

Use of Bamboo as a Construction Material in the North-East and Southern Vernacular Settlements of India

Vijayalaxmi J. & Heisnam Roni Singha

School of Planning and Architecture, Vijayawada, India

Email: vijayalaxmij2@gmail.com, roni.singha29@gmail.com

Abstract

India is one of the largest producers of bamboo in the world with a vast knowledge of its usage among communities and artisans. It is necessary to stress on the importance of the use of Bamboo in with regard to sustainability, creative ideas, concepts and various construction methods in the modern world.

The objective of this paper is to study the use of bamboo with respect to the design and techniques in vernacular buildings of India. There, it is used and grown extensively as one of the important construction materials. This paper aims to research and analyze the style of bamboo construction in the Northeast and Southern parts of India through literature studies and field studies. The study will discuss, compare and chart the different traditions and techniques of use of bamboo in both the regions and their evolution through time, influenced by the species, climate, culture, research and development of the material. Bamboo today is considered as a 'Poor Man's Timber' and the acceptance of it as a preferred material for the new age of architecture is therefore hindered.

The results help us in understanding the use of Bamboo and the various technologies related by changing the public perception. It will develop communities by spreading awareness through the academic platform amongst the common Man for optimizing the use of a locally sourced material in a sustainable and appropriate manner.

Keywords: Bamboo architecture; Sustainable; Technique; Vernacular buildings.

Introduction

Bamboo is widely used in various forms of construction, crafting and other useful products which vary from region to region. Though modern architecture has taken the throne in today's world, traditional architecture is always referred and looked up in academic literature, as a guide for various environmental practices. Vernacular architecture is a result of conditions in society that evolves over time to reflect the environmental, cultural and historical contexts (Wahid, 2012). This particular research work will highlight the importance of bamboo as a modern day material and the different construction techniques through the study of literature, online sources, analysis and comparison of case studies done on traditional and modern bamboo construction systems.

India has a very diverse range of bamboo buildings and structures with various indigenous technologies based on long-term cultural traditions. There is a need to evaluate and learn the various building techniques of bamboo both in terms of technical and cultural sense to develop it as a modern sustainable building material. It is in view of these factors that this

paper will find answers, to explore the best use of bamboo as a construction material which is hardly being acknowledged as a strong alternative.

Communities living in areas where bamboo is used extensively are highly dependent on the materials for their livelihood. Due to the diversity of climate across the country, the types of bamboo found are also different from place to place. Hence, in response to the local climate, the typologies and traditional building techniques of bamboo developed over the centuries are also diversified.

The traditional Bamboo houses in the North-East India are a fine example of houses developed over the period by the specific community, region, climate and topography of that place. Some of the features seen here are the woven bamboo sandwiched walls between layers of mud processed by adding lime, cow dung and straw or jute, which have a distinct difference between the rural and urban houses where bricks are used along with bamboo (Singh, 2008).

In the North Eastern part of India, bamboo is extensively used for walls and floors. The stem of the bamboo are anchored at equal distance into the ground for the structural grid and bamboo beams are either tied or nailed to the columns. Sliced bamboo strips are often used as structural frameworks, which are dabbed with a mixture of mud, cow dung and straws. Roofing is made with either thatch or Corrugated Galvanized Iron sheets and are sloped due to heavy monsoons in the region. (Das, 2017).

Most of the bamboo construction in the North East region are thatch houses which are also known as the Assam type housing locally known as 'Ikra'. These are common housing typologies throughout the area mostly used for residential purposes. Lightweight and locally available materials like bamboo, wooden planks, thatch etc. were typically used to build these houses which have a proper system of bamboo based beam-column structures and also fulfil the earthquake safety requirements of the region with basic rectangularity and simplicity of forms. (Kakkad, 2011).

A study conducted by the Kerala Forest Research (KFRI) in Kerala and Karnataka showed that bamboo houses are economically viable, as assessed in terms of availability, affinity, adaptability and cost of construction. (Dhamodaran, 2011). Engineered bamboo-based building systems are already available in many industries and it has also been recently regarded as a mainstream construction material by the Public Work Department of India.

The architectural construction of bamboo based structures in South India shares its typology with the Southeast Asian style. For example, the wooden architectural construction in Kerala have been rooted on bamboo tectonic tradition,

The Southeast Asia follows suit because of the availability of bamboo groves and forests in the fertile farmland. This is a natural response among the builders, artisans and people of the society (Widiastuti, 2015). The most common type of bamboo vernacular construction is made of weaved bamboo, thatched roofs and wattle and daub construction. Typical bamboo houses in South India are more or less of the same structure and patterns made of thatched and tiled houses. Both these types are invariably used for making the roof structures whereas in certain houses, especially the thatched ones, bamboo is also used for walls, doors and partitioning. (Muraleedharan et al., 2004).

Recent studies show that the potential of bamboo as a construction material is limitless and can even replace steel in many aspects (Kaur, 2016). However, India, being rich in the usage and availability of bamboo, still needs to catch up in developing a more contemporary form of bamboo construction technology for the mainstream building.

This paper aims to compare the different bamboo techniques used in North East and South India and assess its contemporary application, which will help in understanding the various practical application of major bamboo construction in India and enable us to develop a new construction skill and style perfected over centuries that can be adopted in the contemporary context. .

Study Area

The study is carried out in North-East India, which is the eastern most region of India and the Southern States of India. The Northeast comprises of the states of the seven sisters which are Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland and Tripura. Sikkim was integrated later in 2002 as the eighth state, whereas the states in the Southern Region include Andhra Pradesh, Kerala, Karnataka, Telangana and Tamil Nadu. North East lies within the coordinates 25.5736°N and 93.2473°E covering an area of 262.179 km² with a population density of 159 persons/ km² according to the 2011 census data and South India is located between 12.2602°N and 77.14 61°E with an area of 635.780 km² and a population density of 463 persons/ km².

The selection of the bamboo based structures in both the study areas are characterized by the different types of patterns and styles of construction found in different terrains and locations. This study is carried out with respect to the traditional and modern styles of bamboo architecture, which have developed a sustainable form of living with Nature.

The North East India is comprised mostly of forests and hills and is geographically categorized into the Eastern Himalaya, the Brahmaputra and Barak valley plains. The Southern part of India is surrounded by the Bay of Bengal in the East, Arabian Sea in the West and Indian Ocean in the South. The South is also diversified with two main mountain ranges – the Western and the Eastern Ghats.

Bamboo is available in abundance in the North East as the region experiences a sub-tropical climate with humid summers, mild winters and severe monsoons. This enables the growth of best quality bamboo in the country. It accounts for more than 50% of the growing stock in India (FSI - 2017) and is the second richest country of the world after China in terms of bamboo genetic resources (Lobovikov et al., 2005).

The maximum concentration of Bamboo in South India can be found in the tropical moist deciduous forests of the peninsular region. Their geographical location of bamboo growth is governed by the conditions of rainfall, temperature, and the altitude and soil, which suit the growth of Bamboo in these areas.

Topological Factors: In the North East, the topography consists mainly of mountains, hills, plains and rivers. The Brahmaputra is the major river of this region, which is considered as an unpredictable river since its tributaries change their course very often. In South India, the terrain is made up wholly of the Deccan Plateau surrounded by the two main mountain ranges, which are the Western Ghats, and Eastern Ghats closely located to the seashores.

Rainfall: North-East India is one of the wettest places in the country, which receives rainfall higher than 1000mm, which is the average for the whole country. Most of the rainfall is received during summer, from late April to October where June and July are the wettest months. The monsoon season in most of the South Indian cities is from June to September, which receives high rainfall from the South West Monsoon Winds.

Bamboo Housing Typology: Since Bamboo is available in abundance in the North Eastern states, people build houses using this local material to the maximum extent. The typical hill houses use thatch made of bamboo leaves as the roof and hand-woven bamboo mats for walls. In South India, some typical houses use bamboo in walls as a wattle-and-daub system with composite mud plastering in rural areas. In urban areas, bamboo is used mainly in the roofing structure for both sloped and flat lime surki roofs. (Manjunath, 2015). The other kind of roof systems built in the South are made of mud and bamboo with the use of various local leaves to make it waterproof. The famous Madras Terrace roof is said to have evolved from thatch, bamboo and unsterilized mud roofs. (Joseph, 2018).

Methodology

The study was initiated in two different zones of the country to describe the typical bamboo construction techniques with a specific focus on the local practices that have been carried out in the region over a period of time. A comparative analysis was done studying the role of local style of architecture and the application of bamboo in traditional housing system to the modern day scenario.

The topography of the North East region is diversified and consists of plains, mountains and frequent flood affected areas. As a result, the traditional bamboo houses are also different in many regions based on the type of location. These conditions have resulted broadly into three types of bamboo housing patterns, which are Houses on Plains, Houses on Mountain Slopes and Houses on elevated foundations, which have been shown in the figure 1 below (Das, 2012).

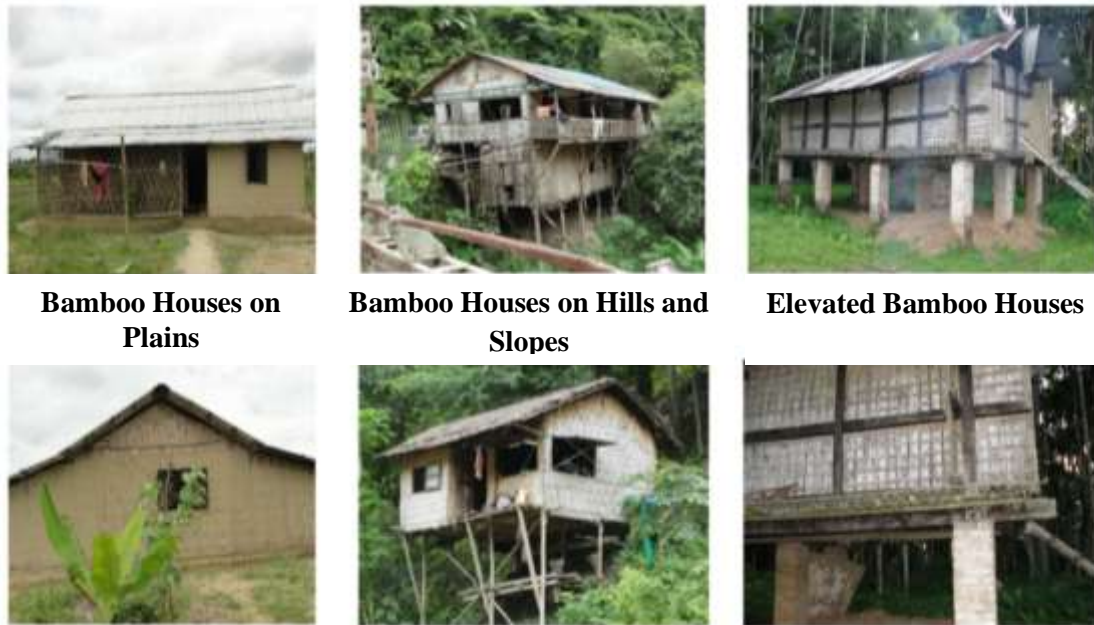


Fig. 1: Types of Bamboo Houses in the North East
Source: Author

Houses on Plains: The houses here are constructed directly above the ground where the culms (the stem portion of the bamboo between the nodes) are anchored inside the ground and structural frames as well as joints are erected upwards. The floor and walls are done using mud and cow dung where the walls have a supported bamboo framed structure. Roofs are mostly made of Galvanized Iron Corrugated sheets (G.I.Sheets).

Houses on Slopes: They are found mostly in the hilly terrains of the states of Meghalaya and Mizoram where the houses are supported by timber or bamboo poles used as vertical struts. The poles are anchored into the ground and foundation is prepared using a network of timber logs. Split bamboos are used for flooring and are finished with flattened bamboos. Roofing is either G.I corrugated sheets or bamboo purlins and rafters covered with thatch.

Elevated Bamboo Houses: These houses are found near river banks and flood prone areas. They are constructed on brick columns. Woven bamboo slats are used for flooring and finishing is done using flattened bamboo. Wall frames are made with bamboo slats mesh and covered with flattened bamboo with a mixture of mud and cow dung. Roofing is mostly G.I Corrugated Sheets. Timber logs are used as primary beams whereas bamboo is used as secondary beams.

Prominent Bamboo Style Houses found in North East India

A survey conducted by The CSIR-CBRI, Roorkee-Uttarakhand shows that the typical bamboo houses in the North East combine both the traditional as well as colonial wisdom in the construction process and are made traditionally with bamboo or reeds which are sandwiched between two mud layers and has proved to be very efficient in resistance to earthquakes. These bamboo and mud houses are commonly found in the villages of Assam, Tripura and Mizoram (Lala, 2017).



Fig. 2: Bamboo Houses of Arunachal Pradesh

Source: Author

In Arunachal Pradesh, the walls of most of the vernacular houses are made with bamboo mats and floors are constructed with flattened bamboo. They are perched either on wooden stilts and stone masonry depending upon the terrain as shown in Fig. 2.



Fig. 3: Bamboo Houses of Manipur and Nagaland

Source: Author

The vernacular houses of Manipur consist of thick mud walls reinforced with straws up to the roof. Split bamboo are bonded with bamboo strips or creepers above the walls for roofing whereas the houses in Nagaland use bamboo beams and columns, which are embedded into the ground and are, tied with bamboo rope or canes. The roof of Nagaland houses are high pitched roofs covered with thatch as shown in Fig. 3.



Fig. 4: Bamboo Houses of Meghalaya and Sikkim

Source: Author

Houses in Meghalaya are earthquake resistant supported with timber logs or bamboo poles varying in height due to the uneven ground (Fig. 4). They are built using post and beam principle. In Sikkim, some of the tribes use raised bamboo houses on timber and stone foundation. Split bamboo woven frames are used for frameworks, which are plastered with rammed earth, and straw roofs are used as coverings.



Fig. 5: Bamboo Houses of Assam, Mizoram and Tripura

Source: Author

The traditional bamboo houses of Assam are stilt houses where bamboo posts are generally used for support structures (Fig. 5). Walls are made of reeds and bamboo. Most of the houses in Mizoram are houses on slopes where long solid bamboo are laid over the cross beams. Walls and floors are of bamboo matting and in some cases the floors, doors and windows are also made with split bamboo. Roof consists of either solid or split bamboo frames. Tripura bamboo houses are typical hill dwellings and are called Riang houses and are similar to those found in Assam.

Bamboo Construction Technique common in the North East region

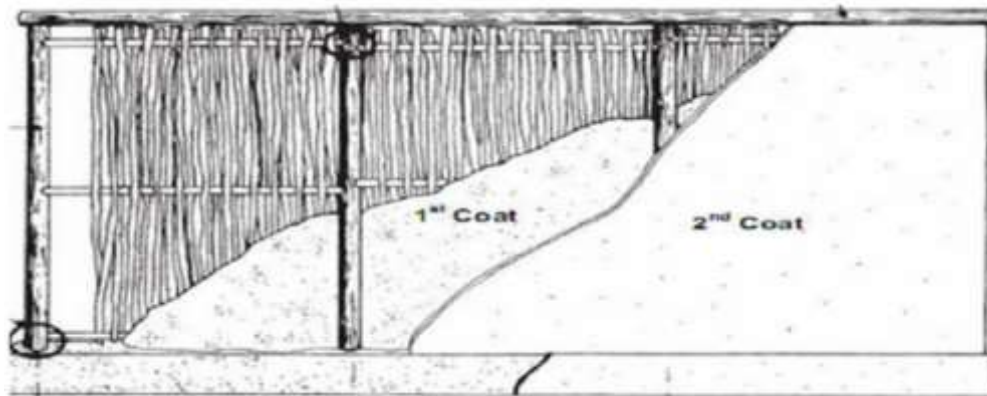


Fig. 6: Section of a bamboo strips frame wall plastered with mud or cement (Ikra Wall)

Source: Author

The different elements and materials used in Ikra type of the walling system have proper connection detail and has integral action between every material to act as one single unit. They are built with lightweight and locally available materials like bamboo, wooden planks, thatch, mud, cow dung, etc as shown in figure 6. The Ikra type of construction is also called as the Assam type houses. The name Ikra is derived from reeds, which grows in river plains and lakes across the state of Assam and are used extensively in walls and roofs of such housing typologies. They can be found both in rural as well as urban areas.

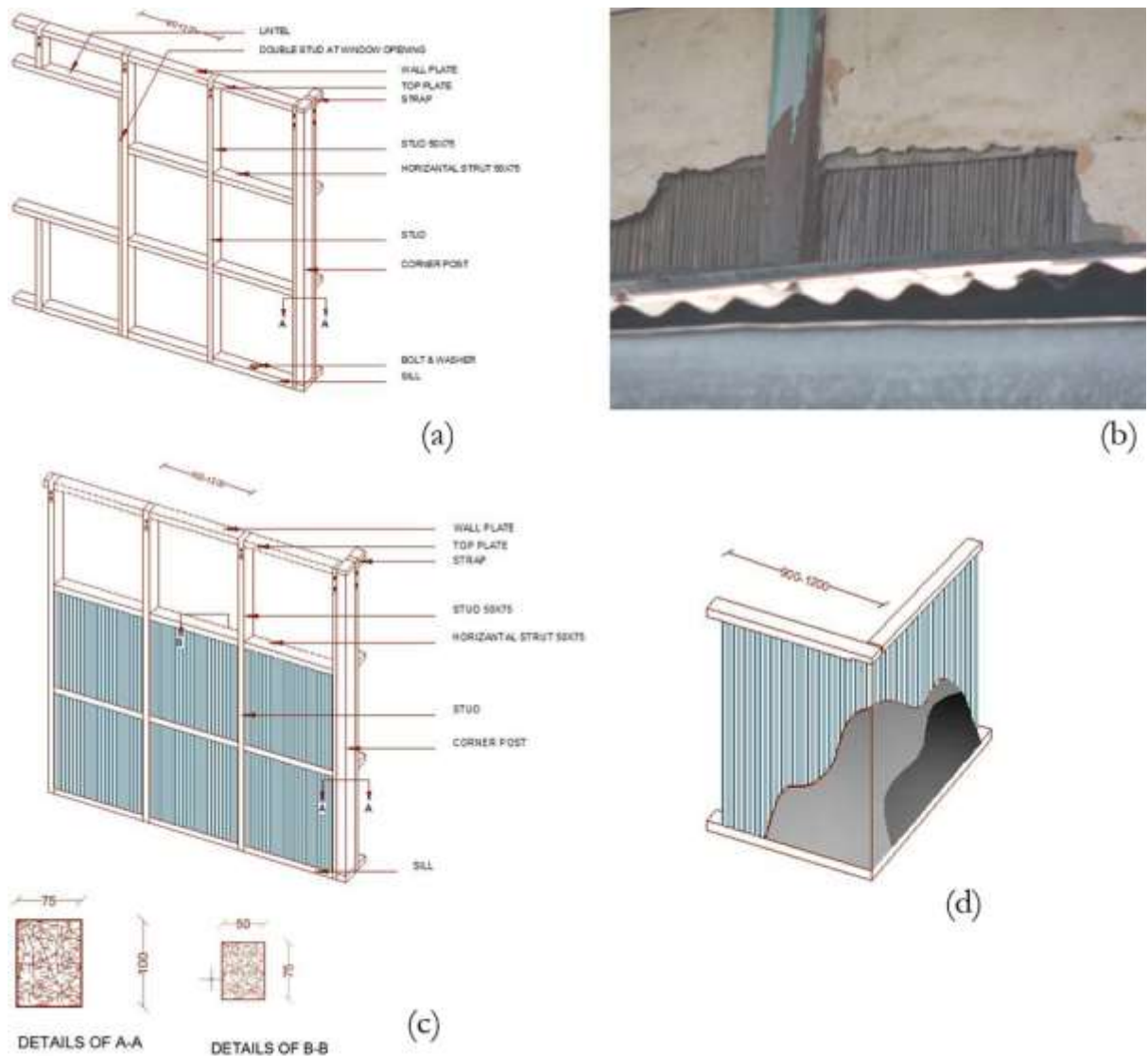


Fig. 7: Ikra walls Construction Sequence: (a) details of framing, (b), (c) Ikra reed and bamboo mats placement in the frame, (d) plastering of walls.

Source: Kaushik, 2012

The Ikra walls consist of reed and bamboo mat panels placed in between the wooden frames. Plastering is done by preparing an equal proportion of cow dung and mud slurry mixed with sufficient water to form a thin paste, which is used to fill the gaps between the panels.

Application of the plastering is done frequently over the Ikra panels after every summer or rainy seasons. Two types of Ikra walls are generally constructed in the region: simple and fine type. In simple type, the reeds are placed vertically in the frame whereas in the fine type, there are longitudinal grooves in which the ikra reeds are slipped (Fig. 7). The joinery details are shown in Fig. 8.



Fig. 8: Typical Joinery details of bamboo commonly seen in the North East: Bamboo Tie with Cane Ropes (left) and Dowel & Tenon Joint (right).

Source: Subhankar, 2013

Flooring structure of most north eastern houses normally consists of bamboo joists which are laid without fixing that spans along the shorter side of the floor perimeter and bamboo mats (Figure 9).

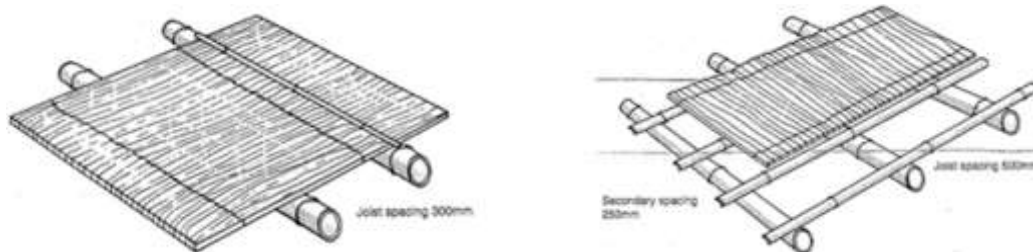


Fig. 9: Bamboo Flooring System used in the North East (Application of Bamboo in Building Industry, 2011)

Source: Author

Bamboo Construction Technique common in the Southern region

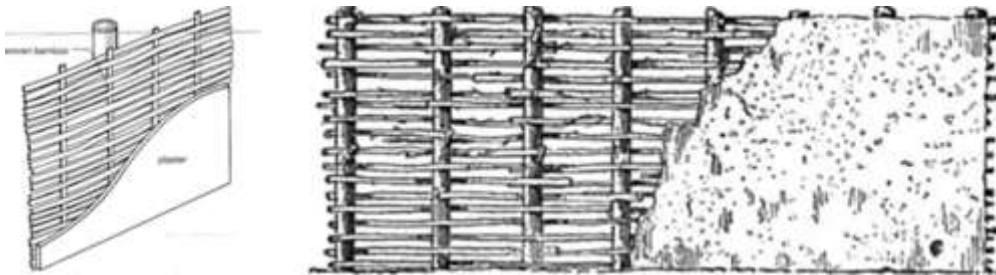


Fig. 10: The Wattle and Daub Wall Construction Technique seen in South India

Source: Author

The walling systems common in parts of southern India are the wattle-and-daub walls that comprise of coarsely woven panels of bamboo strips plastered with organic fiber, cow dung, on both sides (Figure 10).

The type of bamboo construction system in South India is the same structure and follows a similar pattern. Most of the bamboo houses in both the regions can be grouped into: Bamboo Thatch Houses and Bamboo Tiled Houses (Figure 11). The thatched bamboo houses are common as owners of the tiled house belong to a higher income group.

In both these type of houses, the bamboo material is mostly used for making the roof structure. In certain houses, bamboo is also used for making walls, doors and partitioning,

especially in the thatched houses. In Kerala, the thatch bamboo houses have an average plinth area of about 40 m² while in Karnataka, they are 30 m². In both the states, the tiled bamboo houses are found to be bigger than the thatched ones.

Tiled Bamboo House



Thatched Bamboo House



Fig. 11: Types of Bamboo Houses in South India

Source: Author

A study conducted by Muraleedharan et al. (2004) shows that there has been a decline of bamboo houses in Kerala and Karnataka due to a massive felling of private forests and low availability of bamboo for the housing sector with high prices of bamboos. It was also reported that most of the dwellers preferred thatch bamboo houses over tiled ones because of its durability and low maintenance cost. This region could gain more popularity in bamboo construction by providing more amenities and better appearance of the bamboo houses for aesthetics.

The most humble form of vernacular construction seen here is made of weaved bamboo, wattle-and-daub construction and roofs covered with thatch until it was banned in 1759 AD and altered with Mangalore Tiles. The traditional roof construction of South India is unique and found nowhere else across India except for some parts of the North East Region with very little similarities. (Widiastuti, 2013). The majority of the thatched bamboo houses were constructed mostly with either mud or sand whereas the tiled houses had proper basement and were constructed either with brick or granite. The tiled bamboo houses therefore have a long term benefit lasting for about 50 years as compared to a bamboo reinforced mud wall or the thatched houses that last for about 2 to 15 years depending upon the quality of bamboo used. It was also found that the frequency of maintenance done in the case of thatched houses were more than that of the tiled houses.

In parts of Karnataka where bamboo is available, most of the dwellers prefer bamboo houses as they are affordable and comfortable. This shows a social and cultural affinity towards the material due to familiarity. Whereas Kerala provided a different picture with the socio-cultural acceptability of bamboo was low due to repeated repair, maintenance and lack of technological know-how. Construction of the tiled bamboo house was an important development in the history of bamboo houses in South India because it increased the longevity of the structures making it economically beneficial and having a socio-cultural acceptance in the region.

Prominent Bamboo Based Construction System Seen in South India

In Kerala, the common building materials used for vernacular construction are mud, laterite, granite, lime mortar, bamboo, clay roofing and coconut palm leaves. The local architecture incorporates a bamboo framed top for the roof structure covered with thatch or shingled terracotta tiles (Fig. 12). The roofs are structurally supported by the pillars on the walls which rest on a plinth and are raised above the ground giving protection e from dampness and insects since the region lies in a tropical wet climate. Bamboo and other forms of timber are primarily used for structural components. The kazhukol-vala construction which is mostly

found in Kerala is also a simple rope-tied construction which is usually utilized in humble bamboo huts (Gupta et al., 2020).



Fig. 12: Vernacular Houses of Kerala (Bamboos used mostly for roof structure)
Source: Author

In the sub-tropical coastal parts of South India, timber and bamboo are some basic construction material found abundantly and play a major role in the local architecture of the region.



Fig. 13: Contemporary Bamboo Architecture of Bangalore, Karnataka: Bamboo Symphony (left), House of Five Elements (centre) and Proposed Bamboo Metro Station (right)
Source: Author

The state of Karnataka especially in the region of Bangalore has adopted a more contemporary and modern style of bamboo based designs inspired from the traditional technologies that have existed for centuries (Figure 13). This has given a boost in the confidence which would serve as a future reference for anyone wanting to build with bamboo material in India (Manjunath, 2015).

Some of these modern bamboo structures experimented with new forms and used innovative construction materials and technologies such as Bamboo-crete walling system with precast wall panels, green shell roof over lattice grid made of bamboos, which were also supported, by bamboo beams and columns, bamboo mud paper blocks and bamboo reinforced concrete with bamboo fibres.

Modern Bamboo Construction Techniques of Bangalore, Karnataka

An attempt has been made to rebrand Bamboo as a desirable and sustainable material, which can replace steel and concrete. Some of the modern construction techniques showcases the inherent strength of a single bamboo stem and designed as a hybrid of synergetic and tensegrity system (Maikol et al., 2020). The bamboo columns were placed haphazardly but having a definite size, position and inclination, which were structurally relevant whereas the slabs in most of these modern bamboo houses were cast with Bamboo Fibre Reinforced Concrete (BRFC) with bamboo splits for reinforcement as shown in Fig 14.



Fig. 14: Modern practices of Bamboo Construction in South India
Source: Author

The prefabricated bamboo-crete wall even when used as splits shows a desirable tensile strength. The 'Bamboo Crete' technology uses splits of bamboo and chicken wire mesh for the reinforcement of walls. The bamboo mud paper blocks uses strong bamboo fibers in the mix for stabilized mud blocks which greatly enhances the strength of the blocks and is suitable for both external and internal walls. A light weight block can also be achieved by compressing bamboo and newspaper waste with mud and can be used for making bamboo based furniture (Fig. 15).



Fig.15: Stabilised Bamboo Fibre (left) and Bamboo, Newspaper waste (centre) mud blocks
Source: Author

Modern Bamboo Connector Joints

Based on the conventional modern techniques of bamboo construction, connectors were developed and used in bamboo buildings such as the **Das Clamp** designed by the Bhagaipur College of Engineering in India, where a steel band with an integral blot eyes were fitted around the bamboo sections as shown in figure 16. The bolting of the clamp with the bamboo tightens both the elements together where additional straps can be used if required. This system is best suited for connection in one pane such as the bamboo truss systems. (Phanratanamala, 2015)



Fig.16: Das Clamp Connector
Source: Author

Another form of modern bamboo joineries is the Gusset plate system. The gusset plates are attached to the outside of the bamboo culms, which are the stems between the nodes (Figure 17). Their development was based on the traditional techniques of bamboo construction, and the uniqueness of bamboo, which provided an upgrade from the traditional joints. They are commonly constructed from a timber such as plywood or solid timber and sometimes steel

gusset plates are also used. Such plates are applied to joint assemblies, like in trusses, and fixed with bolts, dowel, or bamboo pegs and shows improved stiffness and strength when compared with traditional joining methods.

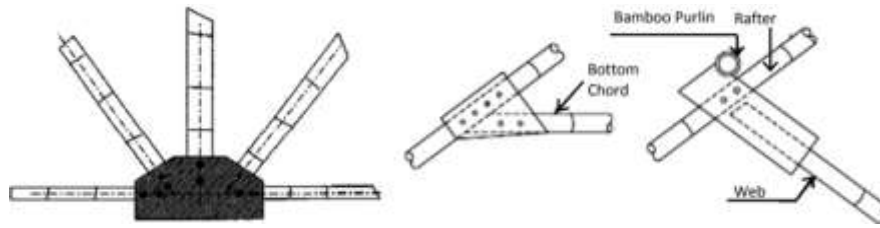


Fig. 17: Gusset Plate Joints

Source: Author

Comparative Analysis

After years of unsustainable practices in the construction industry, the architectural community has seen a turn around by the need to produce a more environmental friendly material in the form of bamboo. It works well with the climate and nature in both the technology-intensive approach and traditional methods. It depends upon the inherited experience and knowledge to address the cultural, technological, climatic and socio-economic dimensions for a more holistic approach towards a sustainable development.

The following table 1 shows the overview and comparison of the different bamboo techniques seen in various building components of a traditional house in the south and north east India.

Table 1: Comparison of the Traditional Construction Systems of Bamboo Buildings

Source: Author

No.	Building Components & Features	North East India	South India
1.	Foundation and Structure	Building on Bamboo Beam and Post System: Flooring is made with bamboo panels and bamboo mats supported by the structure.	Local Stone foundation with mud base and mud flooring. Bamboo roofing with column and beam system in combination with local timber.
2.	Walls	Ikra System: Woven bamboo mats with bamboo strips are used to make walls. Plastering is done depending upon the regions climatic conditions.	Wattle & Daub method used for wall construction where the bamboo splits are spaced widely and covered with mat or jute and daubed with clay, sand, animal dung and straw.
3.	Roofing	Pitched roofs: Most of the roofing structure is made entirely out of bamboo covered with thatch or corrugated sheets.	Sloped roofs: The roof structures are made with bamboo rafters, purlins and truss system that are covered either with thatch or tiles supported by bamboo/timber pillars on walls.
4.	Plastering	Done by mixing equal proportion of mud, water and cow dung dabbed with straws or jute and finished with mud slurry.	Plastering uses mud or lime mortar once the daub was hardened with a combination of organic fibre. The surface plaster is finished with lime and sand.
5.	Aesthetic Elements	Bamboo is used as a structural element as well as a decorative element. The aesthetic elements are incorporated within the walling system with different patterns and design in the weaving technique of mats and bamboo strip.	The roof construction of South India mainly in Kerala looks like a structural advancement of bamboo craftsmanship into a more sophisticated prefabricated wooden construction due to the overwhelming scale and pyramidal shape.

6.	Spatial Planning and Form	Built on both flat and sloped terrain. On flat terrain houses are typically rectangular or L - C shaped whereas bamboo houses on hills are rectangular in shape which rests on stilts and accessed via the hillside.	The distinctive feature is the dominant massive earthen construction, the observance toward Vastu & Hindu value and traditional typology courtyard house with traditional forms. They have a square or rectangular plan with high pitched roofs.
----	---------------------------	--	--

Some of the key features observed is that, in the North East, bamboos is used primarily as load distributors and not as a load-bearing element. The major use of bamboo is in the walling systems and flooring with secondary beams. In the case of South India, bamboo is used mainly for the load bearing elements such as beams, columns, rafters, etc. The major use of bamboo was in the roofing elements and structures. Some of the modern construction techniques used bamboo as a composite material for walls and floors. The roof construction is generally hip or hip-gable supported by horizontal bamboo beam with storage facilities in the attic space covered by tiles or earlier thatch leaves. The roof also consists of gable board on the roof edge for ventilation purposes.

A study conducted by Charu Monga (2018) of South East Asian Monuments highlights an important design element which states that the roof exterior in India is closer to the hip. In some countries of South East Asia, the rooftop is a traditional thatch or tiled roof with lateral support from bamboo and a curvilinear form making it more aesthetic than functional which can also be seen in the Southern parts of India because of its influence.

The influence of bamboo in traditional architecture of both these regions shows its relevance as a socially acceptable building material only in the rural areas but a few experts from the bamboo industry indicate the material has failed to live up to the social urban image of India. This can be dealt with by modern and contemporary bamboo construction with an aesthetic architectural design using global innovations and best practices taking inspiration from the traditional techniques.

Conclusions

The bamboo architecture and construction techniques of both the study areas relate to the socio-economic setup, the cultural identities of the region and effective climate responsiveness. People living in the bamboo communities especially in the Northeast region of India know the traditional method of preservation and construction technology. Mostly the socially and economically weaker sections of the society construct bamboo houses in the rural parts of India opting for a low-cost bamboo structure because of their poor economic conditions. The technological advancement in the bamboo material for the building sector is slow as compared to other nations and hence needs to be improved especially in the field of material science, treatment methods, building components and construction systems.

In some of the modern practices of bamboo construction in India, it is seen that bamboo combined with conventional building materials remain serviceable for much longer periods than other forms of housing. However, some of the traditional joinery techniques do not produce enough stiffness in connection, which can be improved by modern techniques such as clamping the culm between pieces of wood or plywood connected with bolts, which increases the rigidity.

Some of the houses in its vernacular form cannot meet the demand of the growing population as these structures can go up to only a limited number of storeys. Moreover, the traditional techniques cannot be directly applied in an urban context and hence needs to be explored and adopted to modern context with technological inclusions. Today, bamboo construction is one of the most advanced technologies creating a nature friendly and harmless material which has significantly expanded its scope as a building material. However, there are still several problems in the development and designing of buildings and structures from bamboo.

Once we are aware of the limitations of the traditional typologies of bamboo construction techniques, the contemporary application can be implemented and enhanced to make the local practices effective in the long run, which will contribute to a modern yet sustainable bamboo architectural style in India.

References

- Wahid, A. (2012). Adaptive Vernacular Options for Sustainable Architecture. *Journal of the International Society for the Study of Vernacular Settlements*, Vol. 2, no.2
- Manoj Kumar Singh, S. M., (2008), Bioclimatism and vernacular architecture of north-east India. *Building and Environment*, 44, pp 878–888
- Sutapa Das, P. M., (2017), Multi-hazard disaster resilient housing with bamboo-based system . 7th International Conference On Building Resilience Using Scientific Knowledge To Inform Policy And Practice In Disaster Risk Reduction, ICBR2017, 27 – 29 November 2017, Bangkok, Thailand
- Maulik D.Kakkad, C. C., (2011), Comparative Study of Bamboo (Ikra) Housing System with Modern Construction Practices. National Conference on Recent Trends in Engineering & Technology.
- T.K Dhamodaran, R. G. (2011), Demonstration of Appropriate Construction Practice and Construction of Durable Model Bamboo House. Wood Science and Technology Division, Kerala Forest Research Institute.
- Widiastuti, I. (2015). The Vernacular Architecture Of Kerala, South India:An Architecture Knowledge On The Cross-Road Between Southeast Asia And South Asia. SEAARC Symposium NUS.
- Muraleedharan, Simon, Anitha, (2004). Present status and socio-cultural acceptability of traditional bamboo houses: a study in Kerala and Karnataka states of India. *Journal of Bamboo and Rattan*, 3(3), 283–296. doi:10.1163/1569159041765344
- Perminder Jit Kaur, K. S. (2016). Bamboo: The Material of Future. *International Journal Series in Multidisciplinary Research (IJSMR)*.
- Maxim Lobovikov, Shyam Paudel, Marco Piazza, Hong Ren and Junqi Wu (2005), World bamboo resources A thematic study prepared in the framework of the Global Forest Resources Assessment 2005, Food And Agriculture Organization Of The United Nations Rome, 2007 .
- Priya Joseph (2018), Native Roofing Systems of South India, Built Spaces, Module, (<https://www.sahapedia.org/native-roofing-systems-of-south-india>) accessed on 25th Oct. 2021
- Puspanjali Das, C. K. (2012). Traditional bamboo houses of North-Eastern Region: A field study of Assam & Mizoram. *Key Engineering Materials* Vol. 517.
- Sayantani Lala, Goplalkrishnan N, Ashok Kumar (2017), A Comparative Study on the Seismic Performance of the Different Types of Bamboo Stilt Houses of North-east India, Conference: 4th National Conference on Innovations in Indian Science, Engineering & Technology with a focus on "RURAL HOUSING", CSIR – National Physical Laboratory (NPL), New Delhi
- Hemant Kaushik B., Ravindra Babu K.S., (2012), Assam-type House, World Housing Encyclopedia Report No. 154, Published by Earthquake Engineering Research Institute (EERI), USA and International Association for Earthquake Engineering (IAEE), Japan.
- Nag Subankar, Gondane Amol (2013), A brief study of the vernacular typologies of North east India and their sustainable backgrounds. *Journal of Indian Institute of Architects*, December 2013.
- Widiastuti, I. (2013). Arapura: Spatial Configurations of Granary Houses in Kanyakumari, South India. *Journal of the International Society for the Study of Vernacular Settlements*, Vol 2, No 3, pp 50-60
- Widiastuti, I. (2013). The Living Culture and Typo-Morphology of Vernacular Houses in Kerala. *Journal of the International Society for the Study of Vernacular Settlements*, Vol 2 No. 4, pp 41-54

- Janmejy Gupta, Naushaba Jameel, Pushpita Padhy (2020), Architecture shaped by socio-cultural influence and climate: Lessons learnt from study of vernacular architecture of Kerala, *International Journal of Cultural Inheritance & Social Sciences*, Vol. 2 (1)
- Manjunath, A. N. (2015). Contemporary Bamboo Architecture in India and its Acceptability. 10th World Bamboo Congress, Korea.
- Solanilla Medina Yor Maikol , Shuvalov Vasily Maksimovich , Bykova Galina Ivanovna and Sultanova Ainur, (2020). Bamboo Structures for Modern Sustainable Architecture. *Journal of the International Society for the Study of Vernacular Settlements*, Vol. 7, no.3.
- Phanratanamala, Susira. 2015. The study of Design and Structural Potential of Bamboo Practical Joints and Frame Truss System: Pilot Project of “Kashiihama House for All.” Scribd. <https://www.scribd.com/document/282461023/2HE12094P>
- Charu Monga, A. K. (2018). A Comparative Visual Study of Design Elements of Social Cultural Institutions, ‘Namghar’ with Monuments in South East Asia. *Journal of the International Society for the Study of Vernacular Settlements*, Vol 5, No 2, pp 31-42