Use of Bamboo as a Sustainable Material in Vernacular Settlements: Potentials in Modern India

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Abstract

Throughout human history, bamboo has consistently held a significant position in the everyday lives of many people particularly in vernacular settlements. Renowned for its sustainable qualities as a building material, bamboo possesses the advantage of rapid growth and easy cultivation, making it highly renewable and reusable. The use of sustainable materials is crucial in mitigating the negative environmental impacts resulting from human actions. Indeed, it also contributes to the preservation of resources for future generations.

Moreover, bamboo's lightweight nature and flexibility make it an ideal construction material both easily manipulatable and bent. It is considered better than most other materials used in construction. India grows 125 bamboo species under 23 genera. 66% of bamboo is grown in the Eastern states of India. It is considered to lug tensile strength than (PCC) prestressed concrete cement. Hence, it is even suggested that bamboo reinforcement should be used in concrete structures.

This study examines bamboo as a sustainable material to determine the potential of bamboo as a viable alternative for sustainable construction in modern India. It ascertains the potentials of bamboo as a renewable resource that might be used in a range of applications, including furniture., It focuses on its usability in architecture in creating the style of Eastern states of India. In conclusion, this research highlights the significant promise inherent in using bamboo as a sustainable construction material.

Keywords: Bamboo, Eastern states of India, Sustainability, Bamboo use, Decorative elements.

Introduction

A material is considered sustainable if it is produced, used, and disposed of in an ecological manner that fulfils the requirements of the present without jeopardizing the ability of the future generations to meet their own needs (Maikol, 2020). This includes characteristics like renewability, recyclability, minimal environmental impact, and responsibility in its manufacture and use.

Bamboo is an essential material of India's economic system and method of life (Rathour, 2022). According to the Forest Survey India 2011, 12.8% of the forest covering approximately 14 million hectares is dedicated to bamboo growing. India is the second largest country to have such a large production after China. The Eastern region of India is abundant with bamboo, which has been extensively utilized throughout history for a diverse range of purposes. This includes the construction of houses, furniture, and decorative elements, among others. The states in the Eastern region have a longstanding tradition of harnessing the potential of bamboo in various applications (Raj, 2014).

With its rapid growth rate, bamboo stands out as one of the most swiftly maturing plants, allowing for harvest cycles every three to five years without any detrimental effects on the environment (Tewari, 2014). Furthermore, bamboo is considered a low-impact crop since it can be cultivated without the need for pesticides or fertilizers. As a result, bamboo cultivation minimizes soil degradation and water pollution, making it a more ecologically sustainable choice compared to the conventional crops (Rathour, 2022).

The use of Bamboo as a sustainable material has increased in popularity in recent years, particularly in the context of modern architecture (Nguyen, 2018). As a renewable resource, it has been regarded as the environmentally friendly material available. It has also played a crucial role in the aesthetics of Indian architecture (Manandhar, 2019). It has also been employed as a natural material for ventilation and shade and improving air quality. Bamboo has long been recognized as a significant material in Indian architecture, and its role has only expanded in recent years with the growing adoption of bamboo as an eco-friendly construction material (Borowski, 2022).

In this context, this research examines the utilization of bamboo as a sustainable material in construction, focusing on its potential applications and benefits within the Eastern states of India. The study aims to recognise the historical significance of bamboo in the region's architectural practices. It seeks to examine the mechanical properties and suitability as a construction material, explore its diverse applications and assess its environmental and cultural relevance. It's aim is to provide insights into the advantages and challenges of using bamboo, as well as to identify its role in promoting sustainable construction practices to preserve the cultural heritage of the Eastern states.

Its objectives are:

1. To examine the sustainable attributes of bamboo as a building material, including its rapid growth, renewability and low environmental impact.
2. To analyse the historical significance of bamboo in construction, highlighting its cultural relevance and engineering prowess across various civilizations.
3. To assess the distribution and diversity of bamboo species in the Eastern states of India and their potential applications in construction.

Research Methodology

This research employed a literature survey as a research methodology. It was conducted across various online platforms including ResearchGate, Google Scholar, and Science Direct using keywords such as Bamboo, Eastern states of India, Sustainability, and Decorative elements. A total of seventy papers were identified, out of which thirty were deemed relevant to the topic and shortlisted for further analysis. The selected papers were carefully examined to ensure their relevance to understand the use of Bamboo.

Findings and the Discussion

Most of the studies centred around the Indian context, while others delved into the role of bamboo in architecture. Additionally, there were 10-15 papers dedicated to bamboo as a material and its environmental impact. Four papers specifically discussed bamboo characteristics,

encompassing both its advantages and disadvantages, as well as its inherent properties. Moreover, a group of papers concentrated on bamboo construction techniques, while another collection delved into the sustainability dimensions of bamboo. There were also papers dedicated to the historical significance of bamboo, while others examined the production and distribution of bamboo.

Table 1 provides a catalog of the papers and their respective sources, detailing where they were discovered. In Table 2, each paper is categorized according to its relevant sub-topic or theme, explaining why it was chosen and included in this research.

Table 3: List of papers along with their respective search systems
Source: Author

No.	Paper citation	Search system
1	Ahmad, 2020	Google scholar
2	Ahmad, 2021	Research Gate
3	Ahmad, 2023	Science Direct
4	Amada, 1997	Google Scholar
5	Amada, 2001	Google Scholar
6	Auwalu, 2019	Google Scholar
7	Bacosa Jr, 2023	Research Gate
8	Baghel, 2017	Research Gate
9	Bala, 2023	Science Direct
10	Borowski, 2022	Google scholar
11	Chaowana, 2021	Research Gate
12	Chele, 2012	Google Scholar
13	De Souza, 2021	Google Scholar
14	Das, 2012	Research Gate
15	Das, 2018	Google Scholar
16	Dhiman, 2022	Google Scholar
17	Emamverdian, 2020	Google Scholar
18	Gao, 2018	Research Gate
19	Ghavami, 2005	Science Direct
20	Gottron, 2014	Science Direct
21	Ha, 2014	Google Scholar
22	Horikawa, 2010	Science Direct
23	Huang, 2021	Science Direct
24	Janssen, 2000	Google Scholar
25	Kasinath, 2021	Google scholar
26	Kaur, 2018	Google Scholar
27	Krötsch, 2013	Research Gate
28	Laleicke, 2020	Google scholar
29	Lomas, 2015	Google scholar
30	Loushambam, 2017	Research Gate
31	Manandhar, 2019	Google scholar
32	Maikol, 2020	Google scholar
33	Mohan, 2020	Google scholar
34	Nguyen, 2018	Google scholar
35	Nurdiah, 2016	Science direct
36	Paudel, 2008	Google Scholar
37	Raj, 2014	Research Gate
38	Rathour, 2022	Research Gate
39	Satya, 2016	Research Gate
40	Shah, 2012	Research Gate
41	Sharma, 2014	Google Scholar
42	Shu, 2020	Google Scholar
43	Syeda, 2014	Google Scholar
44	Tewari, 2019	Research Gate
45	Tewari, 2014	Research Gate

46	Van Der Lugt, 2014	Google Scholar
47	Yadav, 2021	Science Direct
48	Yang, 2004	Research Gate
49	Yu, 2011	Science Direct

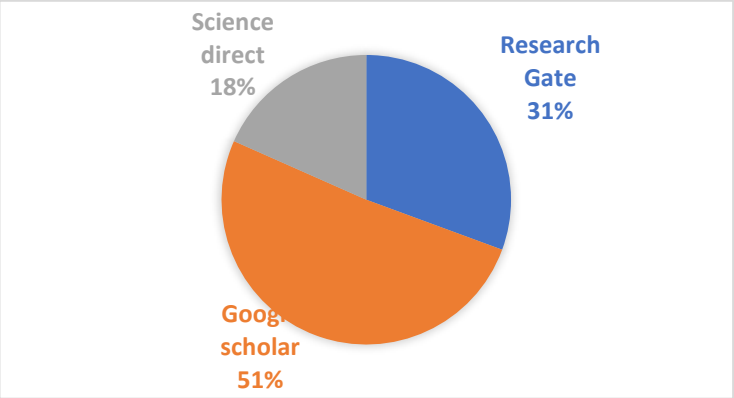

Fig. 1: Ratio of the search systems from where the papers were found.
Source: Author

The pie chart illustrates the distribution of research sources used in this study. Google Scholar is the most extensively utilized source, indicating its prevalence as a primary academic research platform. ResearchGate also holds a substantial share, emphasizing its significance in accessing scholarly materials. ScienceDirect, although a valuable resource, contributes to a smaller portion of the research sources, highlighting its more specialized or selective use in this study.

Table 2: List of papers with their categories
Source: Author

No.	Paper citation	Classification
1	Ahmad, 2020	Bamboo characteristics and history
2	Ahmad, 2021	Distribution of bamboo, quantity, and production
3	Ahmad, 2023	Bamboo characteristics and history
4	Amada, 1997	Bamboo characteristics and history
5	Amada, 2001	Bamboo characteristics and history
6	Auwalu, 2019	Bamboo construction
7	Bacosa Jr, 2023	Comparison to other construction materials
8	Baghel, 2017	Bamboo construction
9	Bala, 2023	Sustainability of bamboo
10	Borowski, 2022	Sustainability of bamboo
11	Chaowana, 2021	Sustainability of bamboo
12	Chele, 2012	Comparison to other construction materials
13	De Souza, 2021	Bamboo construction
14	Das, 2012	Bamboo construction
15	Das, 2018	Bamboo construction
16	Dhiman, 2022	Comparison to other construction materials
17	Emamverdian, 2020	Bamboo characteristics and history
18	Gao, 2018	Application of bamboo
19	Ghavami, 2005	Bamboo construction
20	Gottron, 2014	Bamboo characteristics and history
21	Ha, 2014	Sustainability of bamboo
22	Horikawa, 2010	Sustainability of bamboo
23	Huang, 2021	Comparison to other construction materials
24	Janssen, 2000	Bamboo characteristics and history

25	Kasinath, 2021	Bamboo construction
26	Kaur, 2018	Bamboo characteristics and history
27	Krötsch, 2013	Bamboo construction
28	Laleicke, 2020	Sustainability of bamboo
29	Lomas, 2015	Application of bamboo
30	Loushambam, 2017	Distribution of bamboo, quantity, and production
31	Manandhar, 2019	Bamboo characteristics and history
32	Maikol, 2020	Sustainability of bamboo
33	Mohan, 2020	Bamboo characteristics and history
34	Nguyen, 2018	Sustainability of bamboo
35	Nurdiah, 2016	Bamboo construction
36	Paudel, 2008	Bamboo characteristics and history
37	Raj, 2014	Bamboo construction
38	Rathour, 2022	Sustainability of bamboo
39	Satya, 2016	Application of Bamboo
40	Shah, 2012	Bamboo characteristics and history
41	Sharma, 2014	Bamboo characteristics and history
42	Shu, 2020	Bamboo construction
43	Syeda, 2014	Sustainability of bamboo
44	Tewari, 2019	Distribution of bamboo, quantity, and production
45	Tewari, 2014	Bamboo characteristics and history
46	Van Der Lugt, 2014	Comparison to other construction materials
47	Yadav, 2021	Distribution of bamboo, quantity, and production
48	Yang, 2004	Bamboo characteristics and history
49	Yu, 2011	Sustainability of bamboo

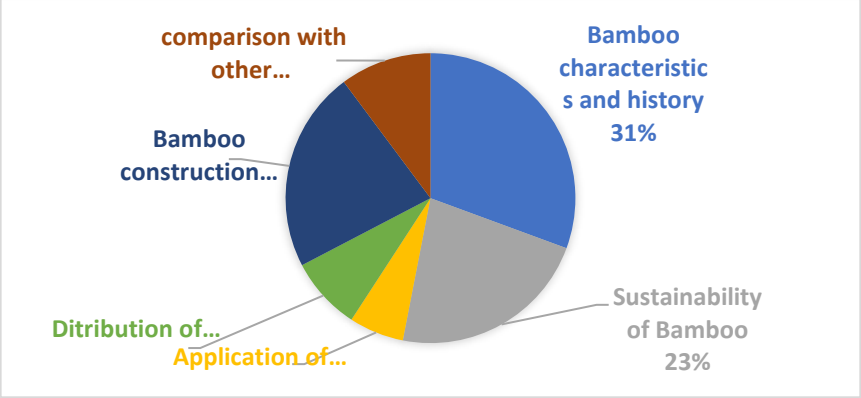

Fig. 2: Categorization of papers on the basis of the sub themes.
Source: Author

The above pie chart illustrates the distribution of topics within the broader subject of bamboo. The largest portion is dedicated to "Bamboo Characteristics and History," emphasizing a significant focus on understanding properties of bamboo and its historical significance. "Bamboo Sustainability" and "Bamboo Construction" also constitute substantial segments, indicating substantial interest in both eco-friendly aspects and practical applications. "Distribution of Bamboo, Quantity, and Production" follows, suggesting an interest in the logistical aspects of bamboo. Lastly, "Comparison with Other Construction Materials" highlights an exploration of bamboo's competitive edge in construction. This distribution reflects a comprehensive approach to studying bamboo across various dimensions.

Bamboo as a Sustainable Material in Construction.

Bamboo, a rapidly growing plant native to tropical and mid temperate regions, exhibits a distinctive rhizome-dependent mechanism that enables it to grow at a rate three times faster than many other plant species (Mohan, 2020). The Eastern region of India is particularly abundant in bamboo species, encompassing states such as Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, and West Bengal.

Other bamboo-rich areas in India include the A&N Islands, Chhattisgarh, Madhya Pradesh, and the Western Ghats (Tewari, 2019). Another benefit of choosing bamboo is that it has a minimal carbon footprint (Laleicke, 2020). During the production process, bamboo uses less energy and emits less greenhouse gases than other construction materials such as steel, concrete, and plastic (Van der lugt, 2014). As a result, it is a more environmentally friendly and long-lasting alternative to typical building materials. Furthermore, bamboo has a high strength-to-weight ratio, making it a long-lasting and dependable building material.

Bamboo demonstrates higher tension and bending strength than steel, making it a suitable material for construction (Nurdiah, 2016). Its fibrous structure and natural composition contribute to exceptional performance. While steel offers advantages like standardized properties, bamboo's renewable nature and environmental benefits make it an appealing choice for sustainable construction practices. Consideration of project requirements is necessary when deciding between the two materials (Dhiman, 2022).

History of Bamboo as a Construction Material in the Global Context

The history of bamboo as a construction material is a captivating narrative that spans across diverse ancient civilizations, showcasing the ingenuity and resourcefulness of human architectural practices. In China, bamboo has been a vital component of traditional architecture for centuries, with documented evidence dating back to the Song Dynasty (960-1279 AD) (Yang, 2004). The famous Bamboo Temple in Kunming, built during the Tang Dynasty (618-907 AD), stands as a testament to the durability and aesthetic appeal of bamboo in architectural design. One notable historical application of bamboo is its extensive use in traditional Chinese architecture, where it served as a primary building material for structures like temples, pagodas, and bridges, showcasing its structural strength and cultural significance. Additionally, Southeast Asian countries such as Indonesia, Thailand, and the Philippines have a rich tradition of utilizing bamboo in various construction applications. The traditional stilt houses of the Batak people in Indonesia and the iconic bamboo bridges in Thailand exemplify the cultural significance and engineering prowess associated with bamboo.

South American civilizations, such as the Inca and Maya, also made remarkable contributions to the history of bamboo in construction. The Inca civilization utilized bamboo extensively in their architectural marvels, including the renowned Machu Picchu in Peru. Similarly, the Maya civilization incorporated bamboo in their buildings, such as the traditional palapa thatched roofs. These examples illustrate the widespread adoption of bamboo as a structural material and its ability to withstand the test of time.

In modern times, architects and builders have recognized the ecological and sustainable attributes of bamboo, leading to a resurgence of its usage in construction. Notable architects like Simón Vélez and Vo Trong Nghia have embraced bamboo as a versatile and eco-friendly material, integrating it into their innovative designs (De Souza, 2021). Their projects, such as the Bamboo Pavilion in Colombia and the Green Ladder House in Vietnam, showcase the immense potential of bamboo as a sustainable building material.

The Indian Context

The history of bamboo as a construction material in the Eastern states of India reveals a rich and enduring tradition that has spanned centuries. Throughout the region, bamboo has played a vital role in indigenous cultures, serving as a primary resource for building sturdy and sustainable structures (Kasinath, 2021). The Eastern states, including Assam, Meghalaya,

Manipur, Mizoram, Tripura, Arunachal Pradesh, and Nagaland, have witnessed the extensive utilization of bamboo in various architectural forms, ranging from vernacular houses to bridges and temples (Das, 2012). The inherent properties of bamboo, such as its strength, flexibility, and abundance, have made it an ideal choice for construction, enabling communities to create dwellings that are well-suited to the local environment and climate conditions (Baghel, 2017).

Furthermore, bamboo has significant cultural and symbolic significance in the Eastern states, reflecting its deep-rooted connection to traditional practices and beliefs. This historical legacy has contributed to the continued recognition and adoption of bamboo as a sustainable and ecologically sound construction material in the present day. The ongoing utilization of bamboo in the region not only preserves cultural heritage but also promotes the principles of environmental conservation and responsible resource management. As the Eastern states of India continue to evolve and embrace sustainable development, the history of bamboo as a construction material serves as a reminder of the invaluable contributions this versatile plant has made and continues to make in shaping the architectural landscape of the region (Manandhar, 2019).

Bamboo Species at a Global Scale

Bamboo resources are widely distributed throughout India's Eastern regions, providing prospects for sustainable building and economic growth. Assam contributes the most, followed by Manipur, Mizoram, Arunachal Pradesh, Meghalaya, Nagaland, and Tripura. These states have considerable bamboo-bearing regions and bamboo stocks, emphasizing the availability and potential for sustainable bamboo use in buildings and other sectors.

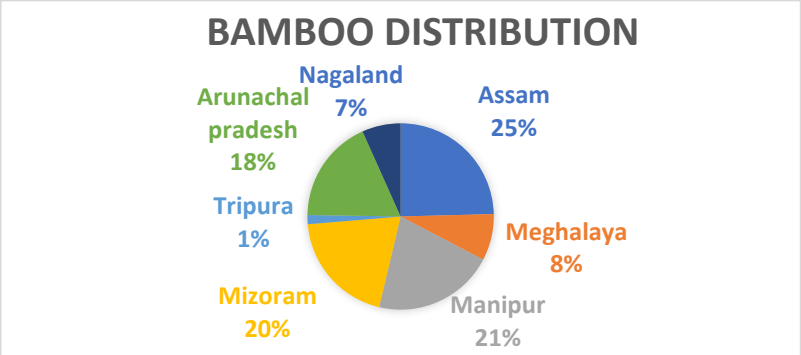

Fig. 3: Distribution of bamboo in East India.
Source: Loushambam, 2017

The bamboo distribution data for Northeastern Indian states reveals a notable distribution of bamboo resources. Assam emerges as the frontrunner with the highest stock, while Manipur and Mizoram also showcase substantial bamboo resources. These findings underscore the regional potential for bamboo-based industries and sustainable initiatives, emphasizing the need for responsible resource management and utilization to drive economic growth. These states contribute significant percentages of bamboo production, highlighting their importance in the overall bamboo resources of the region.

Table 3: Status of Bamboo in India.
Source: Shah, 2012; Loushambam, 2017

States	Bamboo bearing area	Bamboo stock (MT)
Assam	7, 238km2	13.41
Meghalaya	4,793 km2	4.41
Manipur	9, 303km2	11.47
Mizoram	9, 245km2	10.89
Tripura	3, 246km2	0.86
Arunachal Pradesh	16, 083km2	9.84
Nagaland	4, 902km2	3.66

Table 3 presents data on bamboo resources in the Eastern states of India. It includes two key columns: "Bamboo bearing area" (in square kilometres) and "Bamboo stock (MT)" (in metric tons). The bamboo bearing area represents the total land suitable for bamboo cultivation in each state, while the bamboo stock indicates the existing amount of bamboo available in each region. Moreover, it allows for comparative analysis between states, highlighting variations in bamboo resources across the regions.

Presently, native bamboo species are found primarily in Asia, America, and Africa, with Europe being an exception. The global inventory of bamboo encompasses approximately 123 genera and over 1500 identified species. Among these, there are around 75 genera and 1250 bamboo species worldwide, with about 500 species belonging to 40 genera being observed (Yang, 2004). It is worth noting that a genus is a classification grouping that encompasses organisms sharing similar characteristics and is larger than a species but smaller than a family. On the other hand, a species refers to a group of plants or animals that share the same characteristics and are capable of interbreeding.

The Eastern states of India are home to an impressive variety of bamboos, encompassing nearly 90 different species, out of which 41 are indigenous to India. Among these species, three large genera stand out: Bambusa, Dendrocalamus, and Ochlandra, each containing over 10 species (Ahmad, 2021). Collectively, these three genera account for approximately 45% of the total bamboo species found in India. Conversely, some genera are represented by a single species each. Bamboos in India exhibit remarkable diversity in terms of both their habitats and growth habits, ranging from tropical to sub-alpine zones within various forest types. Bamboo species like Bambusa balcooa are widely used for crafting furniture due to their robust and flexible culms. The abundance of green sound bamboos is highest in Arunachal Pradesh with a count of 26,660 lakhs, followed by Assam with 20,460 lakhs, Manipur with 20,350 lakhs, and Mizoram with 19,530 lakhs (Yadav, 2021). Table 4 presents a comprehensive list of the primary species found in the Eastern states of India, along with their respective genera.

Table 4: Distribution of different bamboo species in East India
Source: Das, 2012

State	Genera/Species	Main genera	Main Species
Arunachal Pradesh	Genera (14) Species (41)	Arundinaria, Bambusa, Chimonobambusa, Cephalostachym, Dendrocalamus	B. balcooa, B. tulda, B. pallida, B. nutans, D. Hamiltonii, Melocanna baccifera, Cephalostachym capitatum, C. fuchsianum, C.pallidum, C. latifolium, Chimonobambusa griffithiana, Chimonobambusa intermedia, Neohouzeana ullooa
Assam	Genera (13) Species (33)	Bambusa, Dendrocalamus, Schizostahyum	B. arundinaria, B. balcooa, B. tulda, B. pallida, B. nutans, D. hamiltonii, B. khsiana, Schizostachyum dullooa, Melocanna baccifera, Dendrocalamus

			patellaris, D. sikkimensis, Neohouzeana dullooa, Schizostachyum polymorphum
Nagaland	Genera (11) Species (23)	Cephalostachym, Dendrocalamus	B. khasiana, B. tulda, D. hamiltonii, Dendrocalamus patellaris, D. hookeri, D. sikkimensis, Cephalostachym capitatum, C. latifolium, Neohouzeana dullooa
Manipur	Genera (9) Species (20)	Arundinaria, Bambusa, Melocanna	Arundinaria clarkei, b. khasiana, B. pallida, B. balcooa, B. tulda, D. hamiltoni, C. fuchsianum, C. latifolium, Chimonobambusa khasiana, Melocanna baccifera.
Mizoram	Genera (7) Species (15)	Bambusa, Dendrocalamus, Melocanna	B. arundinaria, B. tulda, D. hamiltonii, D. hookeri, D. sikkimensis, Cephalostachym capitatum, Neohouzeana dullooa, Schizostachyum polymorphum, Melocanna baccifera
Tripura	Genera (7) Species (36)	Bambusa, Dendrocalamus, Arundinaria, bambbusa, Chimonobambusa, Melocanna	B. balcooa, B. pollida, B. arundinaria, B. tulda, D. hamiltonii, D. hookeri, D. sikkimensis, Cephalostachym captitetum, Chimonobambusa Khasiana, Chi. Hookeri, Neohouzeana dullooa, Schizostachyum polymorphum, Melocanna baccifera
Meghalaya	Genera (5) Species (13)	Bambusa, Melocanna	B. arundinaria, B. pollida, B. tulda, B. balcooa, D. hamiltonii, Neohouzeana dullooa, Melocanna baccifera

Bamboo Application

Bamboo Furniture

Furniture being a basic necessity of human life, should be comfortable, decorative, and visually appealing. They are also major elements of interior designs. In producing interiors, the style of furniture should go with the indoors environment and create harmony. Bamboo furniture is used in indoor as well as outdoor because of its light weight, natural resistance, and mechanical properties. Bamboo furniture includes stools, benches, chairs, tables, cupboards, beds, and bookshelves (Gao, 2018).

In making furniture, Bamboo was cut to the desired size and length throughout the production process. Design and carvings were created, and these sections were then linked together using nails and other materials considered appropriate for the finished result. Varnish is then used to polish these items.

With the technological innovation and development of the bamboo industry, particularly the research and development of bamboo-based panels, the structure and modelling of bamboo furniture is being diversified and embellished. On the one hand, modern bamboo furniture is full of classic elegance, and on the other, it is easy and comfortable (Gao, 2018).

Bamboo furniture is now available in a wider range of shapes and finishes than ever before. Bamboo is preferred by furniture designers for unique designs, (refer to fig. 5 and 6) whether in all-bamboo or composite materials. Bamboo furniture is durable and long-lasting. It is far more resistant to harm than typical hardwoods.

Fig. 5: M.P. Ranjan with the Katlamara bamboo chair designed by him. Courtesy of Aditi Ranjan.
Source: Lomas, 2015

The "Katlamara Bamboo Chair" is a striking creation by designer M.P. Ranjan (Fig.3), showcasing the harmonious blend of traditional craftsmanship and modern design principles. Crafted from bamboo, this chair embodies both strength and elegance, with its minimalist yet sturdy construction. Ranjan's innovative approach highlights bamboo's potential as a sustainable and culturally rich material in contemporary furniture design, making it a noteworthy piece in the world of eco-friendly furnishings.

Fig. 6: The bamboo mosaic series shadow table.
Source: Gao, 2018

The Bamboo Mosaic Series Shadow Table, as depicted in "Fig. 4," serves as an exemplary case that harmoniously blends traditional bamboo cultural symbolism with contemporary design elements, imbuing the product with profound cultural significance. This side table comprises a detachable metal bracket and a tray-like desktop, a design that offers both portability and the option to use the desktop separately.

The ingenuity of this design lies in its thin frame structure, which is transparent and unobtrusive, ensuring that it seamlessly integrates into any space without obstructing sightlines while maintaining a subtle yet significant presence. This minimalist and contemporary side table draws inspiration from the traditional wooden washbasin rack, transforming a conventional piece into a modern work of art.

Country furniture from the 1960s and 1970s, fashioned of unmilled bamboo shoots and poles, is still available. There is also a replacement face for the current type of furniture. Bamboo furniture that has been milled, sanded, and polished surpasses any hardwood furniture in terms of durability and beauty. Add to that the fact that bamboo is one of the world's most ecologically friendly

resources to grow, harvest, and use, and it's easy to see why bamboo has become one of the most popular furniture and building materials on the market.

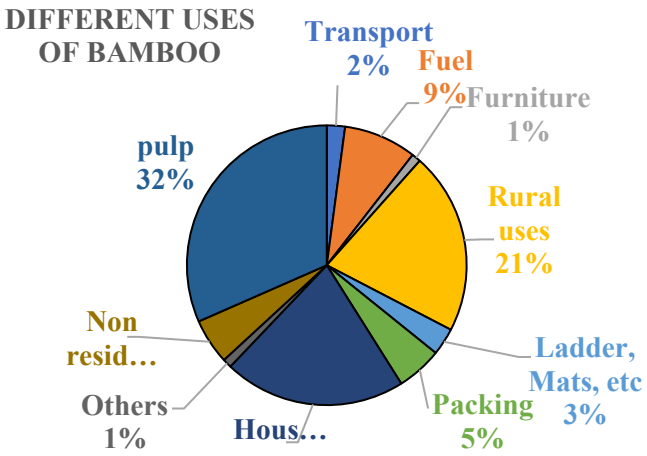

Fig. 4: Diverse applications of bamboo.
Source: Satya,2016

The pie chart above offers a comprehensive view of the wide-ranging applications of bamboo. A significant portion is allocated to "Pulp" production, emphasizing its crucial role in the paper and pulp industry. "Rural Uses" and "Housing" also hold substantial segments, underlining bamboo's importance in rural construction and daily household items. Furthermore, "Fuel" and "Packing" reflect bamboo's role as an energy source and packaging material. "Non-Residential" uses demonstrate its application in commercial contexts. The remaining categories encompass "Transport," "Ladder, Mats, etc," "Furniture," and "Others," indicating relatively limited usage in these domains.

Bamboo as a decorative material

Bamboo offers a plethora of possibilities for enhancing the aesthetic appeal of both indoor and outdoor spaces.

Interior spaces

One popular use of bamboo is as a wall covering or panelling, providing an accent wall that adds texture and serves as a natural backdrop for artwork and decorative elements. Moreover, bamboo is utilized in the creation of unique lighting products, including pendant lights and floor lamps, which leverage its inherent texture and brightness to bring an organic touch to any environment (Nguyen 2018).

Outdoor spaces

In outdoor spaces, bamboo serves as a versatile decorative element. Bamboo fencing, for instance, is employed to provide both security and a touch of natural beauty to outdoor areas. It can create boundaries while adding an aesthetic appeal. Bamboo is also utilized in the construction of pergolas, arbors, and other outdoor structures that offer shade and enhance the overall beauty of gardens or patios. These structures not only provide functional benefits but also contribute to the visual appeal and ambiance of the outdoor space.

Fig. 7: Trusses/ roof
Source: Yadav, 2021

The utilization of bamboo for trussed roofs represents a harmonious blend of tradition and sustainability in architectural design. Bamboo's inherent strength, rapid growth, and eco-friendly attributes make it an excellent choice for constructing robust and visually appealing trussed roofs, especially in regions abundant with bamboo resources like the Eastern states of India. This integration of bamboo into trussed roof construction underscores its potential to provide both functional and environmentally conscious architectural solutions, refer to fig. 7.

Advantages and Disadvantages of bamboo

Advantages

According to Ahmad (2020) Bamboo possesses remarkable strength and durability, allowing it to withstand extreme weather conditions, earthquakes, and strong winds . It exhibits a high tensile strength and can support heavy loads effectively (Sharma, 2014). In addition to its resilience, bamboo is an affordable building material, especially in the Eastern states of India, where it is widely available. Chaowana, (2021) says that, compared to materials such as brick, concrete, and steel, bamboo is a cost-effective option . Moreover, bamboo's natural and unique aesthetic appeal enhances the beauty of architectural spaces. Its versatility enables the creation of intricate and visually appealing designs that serve both functional and decorative purposes (Shah, 2012).

Disadvantages

While bamboo offers numerous benefits, it is important to note that it is susceptible to water damage and can warp or expand when exposed to water for extended periods. This characteristic makes it less ideal for outdoor use or in humid environments. Additionally, bamboo's unique texture and colour, while distinctive, may impose limitations on the available design options (Mohan, 2022).

Conclusions

In conclusion, this extensive literature survey highlights the significant promise inherent in using bamboo as a sustainable construction material. Bamboo appears as an appealing alternative for solving critical environmental challenges while also supporting cultural and economic progress due to its extraordinary characteristics such as quick growth, renewability, and ecological compatibility. Its versatility manifests itself in a wide range of uses, from its essential position as a strong building element to its exquisite incorporation into furniture and aesthetic components, both inside and outside.

The fundamental significance of Bamboo has been clearly proven across a variety of cultures throughout history, and its present rebirth in architectural and design fields demonstrates its ongoing relevance. Bamboo enhances not just the visual elements of constructed settings but also resonates nicely with the concepts of sustainable progress by smoothly fusing traditional ethos with current design paradigms. The diverse range of bamboo species accessible in India's eastern states provides a plethora of resources for sustainable building and design projects.

However, while bamboo has many advantages such as toughness, economic viability, and natural beauty, it is essential to recognise its vulnerability to water-induced degradation and some design constraints. However, with the constant march of technology and the frontiers of innovation, these limitations may be addressed, making bamboo more useful across a broader range of applications. It was discovered that the application of bamboo is the least specified, as well as the gap in papers was discovered after an in-depth review.

This rigorous literature review highlights the fundamental potential of bamboo as an environmentally harmonious, extraordinarily adaptable, and culturally resonant building and design material. Bamboo stands poised to continue its pivotal role in sculpting conscientious, visually captivating, and ecologically balanced architectural and design landscapes in India and beyond through a prudent exploration of its merits and constraints, combined with a celebration of its historical legacy and cultural eminence.

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References

Ahmad, Z., Ding, Y., Emamverdian, A. & Fatemeh. R. (2020) Application of Bamboo Plants in Nine Aspects, *Scientific World Journal,* 7284203, 12(3),1-31

Ahmad, Z., Upadhyay, A., Ding, Y., Emamverdian, A. & Shahzad, A. (2021) Bamboo: Origin, Habitat, Distributions and Global Prospective, *Biotechnological Advances in Bamboo*, 15(4),1-31.

Baghel, A. (2017) Bamboo: A Resilient Material for Mass Housing in Earthquake Prone Zones of Gujarat, *Sustainable Built Environment Interntional Conference Planning*.

Borowski, P. F., Patuk, L., Bandala, E. & E. R. (2022) Innovative Industrial Use of Bamboo as Key "Green" Material, *Sustainability* (Switzerland), 14(4), 34-45

Chaowana, K., Wisadsatorn, S. & Chaowana, P. (2021) Bamboo as a sustainable building material—culm characteristics and properties, *Sustainability (Switzerland)*, 13(13),1-18.

De Souza, C. V. & Meirelles, C. R. M. (2021) Analysis of the bamboo construction process in the architecture of Leiko Motomura and Simón Vélez. *International Journal for Innovation Education and Research*, 9(9),589-600.

Das, P., Korde, C., Sudhakar. P. & Satya. S. (2012) Traditional Bamboo Houses of North-Eastern Region A Field Study of Assam Mizoram, *Key Engineering Materials*, 517, 197-202.

Dhiman, S. & Lallotra. B. (2022) Replacing of steel with bamboo as reinforcement with addition of sisal fiber, *Materials today: proceedings,* 48(5),1708-1712.

Gao, W. (2018) Study on Creative Design of Bamboo Furniture from the Perspective of Ecological Design, *Advances in Social Science, Education and Humanities Research*, 205(3),716-718.

Kasinath, I. V. & Singha, H. R. (2021) Use of Bamboo as a Construction Material in the North-East and Southern Vernacular Settlements of India, ISVS e-journal 8(4),84-99.

Laleicke, P. F., Cimino-Hurt, A., Gardner, D. & Sinha, A. (2020) Comparative carbon footprint analysis of bamboo and steel scaffolding, *Journal of Green Building,* 10(1),114-126.

Lomas, D. (2015) In Conversation India's Design Guru: M.P. Ranjan, *She Ji: The Journal of Design, Economics, and Innovation*, 1(2),157-173.

Loushambam, R. S., Raju Singh, N., Taloh, A. & Mayanglambam, S. (2017*)* Bamboo in North East India, *Indian Journal of Hill Farming* 30(2),181-185.

Manandhar, R. (2019) Environmental, social and economic sustainability of bamboo and bamboo-based construction materials in buildings, *Journal of Asian Architecture and Building Engineering,* 18 (2),52-62.

Maikol, S. M. Y., Maksimovich, S. V., Ivanovna, B. G. & Ainur, S. (2020) Bamboo Structures for Modern Sustainable Architecture*,Journal of the International Society for the Study of Vernacular Settlements,* 7(3),27-39

Mohan. N., Dash, S. P., Boby, N. M. & Shetty, D. (2020) Study of bamboo as a building material – Construction & preservation techniques and its sustainability, *Materials today: proceedings,* 60(1*),*100-114.

Nguyen, T. B. V. (2018) Bamboo - The eco-friendly material - One of the material solutions of the sustainable interior design in Viet, *MATEC Web of Conferences.*

Nurdiah, E. (2016) The Potential of Bamboo as Building Material in Organic Shaped Buildings. *Procedia - Social and Behavioral Sciences*, 216 pp-30-38.

Raj, D. & Agarwal, B. (2014) Bamboo as a Building Material. *Journal of Civil Engineering and Environmental Technology*, 1(3),56-61.

Rathour, R., Kumar, H., Prasad, K., Anerao, P., Kumar, M., Kapley, A., Ashok, A., Kumar Awasthi, M. & Singh, L. (2022) Multifunctional applications of bamboo crop beyond environmental management: an Indian prospective, *Bioengineered (Taylor and Francis Ltd.)*, 13 (4),8893-8914.

Satya, S. & Perminder, J. K. (2016) Bamboo: The Material of Future, *Interdisciplinary and Multidisciplinary Research (IJSMR)*, 2(2),17-24.

Shah, R. A., Bhambhava, H. D. & Pitroda J. (2012) Bamboo: Eco-Friendly Building Material in Indian Context. *International Journal of Scientific Research- Engineering,* 2 (3), 129-133.

Sharma, P. Dhanwantri, K. & Mehta, S. (2014) Bamboo as a Building Material, *International Journal of Civil Engineering Research*, 5(3),294-254.

Tewari, S . (2019) Status of Bamboo in India, *International Journal of Economic Plants* ,6(1), 30-39.

Tewari, K., Kaushal, R. & Tewari, L. (2014) Evaluation of Bamboo species in India: Results from a multilocational trial, *Indian Journal. of Agroforestry*, 16(1),68-73.

Van Der Lugt, P. & Vogltander, J. G. (2014) Life-cycle Assessment and Carbon Sequestration, *The International Network for Bamboo and Rattan*, 35.

Yadav, M. & Mathur, A. (2021) Bamboo as a sustainable material in the construction industry: An overview, *Materials today: proceedings,* 43(5),2872-2876.

Yang, Y. M., Wang, K. L., Pei. S. J. & Hao, J. M. (2004) Bamboo diversity and traditional uses in Yunnan, China, *Mountain Research and Developmenti*, 24 (2),157-165.