

# *Bamboo as a Construction Material in the Structural Industry-A Review*

Ishita Banerjee  
 Civil Engineering Department  
 Dr.B.C.Roy Polytechnic  
 Durgapur,India  
[ishita.banerjee@bcrec.ac.in](mailto:ishita.banerjee@bcrec.ac.in)

**Abstract**—This research evaluates the potential of bamboo as a building material in civil engineering, specifically focusing on its application as reinforcement in reinforced concrete (RCC) structures under harsh and corrosive conditions. The key advantages of bamboo include its durability, resistance to corrosion, and local availability, making it an attractive option for sustainable construction. However, challenges such as mechanical variability, toughness, and the need for proper integration into building codes must be addressed. While bamboo's impressive strength-to-weight ratio and flexibility underscore its potential, they also raise structural safety concerns that necessitate the development of standardized guidelines. The conclusion emphasizes the importance of collaborative research initiatives aimed at establishing safety standards for bamboo use in construction. This review contributes to the existing literature by identifying gaps and supporting informed decision-making regarding bamboo role in modern building practices. Overall, it advocates for further exploration of bamboo's capabilities to enhance sustainable construction methodologies.

**Keywords**—Bamboo, green steel, engineered connections, earthquake based

## I. INTRODUCTION

The development industry is experiencing a significant transformation toward sustainable and mindful practices. As traditional building materials come under scrutiny for their environmental impact and resource depletion, there is an increasing interest in alternative materials that align with these evolving standards. One such material gaining attention is bamboo. Often referred to as “green steel,” bamboo has captured the interest of structural engineers and architects due to its remarkable combination of strength, flexibility, and rapid renewability. Its ability to thrive in diverse climates and potential for local cultivation make it a promising solution for construction in both developed and developing regions. This review aims to assess the viability of bamboo as a structural material in architectural development, focusing particularly on its potential use as reinforcement in reinforced concrete (RCC) structures. This is especially relevant for low-scale developments situated in harsh and corrosive environments. The research will provide a comprehensive understanding of the role bamboo could play in shaping the future of sustainable construction by exploring its advantages, limitations, and safety considerations in this innovative application.

### A. Advantages of usage of Bamboo

This study explores the potential of bamboo and its various applications and benefits in the construction sector. The current energy crisis, exacerbated by unchecked industrial growth, has raised significant concerns about the sustainable management of remaining energy resources and the ongoing environmental degradation. Consequently, there

is an urgent search for materials and manufacturing techniques that are environmentally friendly and energy efficient. Bamboo emerges as a highly desirable choice for construction due to its numerous advantages. With an impressive strength-to-weight ratio, it is not only lightweight but also exceptionally versatile, making it suitable for a wide range of applications, including buildings, bridges, and other structural works. Its ease of manipulation with common tools adds to its appeal, facilitating widespread use. Furthermore, bamboo is an affordable resource that is globally available, particularly in rural areas. As a type of grass, it boasts remarkable growth rates—typically growing between 30 cm to 1 m per day (Su et al. 2021)—which makes it an incredibly renewable resource. The exploration of bamboo benefits in construction is timely, given the pressing need for sustainable materials that can address both ecological concerns and economic viability. As the industry continues to evolve, bamboo could play a pivotal role in shaping a more sustainable future for construction practices worldwide. Bamboo is noteworthy for its ability to absorb more carbon dioxide compared to many hardwood plants, releasing 35% more oxygen into the atmosphere. This makes it an important asset in mitigating climate change. Engineered bamboo components have been effectively utilized in various contemporary structures, showcasing their versatility. However, one of the challenges of using engineered bamboo is its comparatively low rigidity. This characteristic can lead to significant deflection, which limits the span of bamboo structures compared to those made from reinforced concrete or steel. Despite this limitation, many prominent buildings have been constructed using bamboo, though awareness of its potential remains limited. Eco-conscious communities are increasingly impressed by bamboo sustainable qualities, viewing it as an ideal material for environmentally friendly construction. Bamboo serves as a long-term resource for the biomass industry, offering renewable and self-sustaining products. Additionally, depending on the processing technology allied, raw bamboo can be transformed into a wide range of products, further enhancing its value in sustainable development.

### B. Disadvantages associated with bamboo usage

#### 1) Fungal Vulnerability

Bamboo is susceptible to fungal infections, which can compromise its structural integrity. Fungi thrive in humid environments, and exposure to moisture can lead to decay and weakening of the material.

#### 2) Non-sustainability

Despite its many advantages, the non-sustainability of bamboo as a construction material poses significant challenges. Addressing these issues through improved treatment methods and careful planning is crucial to ensure that bamboo can be a viable option for long-term

construction projects. Without these measures, the economic and safety implications of using bamboo could outweigh its environmental benefits. Frequent reports of deteriorating infrastructure, such as roads and bridges, highlight the risks associated with materials that lack durability. Bamboo structures that fail prematurely can pose safety hazards, leading to accidents and loss of life (Aniegbuna and Okolie, 2021).

### 3) Preservation problems

Bamboo presents several challenges when it comes to its transportability and usability in construction, particularly in comparison to traditional materials like steel and iron. Here are some key points regarding these issues: Transport Challenges, Design and Code Limitations, Longevity Concerns, Market Demand for Preservation.

#### 4) Preservation of quality

Bamboo, while promising as a construction material, faces several significant challenges that hinder its widespread adoption and effectiveness in large-scale projects: Quality Concerns, Profitability Issues, Ecosystem Dependency, Load-Bearing Limitations, Market Competition, Fraudulent Practices, Limited Applications.

#### 5) Bamboo joints and connections

Bamboo remarkable properties make it an ideal choice for structural applications in various regions. Its durability, flexibility, and strength have been utilized in construction for centuries. To ensure the structural integrity of bamboo structures, it is crucial to create proper joints and connections (Li et al. 2019). Modern Simply Bolted Joints, Traditional Methods, Engineered Connections are common bamboo connections. The choice of connection method depends on various factors, including design requirements, load considerations, and aesthetic preferences. Properly executed, these connections ensure that bamboo retains its structural integrity while offering a sustainable alternative to traditional building materials.

#### 6) Simple bolted modern joints

Mechanical fasteners like bamboo nails, screws, and bolts play a crucial role in modern bamboo construction techniques, enhancing the strength and reliability of connections between bamboo culms. Bamboo nails, or split bamboo pins, are inserted into pre-drilled holes and secured with wedges or plugs. This approach not only simplifies the assembly process but also maximizes the structural integrity of bamboo components, making it a highly effective method for creating durable bamboo structures. By integrating these fasteners, builders can take advantage of bamboo natural properties while ensuring robust connections that withstand various loads and stresses. This technique demonstrates the traditional materials.

*a) Nails of Bamboo:* Bamboo nails, often referred to as "split bamboo pins" or "Dendrocalamus

giganteus nails," are commonly utilized in modern bamboo construction techniques. These nails are inserted into pre-drilled holes in the bamboo culms and secured with plugs or wedges. This method provides reliable connectivity while remaining straightforward to implement. The use of bamboo nails enhances the structural integrity of connections, making them an efficient choice for assembling bamboo structures. Their ease of use and effectiveness contribute to the growing popularity of bamboo as a sustainable building material.

#### *b) Bamboo screw, bolts*

Bamboo-specific screws and bolts are essential for creating strong and durable connections in bamboo construction. These fasteners are particularly beneficial for larger or more complex structures, providing added stability and support.

## II. BAMBOO FISHPLATE JOINT

A metal fishplate or connector is commonly used to join two bamboo culms in a fishplate joint. In this method, the culms are typically inserted into slots on the fishplate and secured together with bolts. This approach enhances the strength and stability of the connection, making it suitable for structural applications. The fishplate joint effectively distributes loads and improves the overall integrity of bamboo structures, allowing for safer and more reliable designs in construction.

## III. TRADITIONAL METHODS

Traditional or vernacular construction techniques have long been employed in regions where bamboo is abundant. These methods leverage time-tested practices that harness the inherent flexibility and strength of bamboo. Typically, bamboo culms are lashed together using natural fibers such as ropes or vines, creating strong yet flexible connections.

**i) Lashing-**Lashing is the practice of binding bamboo culms together using ropes, vines, or other natural fibers. This technique is a fundamental step in traditional bamboo construction, as it creates strong linkages by tightly twisting the lashings around the culms. Lashing offers a quick and efficient solution for constructing basic structures like fences and small shelters. Its simplicity and effectiveness make it an enduring method, allowing builders to take advantage of bamboo flexibility and strength while maintaining a sustainable approach to construction.

**ii) Dowels-**Bamboo dowels are often employed in traditional construction methods to reinforce joints. In this technique, holes are drilled into the bamboo culms, and dowels made from wood or bamboo are inserted to create a secure connection. This approach is particularly useful for enhancing stability in critical structural areas, providing additional support and load distribution. The use of bamboo dowels showcases the adaptability of traditional techniques, allowing builders to combine materials for improved structural integrity while maintaining the sustainability of bamboo as a primary resource.

#### IV. ENGINEERED BAMBOO CONNECTION

Engineered connections for bamboo are often specialized systems developed by companies or organizations with expertise in bamboo construction. These systems are designed to provide precise and reliable connections tailored for various structural applications.

**i) Metal Connectors:** Designed specifically for bamboo, metal connectors play a crucial role in engineered connections (Hong et al. 2019). These connectors facilitate precise and secure joining of bamboo members and include components such as brackets, clamps, and other specialized hardware. Their design accommodates the unique properties of bamboo, ensuring optimal load distribution and structural integrity.

**ii) Welding:** In certain scenarios, such as industrial projects, artistic installations, and applications subjected to high stress, bamboo members can be connected using welding techniques. This method allows for a strong and dependable connection, as welded joints provide a high degree of structural integrity and load-bearing capacity.

#### V. CODES OF PRACTICE IN INDIA

The recognition of bamboo as a valuable structural material has led to the development of codes of practice for bamboo construction in India and internationally. These guidelines promote safe and sustainable practices, offering detailed standards to maximize bamboo structural potential while ensuring safety and environmental responsibility.

In India, codes of practice for bamboo construction provide essential guidance on various aspects, including bamboo grading, treatment procedures, structural design principles, connection methods, and maintenance practices (Schroeder et al. 2019). Regulatory organizations and institutions uphold these standards to ensure compliance with safety and environmental regulations. Globally, organizations such as the International Bamboo and Rattan Organization (INBAR) and various national standards agencies have also created codes of conduct for bamboo construction. These guidelines focus on sustainable harvesting and advanced technical practices, aiming to harmonize bamboo construction methods worldwide. INBAR technical resources facilitate collaboration and knowledge sharing among international bamboo construction professionals, further enhancing the field's development and sustainability.

#### VI. BAMBOO AS A CONSTRUCTION MATERIAL

Bamboo, with over 1,200 species worldwide, is emerging as a sustainable alternative to steel in concrete applications due to its remarkable strength and flexibility. Its high tensile strength, especially when seasoned, makes it an effective reinforcement material in concrete structures. Bamboo splits can be integrated into concrete, enhancing the overall stability of buildings, particularly in regions where bamboo is readily available (Deresá et al. 2021). Research has shown that bamboo can effectively reinforce concrete beams,

functioning similarly to traditional reinforcement methods. Chemical treatments can enhance bamboo's composite strength, improving bond strength significantly, often exceeding 3.50 MPa when combined with sand particles. Additionally, incorporating bamboo mesh into wall constructions can increase flexibility, providing a more resilient and adaptable structural solution. This innovative use of bamboo not only promotes sustainability but also capitalizes on local resources. The bond development tool plays a crucial role in assessing the effectiveness of reinforcing bars, influencing section stiffness and crack control in concrete structures. Various factors affect bond behavior, including the spacing of reinforcing bars, the properties of transverse reinforcement, the characteristics of both concrete and steel, the surface area of reinforcement bars, and the position during casting. In some countries, innovative housing solutions incorporate plastered bamboo, using wooden skeletons and bamboo mats as the outer layer. These bamboo mats are plastered to provide a cohesive finish while allowing the bamboo frame to be visible both inside and outside the structure. This approach not only enhances aesthetic appeal but also serves practical purposes. Bamboo is increasingly used in constructing affordable housing in developing countries. Various bamboo-based construction materials have emerged, such as coated bamboo and bamboo-reinforced concrete. These materials often match or exceed traditional wood construction in quality, boasting better tensile strength and improved resistance to termites compared to untreated bamboo. This makes them an attractive option for sustainable and cost-effective building practices. Bamboo is notable for its unique rootstalk-dependent system and is among the fastest-growing plants in the world, often growing more than three times faster than other species. Its renewability and versatility make it a valuable resource, particularly in housing, especially in areas with limited materials and dense populations. Regions like Southeast Asia and parts of South America are ideal for bamboo cultivation due to their favorable climates. Bamboo structural properties allow it to be used effectively in bridges, providing tensile strength and support, as well as in various types of buildings. The construction process often utilizes bamboo frames, where walls, floors, and other components are interconnected to enhance strength and flexibility. The utilization of bamboo significantly contributes to rural transformation and enterprise development, making it an environmentally vital resource. Its reusability extends to reforestation efforts, where it helps protect soil and can be intercropped with other plants. This practice not only improves soil fertility but also enhances the overall health of the ecosystem, promoting sustainable agricultural practices and supporting the biodiversity of the region. Bamboo is an excellent alternative to traditional wood in manufacturing and construction, offering a sustainable solution that can enhance forest resources and help mitigate emissions associated with building materials like bricks and cement. Its rapid growth and renewability make it particularly valuable, especially in regions prone to natural disasters. Bamboo structures have proven effective in aiding recovery for communities that have experienced devastation from events like earthquakes. These houses can be constructed quickly and are inherently resilient to seismic activity,

providing a much-needed shelter solution during times of crisis. Additionally, bamboo's extensive root system helps stabilize the ground, reinforcing it against further damage from earthquakes and landslides. Moreover, bamboo's unique properties, such as its hollow structure, give it a higher density while remaining lightweight. This combination of strength and reduced weight makes it ideal for creating earthquake-resilient buildings that can withstand the forces of nature without being overly heavy. By utilizing bamboo in construction, communities can not only recover more effectively from disasters but also contribute to environmental sustainability.

Bamboo tensile strength varies significantly among its different species, often ranging from 50% to 80% of the strength of traditional construction materials, with some species exceeding this. Factors such as the height of the bamboo, the duration of seasoning, and its position play crucial roles in determining its moisture content and overall strength. During the seasoning process, the top portion of the bamboo tends to retain more moisture compared to the middle and base sections. This variation can significantly impact the binding characteristics with cement matrices. Proper seasoning is essential, as insufficient drying can weaken the bamboo and reduce its effectiveness as a reinforcement material in construction.

TABLE I. LITERATURE REVIEW

| SL. NO. | MAIN FINDINGS  | REFERENCE                                       |
|---------|--|---|
| 1.      | Bamboo is highlighted for its renewable nature, low embodied energy, and versatility in construction. Challenges such as standardization, variability, and durability are addressed, emphasizing the need for further research in design codes, structural analysis, and long-term performance.                                      | “Kitti Chaowana, Supanit Wisadsatorn et al,2021 |
| 2       | The benefits of Bamboo Reinforced Concrete (BRC) are highlighted, particularly in terms of flexural strength and crack resistance. Concerns regarding durability, bond strength, and code compatibility are addressed. Additionally, the effects of different bamboo species and treatment methods on BRC properties are summarized. | “Osmi, S.K.C. et al,2016                        |
| 3.      | The advantages of bamboo’s flexibility and resilience in structural applications are emphasized. Concerns regarding standardized design guidelines, mechanical variability, and long-term durability are addressed. A call for collaborative efforts to  | Aider et al,                                    |

|    |  |                           |
|----|--|---------------------------|
|    | establish safety standards is made.  |                           |
| 4. | The attractive mechanical properties of bamboo, including its high strength-to-weight ratio, are highlighted. Applications in roofing, scaffolding, and other construction elements are explored. Challenges related to design standards and treatment methods are identified.   | “Yuxiang Huang et al,2017 |
| 5. | The positive influence of bamboo on bond strength in concrete is discussed, exploring the effects of factors such as surface treatment, diameter, and embedment length. Challenges in ensuring consistent bond behavior due to bamboo’s natural variability are also identified.   | “T.M. Tiza et al,2021     |
| 6. | Bamboo produces twelve times more green building material than wood and offers a diverse range of eco-friendly commercial products for daily use, including shelter and transportation. This significantly reduces timber consumption. Additionally, bamboo roots help prevent erosion by acting as a barrier against water, serving as a protective measure for agricultural crops and villages in developed countries. | Madhura Yadav et al,2021  |
| 7. | An overview of various types of connections between bamboo members and their dowel connection capacity is presented. Additionally, the fabrication and construction of bamboo buildings are discussed, incorporating local experiences as reported in the Colombian Building Code, NSR-10 (AIS, 2010).   | Francisco F. Correal,2020 |

VII. PROMINANCE OF BAMBOO AS RCC MATERIAL IN HARSH AND CORROSIVE ENVIRONMENT

In developing countries with limited funding, bamboo is increasingly being used as reinforcement in reinforced concrete (RCC) structures (Mohan et al. 2022). In corrosive environments prone to natural disasters like earthquakes and floods, bamboo proves to be a superior choice over steel

reinforcement. This is due to bamboo higher tensile and flexural strength, as well as its greater overall durability. Engineers favor bamboo for small construction projects, utilizing it in various structural elements such as footings, roofs, columns, beams, and slabs. Its lightweight nature compared to steel makes it easier to handle and reduces transportation costs. As a result, bamboo reinforcement is becoming a popular and effective solution for constructing resilient buildings in harsh and corrosive conditions, providing an environmentally sustainable alternative for developing regions. Global warming has become a significant environmental concern, particularly with traditional construction methods like steel production, which generates approximately two tons of CO<sub>2</sub> for every ton of steel manufactured. In contrast, bamboo acts as a carbon sink, effectively absorbing CO<sub>2</sub>, making it an eco-friendly alternative for reinforcement in reinforced concrete (RCC) structures, especially for smaller projects. Bamboo ability to absorb water more efficiently than steel is another advantage. This property helps mitigate issues related to water leakage that can arise with steel-reinforced concrete. Additionally, bamboo fast water absorption can enhance its compatibility with concrete. Unlike steel, which can suffer from corrosion due to carbon and moisture, bamboo is resistant to such issues, making it a suitable choice for construction in disaster-prone areas. However, bamboo does have limitations, including susceptibility to contraction and expansion due to climate changes and moisture absorption, which can affect its performance over time (Dauletbek et al. 2021). Despite these drawbacks, bamboo remains a promising material for sustainable and resilient construction practices. While bamboo offers several advantages as reinforcement for RCC structures, there are important limitations and considerations to keep in mind. For effective use, bamboo reinforcement should not be placed less than 1.5 inches from the concrete surface to ensure proper bonding and protection. Additionally, ties connecting the bamboo should ideally be made with natural materials, such as green strips, to maintain the integrity of the structure. It is also crucial that bamboo reinforcement is evenly spaced and aligned correctly in relation to the main reinforcement to ensure optimal performance and strength.

#### VIII. STRUCTURAL PERFORMANCE FROM SAFETY ASPECT

The integration of bamboo as a structural material in civil engineering presents exciting opportunities alongside important safety considerations. Ensuring the safety of any construction material is crucial for the well-being of occupants and the long-term stability of structures. Bamboo has garnered attention for its unique properties, such as high tensile strength and rapid growth, making it an attractive option for sustainable construction. However, when evaluating its suitability for load-bearing applications, several factors must be carefully assessed. These include its variability across different species, its behavior under load, and its response to environmental conditions such as moisture and temperature changes. While bamboo offers numerous benefits, including environmental sustainability and potential cost-effectiveness, its limitations—such as susceptibility to contraction, expansion, and biodegradation—must be thoroughly addressed. Ensuring

proper design, treatment, and construction techniques is essential for building robust structures that leverage bamboo strengths while mitigating its weaknesses. Overall, a comprehensive evaluation is necessary to balance the advantages of bamboo with the imperative of structural safety.

- 1) High Strength-to-Weight Ratio
- 2) Natural Diversity and Grading
- 3) Longevity and Preservation
- 4) Joinery and Connection Methods
- 5) Tradition and Heritage
- 6) Fire Resistance
- 7) Dynamic Loads and Vibrations
- 8) Long-Term Behaviour and Monitoring

#### IX. CONCLUSION

Bamboo stands out as an efficient material for building houses while also contributing to carbon emission reduction. Through photosynthesis, bamboo absorbs carbon dioxide and produces more oxygen—up to 30% more than many tree species. Its remarkable strength rivals that of rock, yet it remains lightweight. Bamboo can grow over a meter in a short time, reaching full maturity in just three years. Its resilience allows it to thrive in harsh weather conditions, functioning as a natural coolant in summer and an excellent insulator in winter. Additionally, bamboo's tensile strength makes it capable of withstanding earthquakes, ensuring structural integrity over time. This versatility makes bamboo an ideal solution for communities facing environmental challenges or economic constraints. It provides a cost-effective building material that helps people endure adverse conditions while promoting sustainability in construction practices. Overall, bamboo proves to be a valuable resource for creating resilient and eco-friendly housing solutions.

Bamboo materials are cost-effective, which minimizes the risk of deformation during construction. They are particularly useful in situations where building resources are scarce and measurements are not fixed, making them ideal for temporary structures and small civil projects. Bamboo can also serve as a finishing material, and with ongoing research and development, it has the potential to be engineered for greater strength and tensile properties, possibly rivaling steel in small engineering applications. Natural bamboo fiber materials offer modern architectural solutions, providing insulation and energy efficiency for buildings. Chemical treatments can enhance bamboo bond strength, reduce water absorption, and limit shrinkage, contributing to improved durability. However, the effectiveness of these treatments can vary based on the quality of the bamboo used. Standard testing for fiber density is crucial, as variations can significantly impact the determination of bond strength. Overall, while bamboo presents promising opportunities in construction, careful consideration of its properties and potential variations is essential for optimizing its use in engineering projects.

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