteriorates rapidly with the onset of fungal decay in the sclerenchymatous fibers. Split bamboo is more rapidly destroyed than round bamboo. For making bamboo durable, suitable treatment shall be given.

Treatability

Due to difference in the anatomical structure of bamboo as compared to timber, bamboo behaves entirely differently from wood during treatment with preservative.

Bamboos are difficult to treat by normal preservation methods in dry condition and therefore treatment is best carried out in green condition.

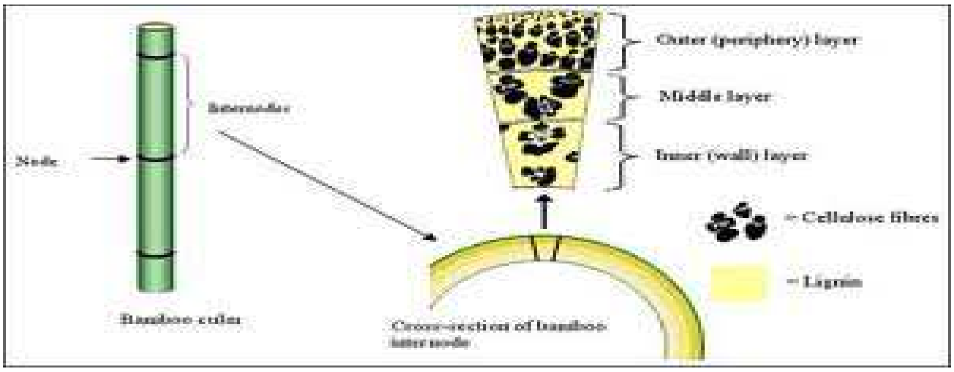


Figure 5

Structural Design Using Bamboo- Code of Practice

General principles involved in the design of structural bamboo in buildings with regard to mechanical resistance and durability of structures. It covers minimum strength data, dimensional stability, grading requirements and traditional bamboo joints for quality assurance. Work on site, fabrication of components off-site and their erection on site is covered to the extent necessary to indicate and ensure the quality of material and standard of workmanship to comply with the assumptions of the design rules and the limitations.

LIST OF REFERRED INDIAN STANDARDS

IS No.	*Title*
875	Design loads for building and structures:
(Part 1) : 1987	Unit weights of building material and stored materials (*second revision*)
(Part 2) : 1987	Imposed loads (*second revision*)
(Part 3) : 1987	Wind loads (*second revision*)
(Part 4) : 1987	Snow loads (*second revision*)
(Part 5) : 1987	Special loads and load combinations (*second revision*)
1734	Methods of test for plywood:
(Part 4) : 1983	Determination of glue shear strength (*second revision*)
(Part 5) : 1983	Test for adhesion of plies (*second revision*)
(Part 9) : 1983	Determination of tensile strength (*second revision*)
(Part 10) : 1983	Determination of compressive strength (*second revision*)
(Part 11) : 1983	Determination of static bending strength (*second revision*)
(Part 12) : 1983	Determination of scarf joint strength (*second revision*)
(Part 13) : 1983	Determination of panel shear strength (*second revision*)
(Part 14) : 1983	Determination of plate shear strength (*second revision*)
(Part 15) : 1983	Central loading of plate test (*second revision*)
(Part 16) : 1983	Vibration of plywood plate test (*second revision*)
(Part 17) : 1983	Long time loading test of plywood strips (*second revision*)
(Part 18) : 1983	Impact resistance test on the surface of plywood (*second revision*)
1902 : 2006	Preservation of bamboo and cane for non-structural purposes (*second revision*)
2366 : 1983	Code of practice for nail-jointed timber construction (*first revision*)
2380	Methods of test for wood particle boards and boards from other lignocellulosic materials:
(Part 4) : 1977	Determination of static bending strength (*first revision*)
(Part 5) : 1977	Determination of tensile strength perpendicular to surface (*first revision*)
(Part 6) : 1977	Determination of tensile strength parallel to surface (*first revision*)
4407 : 1967	Code of practice for reed walling
4924	Method of test for nail jointed timber trusses:
(Part 1) : 1968	Destructive test
(Part 2) : 1968	Proof test
6874 : 2008	Method of test for round bamboo (*first revision*)
9096 : 2006	Code of practice for preservation of bamboo for structural purposes (*first revision*)

Figure 6

Design Considerations for Structures

All structural members, assemblies or framework in a building shall be capable of sustaining, without exceeding the limits of stress specified, the worst combination of all loadings. A fundamental aspect of design will be to determine the forces to which the structure/ structural element might be subjected to, starting from the roof and working down to the soil by transferring the forces through various components and connections.

Unlike timber, bamboo properties do not relate well to species, being dependent among other factors, on position of the culm, geographic location and age. The practice in timber engineering is to base designs on safe working stresses and the same may be adapted to bamboo with the limitations that practical experience rather than precise calculations generally govern the detailing.

Bamboo as Construction Materials

Research indicates that the ultimate tensile strength of some bamboo species is similar to that of mild steel at yield point. This fact in association with the aforementioned merits enhances the use of bamboo for construction.

Bamboo is a versatile material. It has high strength-to-weight ratio, is easy to work with and is easily available. However, it should be chemically treated prior to usage to prevent decay, as it is not naturally durable. It can be used for making roof structure, such as purlins, rafters and reapers, for flooring, doors and windows, walls, ceiling, man-hole covers, etc.

Bamboo Trusses

Bamboo is as strong as the popularly used timber wood, such as teak and sal. Experiments involving a 4 m span truss of round bamboo and different jointing techniques for web-chord connections displayed similar results as that of timber.

Bamboo Roofs Skeleton

The framework of bamboo roofs is made by truss or rafters, and solid bamboo purlins are laid over it and lashed to the rafter with G.I. wire. A mesh of halved bamboo is made and is lashed to the purlins to cover the roof.

Bamboo Walling/Ceiling

As the bamboo material is light in weight it is more advantageous in earthquake prone areas as its chances of falling are very less and even if it falls it can be re-erected easily with less human and property loss with least efforts and minimum cost. Bamboo walls can be constructed in different modes like

- Whole stem, halved or strips of bamboo can nailed to one or both the sides of the bamboo frame
- Split bamboo mats can be fastened to the bamboo posts or mats can be woven, mud can also be applied to both sides of such mats
- Bamboo strips nailed to bamboo frame or posts for interior walling
- Cement or lime plastering can be done on the mud covering for better appearance and hygiene.

It has been found that the bamboo in the vertical position is more durable than in horizontal direction. For partition walls only single layer of bamboo strips are used.

Bamboo Doors and Windows

Bamboo frames can replace timber frames appropriate to function. Bamboo mat shutters fixed to bamboo frame or a panel of bamboo board fixed to the frame which is hinged to the wall can be used as door. Small framed openings hinged to the top in the wall can serve as windows.

Bamboo Flooring

Bamboo can be used as flooring material due to its better wear and tear resistance and its resilience properties. Whole culms act as frame work and the floor covering is done using split bamboo, bamboo boards, mats etc. by means of wire lashing these to the frame.

Reed Boards

Reed boards are made by flat pressing the reed at high temperatures. These reed boards are used in elements like flooring, walls, ceiling and roofing. They can also be used for partitions, doors, windows etc.

Scaffolding

Bamboo poles lashed together have been used as scaffolding in high rise structures due to their strength and resilience. The timber planks can be replaced with bamboo culms and these can be lashed to the vertical culms.

LITERATURE REVIEW ON JOINTS

Design and Techniques of Joints

Bamboo Joints

Round, tubular form of bamboo requires an approach different to that used for sawn timber. Susceptibility to crushing at the open ends, splitting tendency, variation in diameter, wall thickness and straightness are some of the associated issues which have to be taken care of while designing and detailing the connections with bamboo.

Traditional Practices

Such joining methods revolve around lashing or tying by rope or string with or without pegs or dowels. Such joints lack stiffness and have low efficiency.

Lap Joint

In this case, end of one piece of bamboo is made to lap over that of the other in line and the whole is suitably fastened. It may be full lapping or half lapping. Full section culms are overlapped by at least one internode and tied together in two or three places. Efficiency could be improved by using bamboo or hardwood dowels. In half lapping, culms shall preferably be of similar diameter and cut longitudinally to half depth over at least one internode length and fastened as per full lap joint.

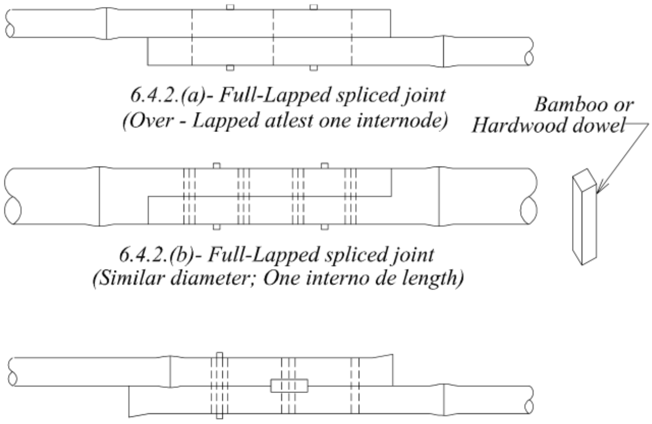


Figure 7

Butt Joint

Culms of similar diameter are butted end to end interconnected by means of side plates made of quarter round culm of slightly large diameter bamboo, for two or more internode lengths. Assembly shall be fixed and tied preferably with dowel pins. This joint transfers both compressive and tensile forces equally well.

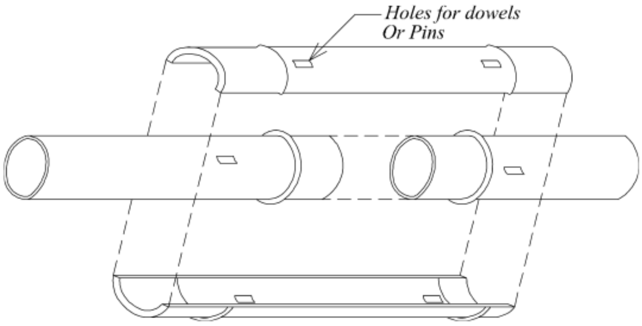


Figure 8

Sleeves and Inserts

Short length of bamboo of appropriate diameter may be used either externally or internally to join two culms together.

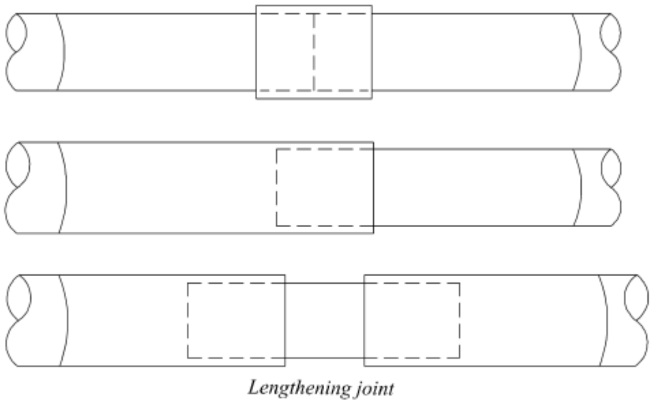


Figure 9

Modern Practices

Following are some of the modern practices for bamboo jointing:

Plywood or solid timber gusset plates maybe used at joint assemblies of web and chord connection in a truss and fixed with bamboo pins or bolts. Hollow cavities of bamboo need to be stuffed with wooden plugs.

Use of wooden inserts to reinforce the ends of the bamboo before forming the joints. Alternatively steel bands clamps with integral bolt/ eye may be fitted around bamboo sections for jointing.

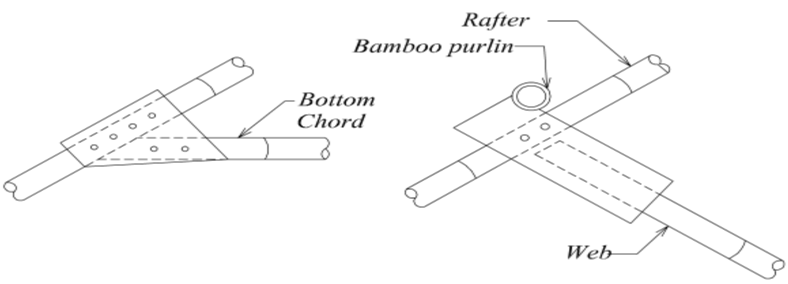


Figure 10

Modern connection by Shoei Yoh in 1989. For his bamboo roofs in Fukuoka, Shoei Yoh used a steel tube put into the bamboo and which is connected to the cane with bolts. Because of the numerous bolts the connection is also suitable for greater loads.

Figure 11

Modern connection by Renzo Piano Building Workshop in 1997. The canes are connected to a special designed steel element via binding wire. Instead of a bolt driven through bar and cane, a wire is tied through the holes and tied around the bamboo.

Figure 12

Wood Core Connection

A piece of wood can be used and glue can be employed to stick it to the inner surface of the bamboo. Two slots are needed in the bamboo cane to control cracking during the insertion of the wood cylinder. The wood fitting can be extended outside the culm to meet the out coming piece of wood from other elements, then normal wood construction methods can be used for connection.

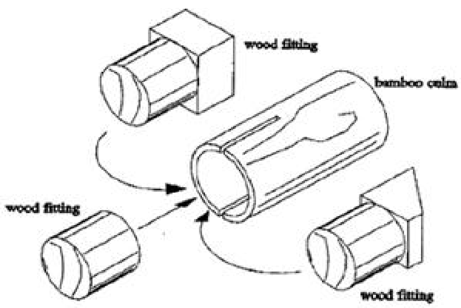


Figure 13

Supply Chain Management of Bamboo Products for Constructions

In India, several issues in its value chain plague the progress of the domestic bamboo industry. The rural populations are the primary users, but lack technical expertise. There are several challenges in its procurement, including regulatory and legislative barriers for its cultivation and harvest. Shortage of market linkages coupled with insufficient market demand constrain its usage to the personal space. Moreover, small firms that have insufficient capital to research and develop value-added products or enhance the quality of the existing ones produce bamboo products industrially. Studies on the bamboo industry in India are scarce, with inadequate data regarding its trade and commerce. Conventionally, bamboo has been confined to the handicrafts sector, as it is considered as a means of livelihood promotion. Government programs too fail to realize the industrial potential of bamboo. Conflicting legislation compounded by archaic and confusing regulatory regimes have thwarted the prospective uses of bamboo.

SCOPE OF STUDY

Objectives of Study

- Study of properties of most used species in Assam to support supply chain management of mass manufacturing processes of bamboo based products in construction and housing as wood substitute using traditional craftsmen.
- Study the role of present traditional technologies in supporting the implementation of advance technology and design aspects to the sector.
- Study the level of possible blend of Traditional and Modern technology in the process so that there is improvement in production standards, and application of the products.
- Study the extent of improvements/ developments in a product line with this blend.
- Study possible Integration of available infrastructural facilities for development of bamboo sector in Assam as per above objectives.

Research Questions

The overall design question will be relevant in finding the right form, technique or system. The technical research questions will try to focus on a specific interest within the broader field of bamboo research. Most preferably a technical research generates input for the design process. The following design questions are:

- In what way bamboo can be reinvented and use it as a structural building material to produce economical and safer housing and to increase traditional craftsmanship?
- What kind of bamboo structures is relevant to improve construction properties in a low cost way?
- How is the image of bamboo constructed and how can we change it?
- Regarding the existing bamboo construction methods, how can they be used or recombined to improve both the aesthetic and constructive value?
- Which methods of glue less ‘all-wood’ joining exist and how can they be applied to bamboo?

Research Methods

- In the course of a three-week field trip, visual and textual information would be gathered via questionnaires. There will be a set of prepared questions and visuals as well as spontaneous conversations obtaining valuable information.
- Furthermore, the existing literature on bamboo would be reviewed to comprehend the purpose of this study and its relevance to fill the lacuna among existing research.
- Thirdly, various tests on mechanical, chemical and anatomical structure will be carried out in Mechanical engineering department on the species commonly available in North East States of India.
- Finally, searching for the future of bamboo as a constructive building material in the Assam, experimental research or prototyping.

Hypothesis

Context specific Design and Technology Transfer will influence improvement and innovation of tools and products to facilitate forming of supply chain for mass manufacturing of bamboo based products in construction and housing as wood substitute.

Design Approach to the Study on Bamboo as Construction Material

Construction industry is one of the most polluting industries of the world. Production of 1 ton of cement emits > 1 ton of CO2 in the atmosphere and production of 1 ton of steel emits > 2 ton of CO2 in the atmosphere. However, production of 1 ton of bamboo consumes only > 1 ton of CO2 of the atmosphere. Bamboo also offers competitive strength to mass ratio.

MILD STEEL	Ultimate strength = 410 MPa	Yield strength = 250 MPa	Young's modulus = 200 GPa	Density = 7850 kg/m³
CONCRETE (Grade M 30)	Tensile strength = 3.8 MPa	Compressive strength = 38 MPa	Young's modulus = 27 GPa	Density = 2400 kg/m³
BAMBOO Dendrocallamus giganteus (Ghavami, 2007)	Tensile strength = 120 MPa	Compressive strength = 55 MPa	Young's modulus = 140 GPa	Density = 700 kg/m³

Figure 14

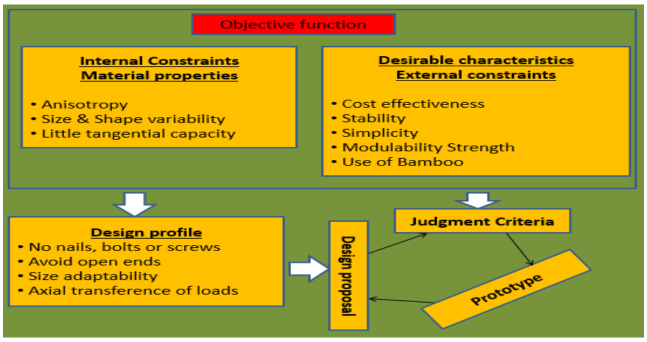


Figure 15

Design Approach to the Study on Supply Chain for Bamboo as Construction Material

The Cultivator grows the bamboo or procures it directly from the forests, and represents the initial stage of the supply chain. This sector is dominated by tribals, who cut bamboo in forests by flouting the existing legislation. Small farmers also grow bamboo alongside their regular crops. Aggregator Middlemen purchase this bamboo from the Cultivator. The Aggregator Middlemen collect the bamboo and sort it depending on its quality grade. The Aggregator Middlemen in turn deliver the bamboo to traders, who transport the bamboo to bazaars in large urban centres. Manufacturer's purchase them at an exorbitant price, but it is generally poorly sorted, unprocessed, and varies in quality. This causes wastage as high as 50%.

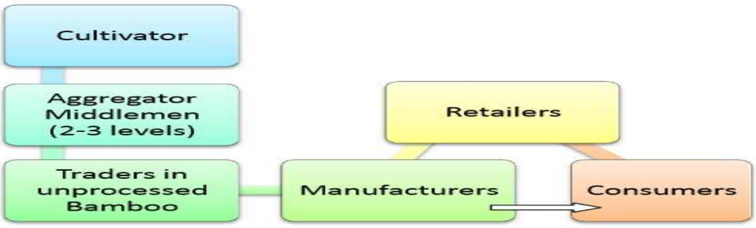


Figure 16

In India, commencing from the level of production, the value chain of bamboo depicts that numerous challenges need to be met at all stages. To present these challenges, the value chain is fashioned as per the terms of the Production to Consumption system framework developed by Belcher, 1995.

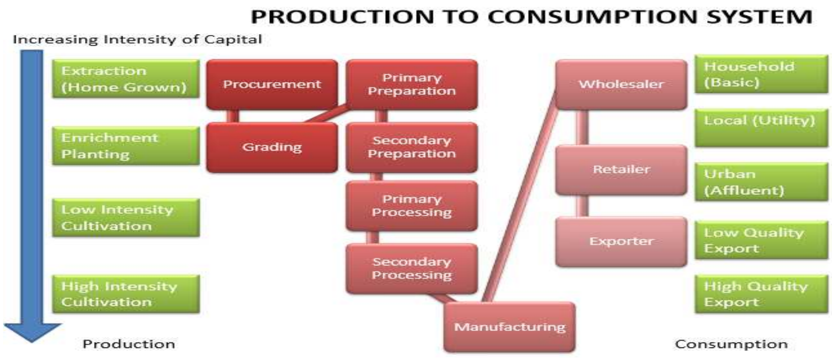


Figure 17

CONCLUSIONS

As Bamboo has been an intrinsic part of human life through the ages. It played a pivotal role in the progress of mankind. In addition to its usage as a woody material, it was also used as food, and thus was popular for several daily activities. Worldwide, bamboo is recognized as the backbone of rural life; this reputation of bamboo continues as the population increases. It is easily available in plenty, and has characteristics of a top-grade building material, allowing its extensive usage in the construction field. It is economically suitable and also its rate of productivity is very high. In fact, annual harvest yield of bamboo surpasses the yield of any other naturally growing resource. Three or four structural bamboo plants would mature in four or five years, and eight years later, it would provide enough material to build a comfortable, low cost house. Therefore, it not only promotes economic development, but is also a sustainable wood substitute. Thus, the usage of bamboo protects forest resources and the ecological environment.

REFERENCES

1. Janssen, J.J.A.1991. Mechanical properties of bamboo. Kluwer Academic Publishers. Forestry Sciences, Vol.37
2. Abd. Razak, O., M. Abd.Latif, W. Liese, and H. Norini. 1995. Planting and utilization of bamboo in Peninsular Malaysia. Research Pamphlet. Forest Research Institute Malaysia.
3. Wise, L.E., M. Murphy, and A.A. D'Addieco. 1946. Chlorite holocellulose, its fractionation and bearing on summative wood analysis and on studies on the hemicelluloses. Paper Trade Journal. 122(2):35
4. Jane, F.W. 1933. The microscopic examination of woody material. Watson's Microscope Record Number 30:9
5. Wilson, J.G. 1954. Specific gravity of wood substances. Forest Products Journal 16 (1):55-61.
6. Farrelly, D. 1984. The book of bamboo. Sierra Club Books, San Francisco, California.
7. Haygreen, J.G., and J.L. Bowyer. 1998. Forest products and wood science. An introduction, Iowa State University Press/Ames. Third Edition.
8. American Society of Testing Materials (ASTM). 1997. Standard test methods for specific gravity of wood and wood-based materials. Annual Book of ASTM Standards Des. D 2395-93 (Reapproved 1997) Vol –4.10. Philadelphia, PA.
9. Janssen, J.J.A. 1995. Building with bamboo, A handbook. Intermediate Technology Publications, London, U.K. Second Edition.
10. Parameswaran, N., and W. Liese. 1976. On the fine structure of bamboo fibres. Wood Sci. Technol. 10:231-246
11. Boehler, J.P. 1993. Failure criteria of structured media. Preceding of the CNRS International Colloquium No 351. Villard-De- Lans. France.
12. Tewari, D.N. 1992. A monograph on bamboo. International Book Distribution, Dehra Dun (India).
13. Shukla, N.K., R.S. Singh, and S.N. Sanyal. 1988. Strength properties of elevan bamboo species and study of some factors affecting strength. Journal of the Indian Academy of Wood Science. 19(2):63-80
14. Limaye, V.D. 1952. Strength of bamboo (Dendrocalamus strictus), Indian Forest Records. 1(1):1-17.46
15. Sattar, M.A., M.F. Kabir, and D.K. Bhattacharjee. 1994. Physical and mechanical properties of Bambusa arundinacea, Bambusa longispiculata, Bambusa vulgaris and Dendrocalamus giganteus. Bangladesh Journal of Forest Science. 23(2):2025.
16. Espiloy, Z.B., A.B. Ella, and A.R. Floresca. 1986. Physico-mechanical properties and anatomical structure relationships of two erect bamboo species. The Philippines Lumberman 32(4):25-27
17. Recht, C., and M.F. Wetterwald. 1992. The bamboos. Timber Press.
18. Kumar, S., and P.B. Dobriyal. 1992. Treatability and flow path studies in bamboo. Part 1.

19. Dendrocalamus strictus nees. Wood and Fiber Science. 24(2):113-117.

20. Anon.1992. Proceeding IUFRO DIV.V/ITTO/FROM. International workshop on improved utilization of timber resources in Southeast Asia. 7-11 Dec. 1992, Kuala Lumpur, Malaysia.

21. Forest Products Laboratory 1999. Wood handbook: Wood as an engineering material. FRS catalogue no.7269, p.3-1, U.S. Department of Agriculture