Chapter

Advances in Bamboo Composites for Structural Applications: A Review

Medha Mili, Anju Singhwane, Vaishnavi Hada, Ajay Naik, Prasanth Nair, Avanish Kumar Srivastava and Sarika Verma

Abstract

The fastest-growing plant on earth is bamboo; it grows three times as quickly as most other species and is a renewable, adaptable resource with high strength and lightweight. Bamboos are a valuable alternative resource with high physical similarities with genuine hardwoods. Using these naturally available renewable bamboo resources provides a practical approach to an eco-friendly industry mainly based on green materials and sustainable technologies with minimum impact on nature. In this regard, developing advanced bamboo-based composites is an attractive step. The extensive use of bamboo composites is a result of their advantageous qualities, including dimensional stability, natural colour, exquisite texture, and ease of manufacturing. The bamboo-based composites have immense potential to perform as a wood substitute that can reduce timber import and meet future timber requirements that are presently fulfilled by cutting trees or importing timber. This chapter aims to exhibit these advanced bamboo composites as a competitive and sustainable substitution for conventional timber material for structural applications. The present chapter highlights the advanced bamboo composites as engineered materials utilised mainly for structural applications in housing sectors and construction industries in the form of standard regular shapes such as beams, planks, lumbers, truss elements etc. One of the sections would be dedicated to the future scope of these advanced bamboo composites and recommendations.

Keywords: bamboo, renewable resources, structural applications, housing sectors, construction industry

1. Introduction

Bamboo is giant woody herbage traditionally used for developing fences, furniture and construction, and financial and social roles. Green Gold and Poor Man's Timber are some of its other names. Due to several serious issues and the restrictions on the felling of trees, there is a growing interest in sustainable materials for structural applications worldwide. It is believed that bamboo is a durable and highly renewable resource that may be farmed in any region with a temperate environment [1].

However, the selection of structural materials can considerably impact the environment. Global worry over the greenhouse effect is growing as the earth's surface temperature rises. The excessive release of harmful chemicals and carbon dioxide into the atmosphere is to blame. Bamboo growth should also be taken into consideration as a solution for an accurate interpretation of the carbon balance in an ecosystem since carbon dioxide is the main cause of this heightened greenhouse impact [2, 3]. In this regard, bamboo and wood are choices as both can absorb carbon dioxide as they grow. Wood can have a high sustainability rate because it is inherently renewable, recyclable, and reused [4–6]. In addition, carbon may be stored for a long time in bamboo and wood constructions. The fastest-growing or herbaceous biogenic materials—also known as fast-growing or herbaceous biomass—are among the various biogenic materials and hold the greatest promise for reducing climate change because they can store carbon much more quickly than trees, whose high carbon content is typical of them, [7–9]. Bamboo, as a sustainable material, meets the requirements of green architecture. As for architects using bamboo was not just technical but also a deep consideration of traditional culture, ecological consciousness, thermal performance, emotional dimension, commercial and many other factors. As is well known, South China is home to two important commercial tree species: Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook.) and Moso bamboo (*Phyllostachy pubescens*). In China, structural timber use and research have received more attention over the last two decades. Due to the high quality of its timber and their economic importance [10–12]. Consequently, the bamboo species have been found to have a lot of potential for the building sectors in the future because their derived products have more sustainability rates and are naturally renewable, recyclable, and reusable, [13]. One of these is forest products, and the increased demand for them will necessitate their expansion and exploitation with little waste and loss. Growing environmental consciousness and dwindling natural resource availability have sparked a need for environmentally friendly materials in an effort to keep the price of conventional synthetic fibre reinforced composites down. Due to its low cost and low energy consumption, natural fibre reinforced green composites - originally developed for the automobile industry- has recently attracted significant scientific interest [14].

Bamboo possesses superior physical and mechanical characteristics similar to hardwoods and is thus considered a potential substitute for wood [15]. Bamboo is a good material for construction in columns and beams, walled envelopes, shear walls, ground materials, and other purposes because of its extraordinary strength-to-weight ratios and optimum thermal, acoustic, and other qualities with high tensile strength [16]. It has a much longer history of use as a construction material than wood, making it an essential component of daily life [17]. Bamboo's quick rate of growth is one of its advantages. By growing between 20 and 100 cm during a day, it can reach its full height of 15–30 m in two to four months [18]. Unlike wood, which takes over 20 years to reach maturity, it does so in just 3–4 years. When fully grown, bamboo has tensile strength that rivals mild steel. It can grow in currently unproductive regions (like on an eroding hillside), and because its root system keeps growing even after harvest, it can produce new shoots. Except for alkaline soils, deserts, and marshes, bamboo may grow on plains, hilly terrain, and high-altitude mountainous areas. According to some research, bamboo yields more biomass than other lignocellulosic crops, growing at a rate of 15-30 m height in couple of months [7, 9, 19]. Therefore, bamboo is more cost-efficient and effectively reduces the greenhouse effect when used as a structural material. In contrast, bamboo is an anisotropic material forming a seismic perspective and an excellent option for structures like bridges erected in seismically active areas due to its lighter weight, viscoelastic qualities, and deformability than steel or concrete. The knots, spiral grains, and wood twists are a few significant elements that affect bamboo's mechanical properties, composed of cellulose, hemicellulose, lignin, and extractives [20, 21]. India's bamboo species mainly suitable for composites are: *B. bamboos, B. Tulda, B. vulgaris, B. balcoa, B. mutans, B. polymorpha, Dendrocalamus strictus, D. asper, M. bacciffera.* However, the tiny diameter of bamboo culms and the wide range of its mechanical qualities limit the use of natural bamboo as a building material. Composite materials made of bamboo have been created to get around these limitations [22].

This chapter will introduce advanced bamboo composites, engineered materials primarily used for structural applications in the housing and construction sectors. These composite materials are typically used in standard regular shapes like beams, planks, lumber, and other components. The primary goal of this chapter is to impart the fundamental knowledge necessary for developing bamboo composites and their use in structural applications. Additionally, it emphasises the critical notion of methods and technology for bamboo composites and their numerous structural applications. One section contains the primary details regarding bamboo and engineered bamboo composites. Another section focuses on improving the understanding of different bamboo composites used for structural purposes. The conclusion and recommendations for further improvement in this area of research are also highlighted.

2. Bamboo- its composition and characteristics

Like wood, bamboo is a naturally occurring organic substance that is heterogeneous and anisotropic. However, there are notable variances in their morphology, structure, and chemical makeup, highlighting particular physic mechanical capabilities. Bamboo has more strength, tremendous toughness, and high stiffness than wood. Bamboo is a very robust material. Its tensile and compressive strengths are greater than those of the majority of other woods. Bamboo can sustain severe stress and has an excellent strength to weight ratio and structural integrity. Bamboo is a very strong material that is used to make flooring, cabinets, furniture, and buildings. Bamboo has the benefit of being "simple to produce." Although bamboo plants are not the easiest plants to propagate, they are relatively simple to plant and flourish in the landscape. It would be simpler if we could just gather the seeds and grow them from there. Bamboo is a popular material because of this. Generally speaking, they have robust features, yet they could be considered weak from a different perspective. Therefore, it is essential to comprehend bamboo resources for their effective utilisation. **Figure 1** shows the unique properties of bamboos.

2.1 Different bamboo structural forms as a building material

When designing with bamboo, whether for furniture, sculpture, or architecture, there is a constant urge to use the material's organic, flowing shapes. However, it's not like all bamboo poles develop as bent poles; some wobble and even twist as they grow, while the majority are rather straight. However, bamboo is frequently used in curving accessories, furniture, construction materials like windows and doors, and integrated building structures. **Figure 2** illustrates how bamboos are handled such that as they grow, they adopt the proper shapes and structures: This is accomplished by moulding into shape using a variety of techniques, such as tying, bolting, and glueing,

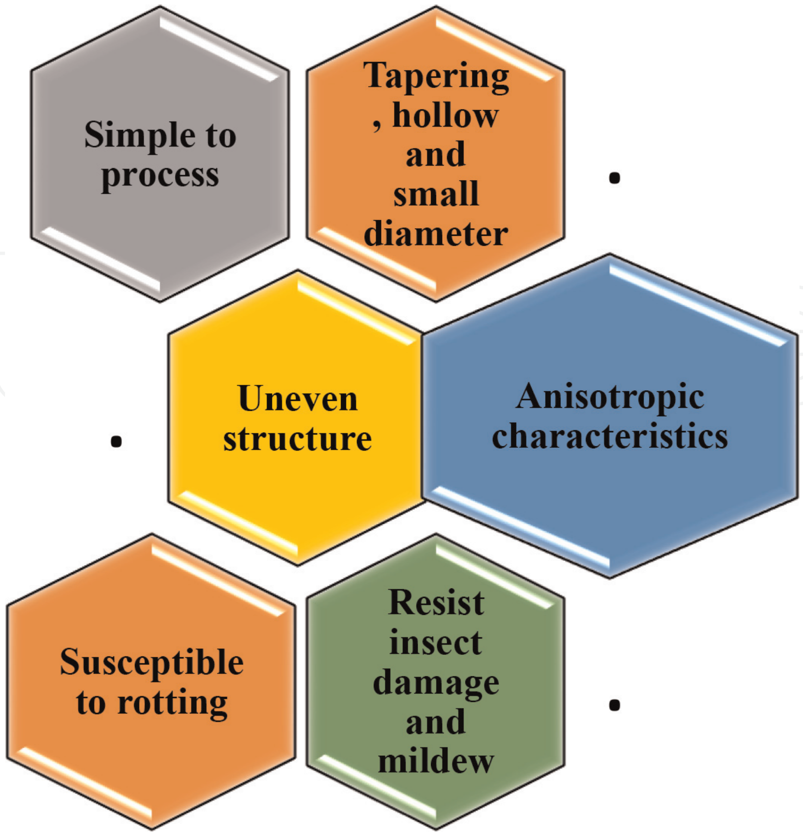

Figure 1.
Unique properties of bamboos.

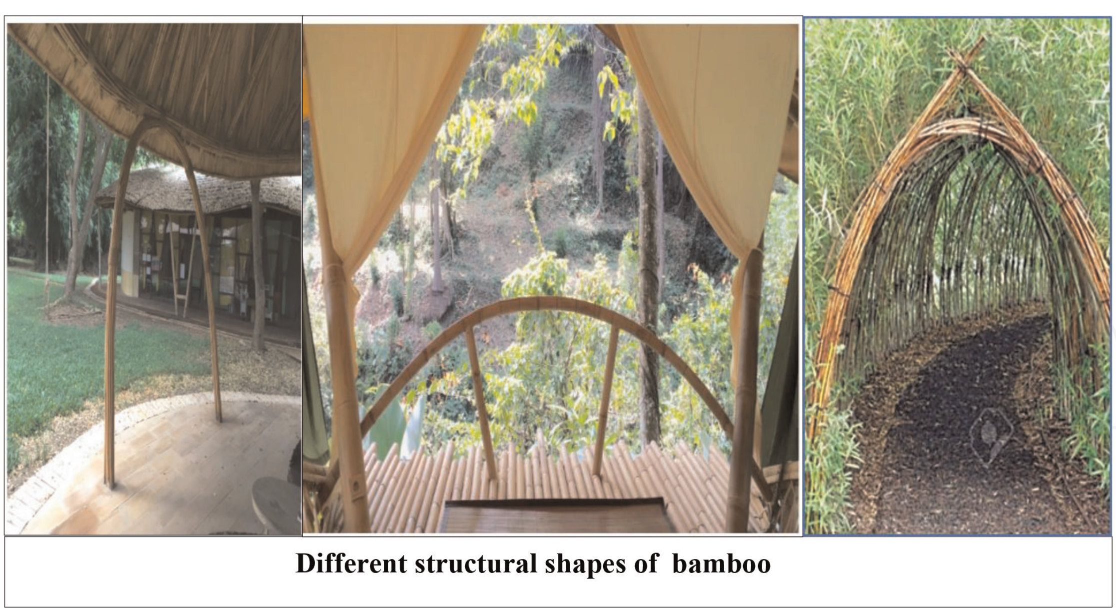

Figure 2.
Different structural shapes of bamboo (adopted from open access). (https://www.guaduabamboo.com/blog/how-to-bend-bamboo and https://www.wikihow.com/Bend-Bamboo).

occasionally in conjunction with an inner core element. Similar to the square shape, a squared cross-section can be produced by compressing a bamboo stalk into a square. Bamboo may be bent into arches by controlling its growth to take on the desired shape. Using this method would have been less expensive than purchasing regular timber to achieve the same result. Additionally, traditional techniques like exerting pressure and heat are used to create the flatter and curved bamboo shapes. A stronger structural element will be created when you combine two or maybe more pole in the same curve. In many regions of South East Asia, this is by far the popular technique for curving bamboo utilised in big scale bamboo building.

2.2 Characteristics of bamboo and its fibre

Large-scale bamboo structures consist of a hollow section and a narrow wall with a particular tapered form [23]. There are over 10 cellular layers in bamboo, each with a unique alignment of the micro fibrils and alternately thick and thin layers on the cell wall of the bamboo fibres. Unidirectional bamboo fibres are strengthened by parenchyma cells ground tissue, which serves as a cellular matrix (**Figure 3**). An indication of bamboo's functionally graded materials is the unequal access of vascular tissue in the radii direction. The aforementioned structures and characteristics give outstanding bamboo durability, hardness, bending flexibility, and lightweight. Bamboo's primary chemical components include cellulose, hemicellulose, and lignin, as well as various extractions, a small amount of ash, and silicon dioxide.

A single bamboo fibre's microstructure features layered cell walls arranged in concentric circles as depicted in **Figure 4**. And the layers comprise a substantial cell wall, a restricted lumen, a few pits, and a small micro fibril angle.

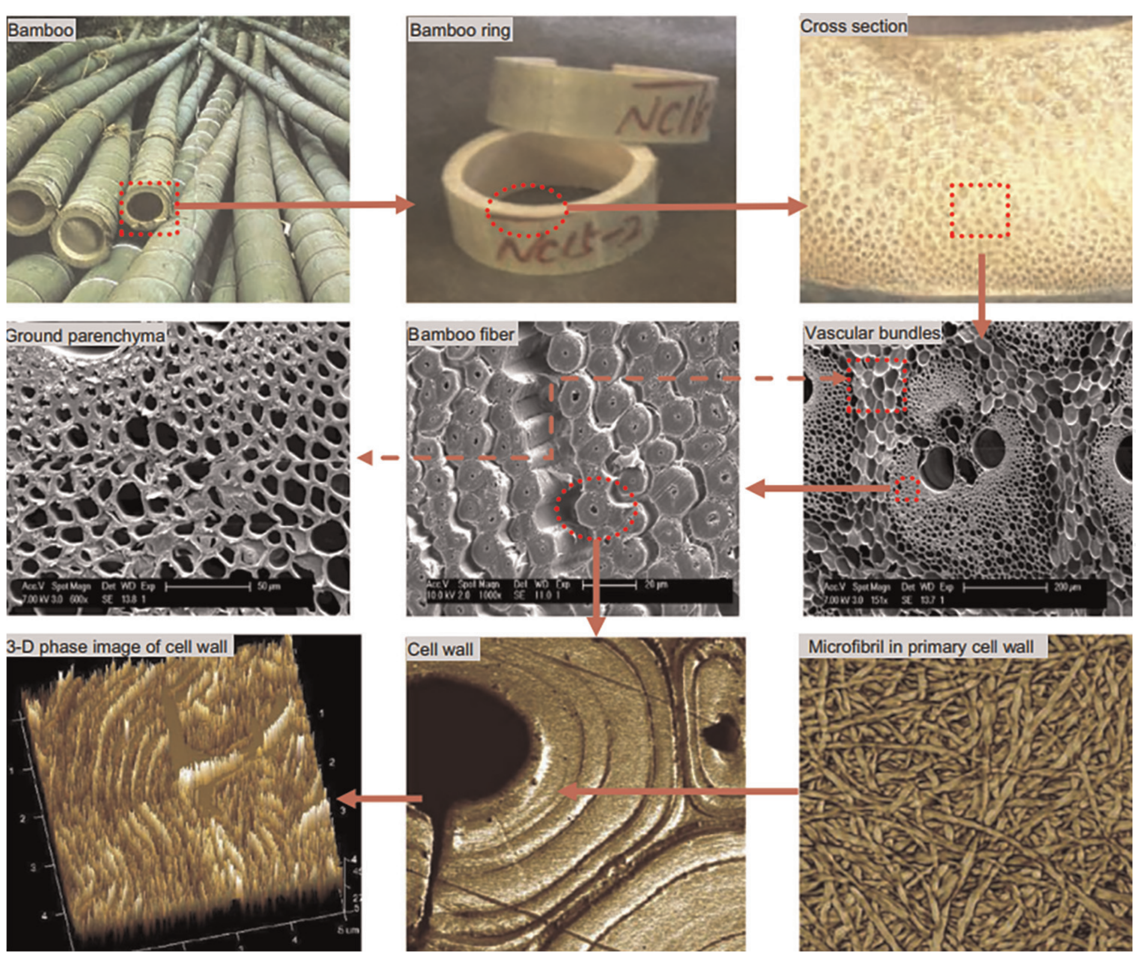

Figure 3.
Morphology and composition of bamboo (adapted from [24]).

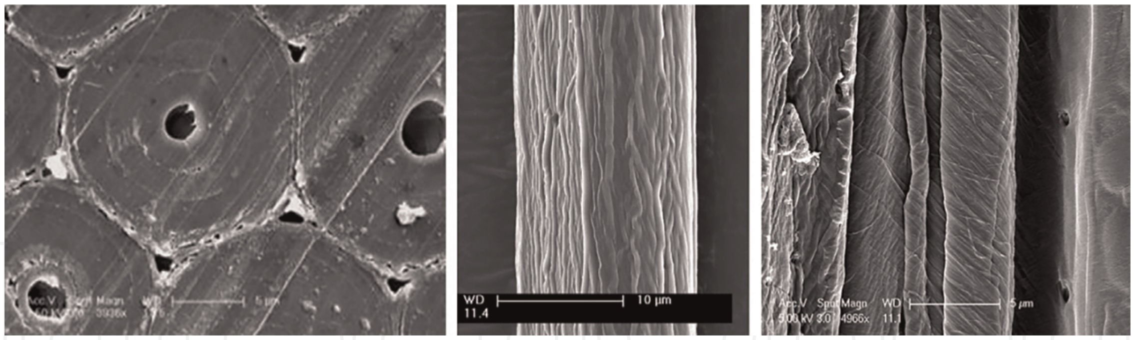

Figure 4.
Emission electron microscope picture of the longitudinal cross section of a single fibre (adapted from [24]).

3. Bamboo-based bamboo composites and panels

The production of bamboo-based composites and panels after being inspired by the advancements made in the woodworking sector was of great interest. Researchers created various types of bamboo-based composites due to their improved understanding of the unique characteristic of bamboo material and the bonding ability of bamboo green, medium, and yellow [25]. Comparing these novel products to wood-based products/panels reveals various distinguishing and attractive characteristics: The bamboo composites exhibit excellent proportions, dimensional stability, minimum distortion, and a constant size together with high wear resistance, adequate stiffness, and sufficient strength. Various other positive advantages such as low maintenance, high impact resistant, weather resistant, etc., can be witnessed in bamboo composite products. As reported in various papers, the bamboo fibres are treated with different polymeric resins like phenolformaldehyde, polyester, polylactic and Polypyrrole to develop a modified bamboo composite for structural application [26, 27]. At a specific amount of resistance to rot and insects, the customer's requests can be accommodated by altering the structure, size, and toughness of the product. Raw bamboo's improved qualities can be observed in many different contexts. To satisfy various needs, the product surfaces can be decorated in a number of ways.

Chen et al. [28] Making bamboo-bundle laminated veneer timber (BLVL) is a crucial step in producing long-span bamboo-based engineering materials. In the preprocessing densification process, phenol formaldehyde (PF) resin, polyvinyl acetate (PVAC), and other resins were combined to create the adhesive. These composites operate mechanically well, absorb moisture well, and bond strongly [29, 30] additionally, the BLVL exhibits outstanding bending characteristics, which allow for applications in bamboo structural engineering [31].

4. Structural applications of the advanced bamboo composites

Modifications and developments to the structural use of bamboo composite are being undertaken globally. Various researchers have researched and examined the use of bamboo composites developed using various resin materials for structural advances. The newest developments in bamboo composite materials for their structural applications undertaken by different scientists and researchers are presented here in this section.

Javadian et al., [32] reported on the unique usage of bamboo as sustainable alternative to synthetic fibres and studied their technical feasibility as reinforcement for structural-concrete beams for producing bamboo fibre-reinforced polymer composites. The bamboo used for this method was *Dendrocalamus asper*, popularly called as Petung Putih bamboo. The bamboo sections were first cooked at 80°C in normal water in a sealed jar for 8 to 20 hours. By reducing the lignin interface's adherence to the cellulose fibres, boiling the bamboo segments helped soften their microstructure, making bundling the segments into fibres simpler. The mix proportions are hand-laid up to generate them. Bundles of the coated, infused bamboo fibres were then placed into a hot-press machinery mould in the fibre direction after being initially dipped with an epoxy resin matrix. A simple yet effective semi-automatic hot-press compression moulded machine with high pressure of 25 MPa and a maximum temperature of 140°C was utilised. Eventually, specimens of bamboo composites were created using the authors' unique processing technology. The results of this study show that the ultimate loads for bamboo composite concrete beams and fibre reinforced polymer reinforced concrete beam that adhere to the ACI standard are comparable. ACI 440.1R-15, "Guide for the development and fabrication of structural concrete reinforced with Fiber Reinforced Polymer (FRP) bars," has provided design standards for the use of FRP materials as reinforcement in concrete. As opposed to steel reinforced concrete members, the FRP reinforced concrete has less ductility, which can be attributed to these guides. ACI 440.1R-15, that takes ductility into account, was the main and most applicable design guide to be employed in this research to analyse the effectiveness of bamboo composite reinforced concrete beams. The principles of equilibrium and compatibility serve as the cornerstone for the design recommendations provided by ACI 440.1R-15. It was decided to use the ultimate strength design method instead of the working stress conceptual design to generate the concrete beams supplemented with bamboo composite reinforcement in order to achieve results that were comparable to those obtained using methodologies used by other standards, such as ACI 318 for steel reinforced concrete design. The outcomes show the newly created bamboo composite materials potential for usage as a novel element for reinforced structural concrete beams. The bamboo composite reinforcement proposed in the paper has a lot of potential for use in real-world applications. This study also demonstrated that these newly created bamboo composite materials can be used to construct low-cost, low-rise housing units in situations where it is challenging to obtain steel reinforcement, there is little demand for ductility, and secondary-element failure adequately forewarns collapse. **Figure 5** shows the longitudinal and transverse bamboo-composite reinforcement system created for this investigation. This study thus exhibits the newly created bamboo composite material's potential for usage as a novel element for reinforced structural concrete components.

A review was proposed by [18] on three categories of novel engineered wood composites, including cross-laminated timber (CLT), fibre-reinforced polymer (FRP) reinforced glulam, and timber scrimber. Also, three types of novel engineered bamboo composites, including glued-laminated bamboo (glubam), laminated bamboo lumber (LBL), and bamboo scrimber were reported.

Engineered wood satisfying the modern structural design suitable for structural applications has been developed in the last decades, embracing wood as one kind of dominant material for modern structures [12]. Similarly, engineered bamboo is gaining increasing interest in the current scenario from structural or construction industries, owing to its relatively low variability in material

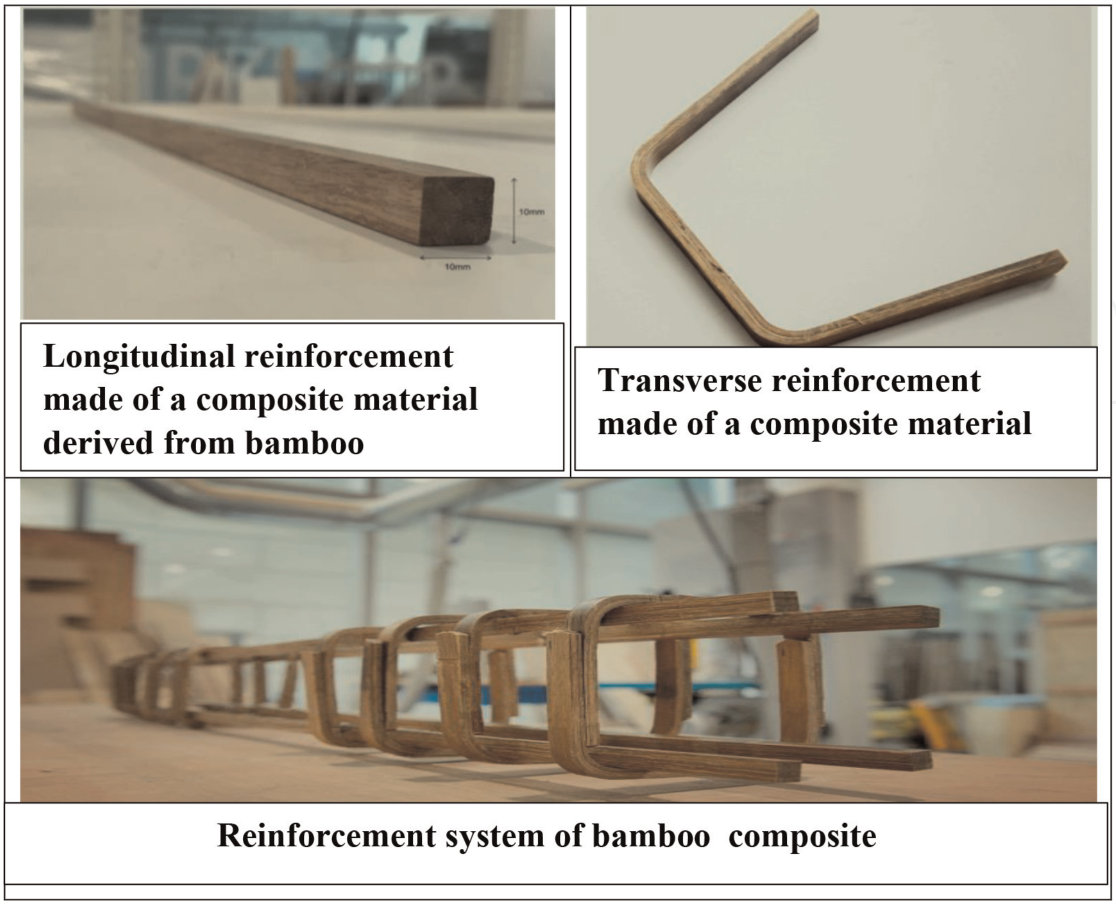

Figure 5.
Longitudinal and transverse reinforcement derived from a bamboo composite material (adapted from [32], with permission).

properties and shape standardisation. Three commonly used engineered bamboo products for structural applications primarily manufactured in China, and is used for the buildings or bridges construction are glued-laminated bamboo (glubam), laminated bamboo lumber (LBL), and parallel strand bamboo (PSB), which are described in detail below:

i. Laminated bamboo lumber (LBL)

   Laminate bamboo lumber (LBL) is a common engineered bamboo product made from bamboo components that have been glued together in various ways (for example, into strands, strips, mats, etc.) to make boards with rectangle cross sections.

   The following can be used to summarise one of the precise processes used to create bamboo-bundle laminated veneer lumber (BLVL) [33], which is basically one type of LBL products:

   1. Each bamboo tube is divided into four pieces that are almost the same size, and the strips are broomed and rolled into laminated reticulate sheets using an untwining machine;

   2. The bamboo sheets are sliced into bamboo bundles, which are then air-dried after they are cross-linked in the width direction.

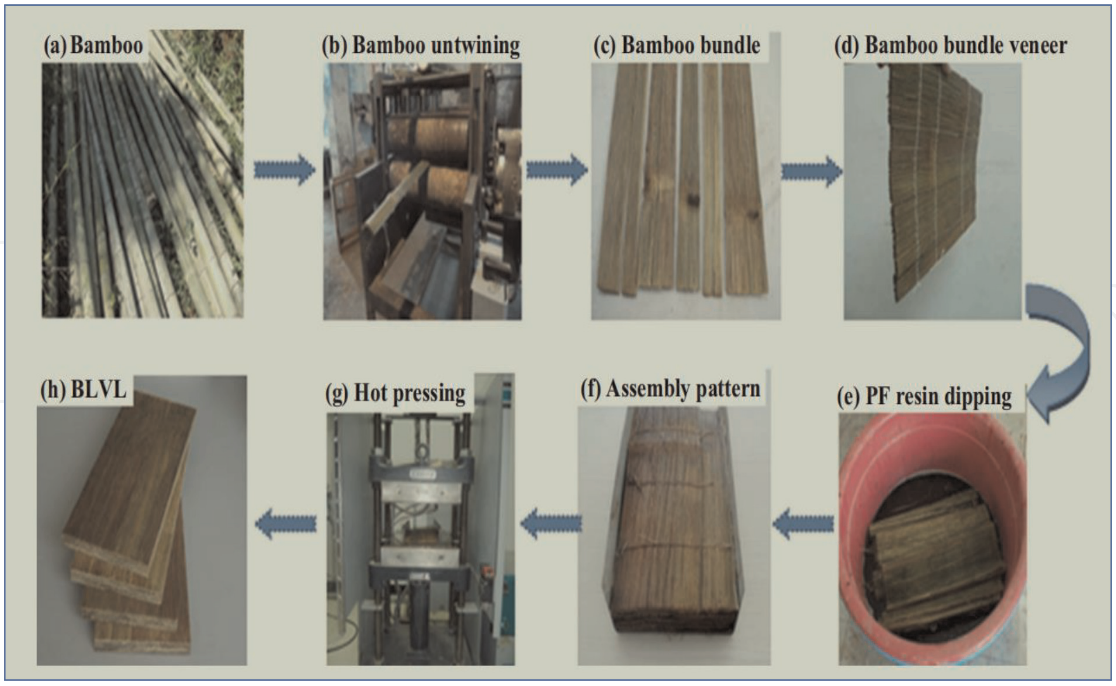

Figure 6.
Systematic representation of LBL manufacturing process (adapted with permission from [18].

3. Using cotton thread, bamboo bundles of thickness 5–7 mm are chosen and positioned in the breadth direction before being knotted together to make a homogeneous one-piece veneer.

4. After submerging in phenol-formaldehyde (PF) and drying, the bamboo veneers are hot pressed into a single BLVL by means of the specially made mould, as shown in **Figure 6**.

Li et al. [34] highlighted a theoretical method for calculating the folding volume of LBL beams and presented a simplified strain-stress relationship for LBL. The internal joints observed in the LBL beams were discovered to have a more significant impact on the specimen during tangent bending than those undergoing radial bending.

ii. Glued laminated bamboo

The term "glued-laminated bamboo" and the trademark "glubam," which alludes to the concept of "glulam" were created for a ground-breaking engineered bamboo product. The five steps that make up the complete global manufacturing process (shown in **Figure 7**) are:

1. choosing raw bamboo;

2. dividing bamboo culms into strips with a thickness of 2–3 mm and a width of 30 mm, and removing wax from the culms' surfaces,

3. bamboo curtains forming by the arrangement of the bamboo strips in parallel to one another;

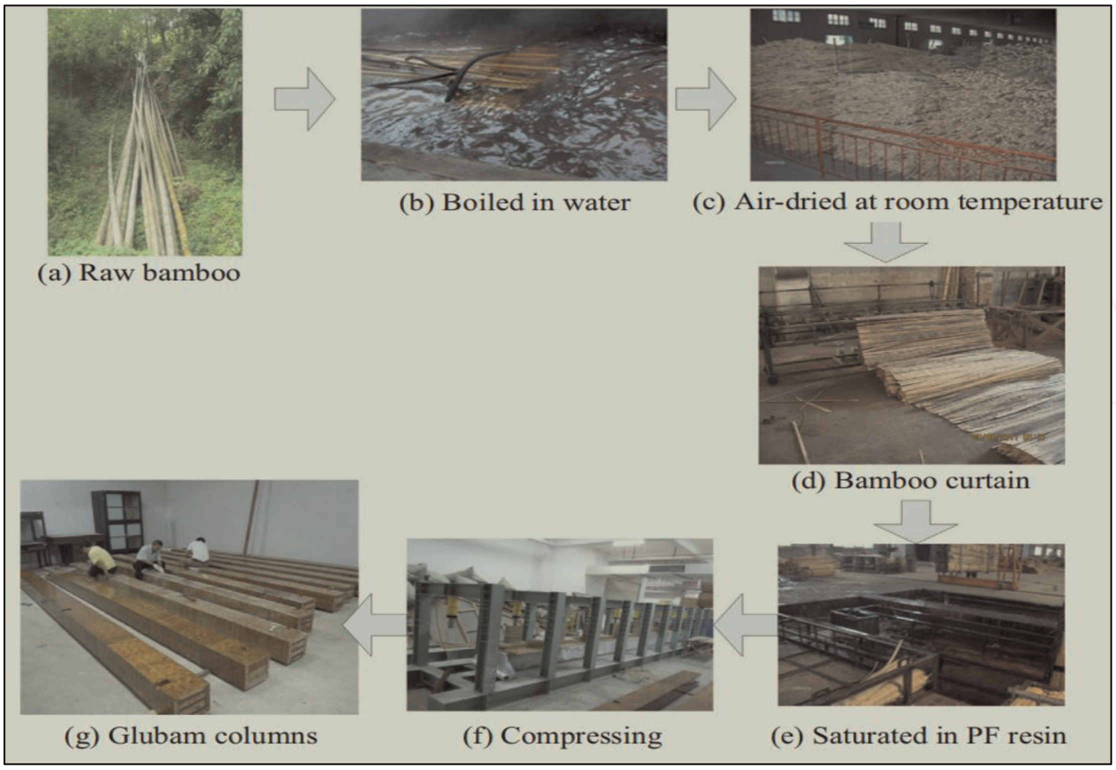

Figure 7.
Manufacturing process of Glubam (adapted from [18] with permission).

4. phenol-formaldehyde resin is used to glue the manufactured bamboo curtains,

5. followed by hot pressing the stacked bamboo curtains to make a single bamboo sheet. The final step is to finger-join these bamboo sheets to create structural elements.

iii. Parallel strand bamboo

Parallel strand bamboo (PSB), known as Bamboo scrimber is produced by compacting fibre bundles that have been crushed and soaked with resin into dense blocks with rectangular cross-sections. Approximately 80% of the raw resources can be used in the resource-efficient production method for PSBs products with multiple mechanical properties suitable for structural applications. Following is a summary of the complete PSB production process: (1) slashing bamboo culm into the bamboo two halves and expelling the bamboo notes; (2) straightening these bamboo halves into bundles of bamboo fibres; breaking in the longitudinal direction and connecting in transversal direction (3) drying those fibre bundles and soaking them in resin PF; and, finally, (4) hot-pressing these resin-soaked bundles of fibre into billets till the resin is cured making the desired PSB product.

Glubam has reasonable mechanical qualities and higher performance when related to other engineered bamboo products, but its relatively high density is a negative that needs to be addressed in the future. Additionally, PSB can offer extremely high parallel-to-grain, however due to its extremely high density, the dimensions of the

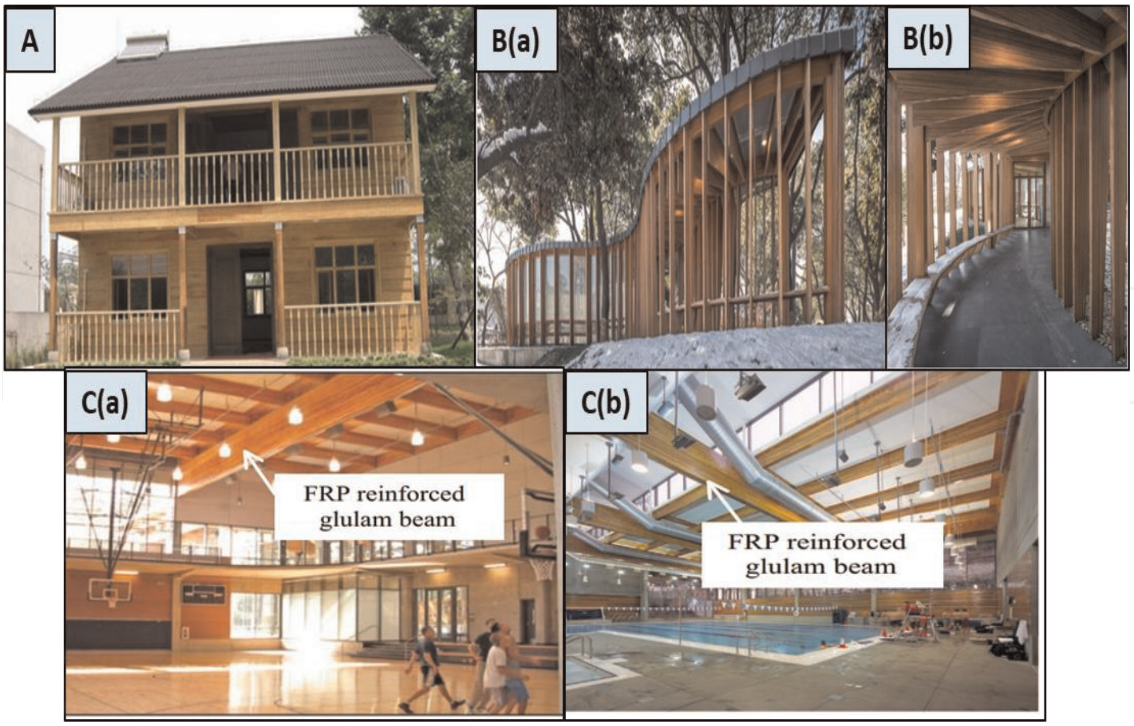

Figure 8.
A) Frame structure with LBL beams and PSB columns. B) Figure of LBL serpentine corridors (a) exterior (b) interior. C) Reinforced glubam beams at WWU (a) main gymnasium (b) natatorium (adapted with permission from [18]).

cross sections of the construction that uses PSB are constrained. However, China-based PSB engineering projects have already illustrated their suitability for structural applications. The application of these tailored bamboo composites for structural purposes is also covered in this review article as depicted in the **Figure 8**:

Although engineered bamboo is used in ornamental and surface applications worldwide, structural uses are only now starting to materialise. In both main and secondary structural applications, laminated bamboo and bamboo scrimber were used, as demonstrated by case studies provided by [35]. The chapter's case studies demonstrated industry advancement by using bamboo scrimber. To separate the fibres and keep the matrix, the raw, green bamboo culm is split and then crushed. The material is then impregnated by dipping the fibre bundles in a resin (such as phenol-formaldehyde). Then, the strips are placed in a mould and cold-pressed into the beam's structure after being soaked in resin. Finally, the composite beams are heated for curing and are ready for application.

These composite beams can be utilised for various structural applications:

a. Utilisation of bamboo scrims in urban construction:

   This work highlighted the utility of bamboo scrims in urban infrastructure construction, for traditional surface applications, particularly those where durability is a factor, bamboo scrimber have been used. The applied product's flexural strength is more vital than that of frequently used wood in these applications because of the product's extremely high density. The findings showed that the bamboo scrimber was appropriate for these uses; the flooring system could attain a stiffness that restricted deflection to situations in which

Figure 9.
Gare du Nord Station infrastructure by bamboo scrimber composite (adapted from [35] with permission).

sub-beams supported it. According to **Figure 9**, the flooring was laid in 2008 and the station has over 200 million visitors annually.

b. Utilisation of bamboo composite in structural sector:

This case illustrates how bamboo composite can be used structurally, an example of the material's potential. **Figure 10** shows the home in the Moso Bamboo Modern Technological Park in china.

Pozo Morales et al., [36] worked on developing a biodegradable composite for structural use as the primary objective of the work. This was accomplished by combining the suitable species of bamboo reinforcement with an appropriate natural thermoplastic polylactic acid (PLA) biopolymer, developing an inventive extraction procedure, and optimising the production process parameters. Bamboo strips were measured

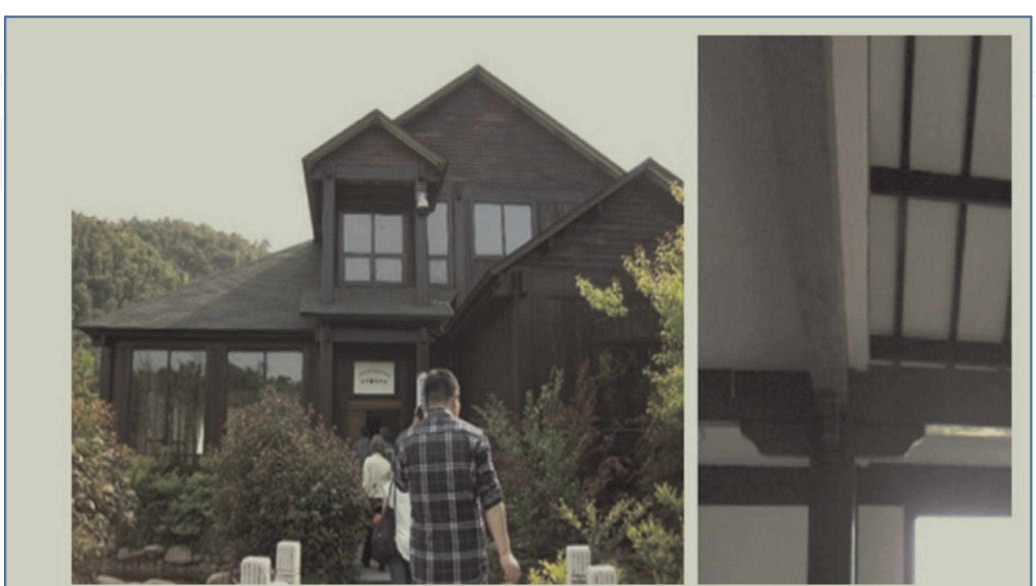

Figure 10.
Bamboo house, Moso bamboo modern Technological Park, Anji, China (adapted from [35] with permission).

Figure 11.
Manufactured bamboo – PLA composite panels (adapted from [36]).

thickness of 1.5 mm and 1500 mm lengthwise. They were further machined into the necessary lay-up and form to create laminates with specified qualities stronger and stiffer than those of traditional E-Glass/Epoxy laminates, as depicted in **Figure 11**. The bamboo strips were joined together using a PLA matrix to meet the criteria for biodegradability. This study's novel mechanical extraction technique can recover natural strip reinforcements at high levels and low prices without harming the environment because no chemical treatments are applied. The discovered material's prospective aircraft uses are fairly limited. Still, its high mechanical qualities may meet the needs of many other manufacturing industries, such as the automobile or energy industries. Glass fibre composites are frequently used to make wind turbine blades, and the substance may also be used in various automotive surfaces. Both industries choose structural materials primarily based on price. Potential markets could also include housing and watercraft.

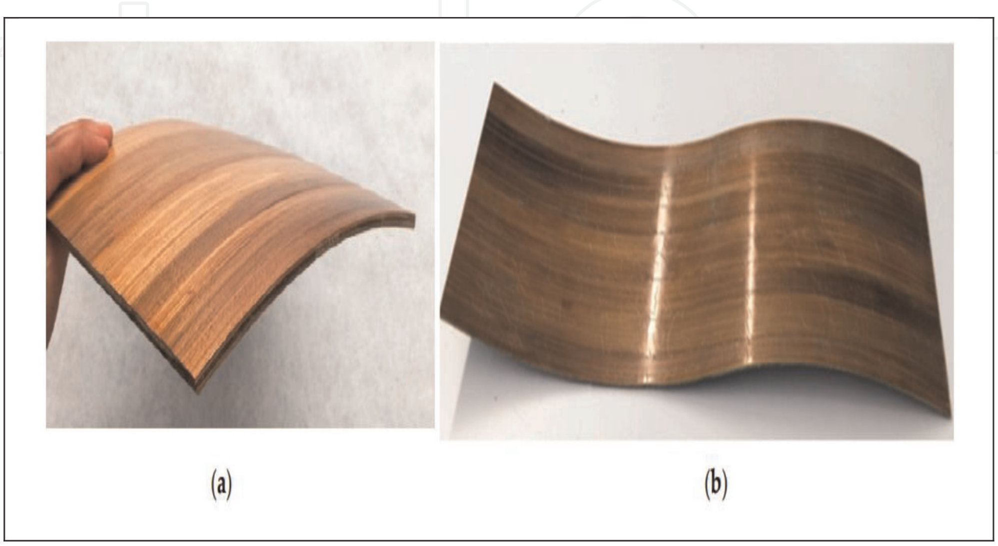

Figure 12.
Demonstrative bamboo panels from bamboo –PLA composite (a) cylinder concave shape (b) concave and convex shape (adapted from [36] with permission).

Two demonstration laminate components with curved geometries were created in order to demonstrate that it is possible to create structures with complex geometries, which is a crucial issue for applications in the future (see **Figure 12**).

4.1 Innovative applications of bamboo composite

Here are some creative ways that bamboo composites have been used. Here are a few instances of structural applications in several areas from a global perspective. Most users are aware of the benefits of bamboo products and support attempts to live sustainably in the world. This is further strengthened by the fact that it has received recognition for its excellence as an innovative material from a variety of sources, demonstrating that hybrid bamboo composite material can outperform other types of materials in a variety of areas including physical, mechanical, and aesthetic such as architecture, construction, interior design, and even auto parts Suhaily et al., [37]. **Table 1** highlights some innovative designs and applications of bamboo fibre bio-composites in various categories.

S.No	Category	Name of Product	Reference
1.	Interior Design	Basketball Court	Smith and Fong [38]
		Bamboo Dome	Nghia [39]
2.	Building and Construction	Kontum indochine café	Nghia [39]
3.	Furniture design	Infinity bench	Williams [40] and Huang [41]
		Hangzhou Bent Bamboo Stool	Min [42]
4.	Automotive components	Renault Megane Bioconcept car (Cloth seats, floor, dashboards)	Makinejad [43]

Table 1.
Innovative designs and applications of bamboo fibre bio-composites in various categories.

5. Conclusion

This chapter's primary objective is to concisely summarise advanced bamboo composites' potential, mainly for structural use. The technological and application advancements are highlighted in this chapter section. Many people are using bamboo as a "green" fibre. It is a natural fibre and may be grown quickly. To minimise any negative ecosystem devastation and manufacture reasonably priced polymeric reinforced composites, researchers are striving to develop composites using natural fibres that are completely biodegradable. As a result, there has been a noticeable rise in the use of bamboo fibres as composite reinforcement material recently. These materials are primarily used for structural applications in the housing and construction industries in the form of standard regular shapes like beams, planks, lumbers, and other elements, among other things. The introduction to advanced bamboo composites as engineered materials is covered in one of the chapter's sections. Additionally, it emphasises the critical notion of method and technology for bamboo composites and its numerous structural applications. The research and data of current studies on bamboo fibre-based composites describe multiple structural applications of bamboo composites. According to the data, examples of structural applications include the display panels of bamboo and PLA composite and the installation of lighter-weight bamboo-based walls in bamboo steel homes. This chapter has tried to enhance the knowledge about advanced bamboo composite for different structural applications. The vision of working towards sustainable approaches using bamboo as the natural raw material helps save the environment from the harmful effects of heat. Better architecting and designing the bamboo-based structural thermal insulating material can further boost the final product's versatile characteristics, especially in structural applications.

Acknowledgements

The authors thank Director CSIR-AMPRI, Bhopal, for providing the necessary institutional facilities and encouragement.

Conflicts of interest

The authors declare no conflict of interest.

Author details

Medha Mili[1,2], Anju Singhwane[1], Vaishnavi Hada[1], Ajay Naik[1,2], Prasanth Nair[1,2], Avanish Kumar Srivastava[1,2] and Sarika Verma[1,2]*

1 Council of Scientific and Industrial Research-Advanced Materials and Processes Research, Institute (AMPRI), Bhopal, M.P, India

2 Academy of Scientific and Innovative Research - Advanced Materials and Processes Research Institute (AMPRI), Bhopal, M.P, India

*Address all correspondence to: drsarikaverma20@gmail.com; drsarikaampri@gmail.com

References

[1] Mitch D, Harries KA, Sharma B. Characterization of splitting behavior of bamboo culm. Journal of Materials in Civil Engineering. 2010;**22**:1195-1199

[2] Valentine R, Matteucci G, Dolman AJ, Schulze E-D, Rebmann C, Moors EJ, et al. Respiration as the main determinant of carbon balance in European forests. Nature. 2000; **404**(6780):861-865

[3] Broadmeadow M, Matthews R. Forests, carbon and climate change: The UK contribution. Forest Communication Information Note. 2003;**48**:1-12

[4] Asdrubali F, Ferracuti B, Lombardi L, Guattari C, Evangelisti L, Grazieschi G. A review of structural, thermo-physical, acoustical, and environmental properties of wooden materials for building applications, build. Environment. 2017; **114**:307-332

[5] Hillis WE. Heartwood and Tree Exudates. Volume 4 of Springer Series in Wood Science. Berlin, Heidelberg: Springer; 1987

[6] Gupta A, Kumar A, Patnaik A, Biswas S. Effect of different parameters on mechanical and erosion wear behavior of bamboo fiber reinforced epoxy composites. International Journal of Polymer Science. 2011;**2011**:1-11

[7] Mili M, Hashmi SAR, Tilwari A, et al. Preparation of nanolignin rich fraction from bamboo stem via green technology: Assessment of its antioxidant, antibacterial and UV blocking properties. Environmental Technology. 2023;**44**(3):416-430. DOI: 10.1080/09593330.2021.1973574

[8] Verma S, Hashmi SAR, Mili M, Hada V, Prashant N, Naik A, et al. Extraction and applications of lignin from bamboo: A critical review. European Journal of Wood and Wood Products. 2021;**79**(6):1341-1357

[9] Mili M, Verma S, Hashmi SAR, Gupta RK, Naik A, Rathore SKS, et al. Development of advanced bamboo stem derived chemically designed material. Journal of Polymer Research. 2021b; **28**(5):1-11

[10] Xiao FM, Fan SH, Wang SL, Xiong CY, Zhang C, Liu SP. Carbon storage and spatial distribution in Phyllostachy pubescens and Cunninghamia lanceolata plantation ecosystem. Acta Ecologica Sinica. 2007; **27**(7):2794-2801

[11] Yiping L et al. Technical Report 32: Bamboo and Climate Change Mitigation. Beijing, China: INBAR; 2010

[12] Li Z, Zhou R, He M, Sun X. Modern timber construction technology and engineering applications in China. Proceedings of Institution of Civil Engineers Civil Engineering. 2019; **172**(5):17-27

[13] Reis JP, de Moura MFSF, Silva FGA, Dourado N. Dimensional optimization of carbon-epoxy bars for reinforcement of wood beams. Composites Part B-Engineering. 2018;**139**:163-170

[14] Lu T, Jiang M, Jiang Z, Hui D, Wang Z, Zhou Z. Effect of surface modifi cation of bamboo cellulose fi bres on mechanical properties of cellulose/epoxy composites. Composites Part B: Engineering. 2013;**51**:28-34

[15] Liu X, Smith GD, Jiang Z, Bock MCD, Boeck F, Frith O, et al. Nomenclature for engineered bamboo. BioResources. 2016;**11**(1):1141-1161

[16] Wang G, Yu Y, Shi SQ, Wang JW, Cao SP, Cheng HT. Microtension test method for measuring tensile properties of individual cellulosic fibers. Wood and Fiber Science. 2011;**43**(3):251-256

[17] Liese W. Research on bamboo. Wood Science and Technology. 1987;**21**(3): 189-209

[18] Sun X, He M, Li Z. Novel engineered wood and bamboo composites for structural applications: State-of-art of manufacturing technology and mechanical performance evaluation. Construction and Building Materials. 2020;**249**:118751

[19] Mili M, Hashmi SAR, Ather M, Hada V, Markandeya N, Kamble S, et al. Novel lignin as natural-biodegradable binder for various sectors—A review. Journal of Applied Polymer Science. 2022;**139**(15):51951

[20] Ramage MH, Burridge H, Busse-Wicher M, et al. The wood from the trees: The use of timber in connection. Renewable and Sustainable Energy Reviews. 2017a;**68**:333-359

[21] Ramage M, Sharma B, Shah D, Reynolds T. Thermal relaxation of laminated bamboo for folded shells. Materials and Design. 2017;**132**:582-589. DOI: 10.1016/j.matdes.2017.07.035

[22] Zhong Y, Wu GF, Ren HQ, Jiang ZH. Bending properties evaluation of newly designed reinforced bamboo scrimber composite beams. Construction and Building Materials. 2017;**143**:61-70

[23] Liu DG, Song JW, Anderson DP, Chang PR, Hua Y. Bamboo fiber and its reinforced composites: Structure and properties. Cellulose. 2012;**19**(5): 1449-1480

[24] Wang G, Chen F. Development of bamboo fiber-based composites. Advanced High Strength Natural Fibre Composites in Construction. 2017: 235-255

[25] Qisheng Z, Shenxue J, Yongyu T. Industrial Utilization on Bamboo. Beijing, China: International network for bamboo and rattan; 2002

[26] Khalil HA, Alwani MS, Islam MN, Suhaily SS, Dungani R, H'ng YM, et al. The use of bamboo fibres as reinforcements in composites. In: Biofiber Reinforcements in Composite Materials. Sawston, Cambridge: Woodhead Publishing; 2015. pp. 488-524

[27] Zhang K, Chen Z, Smith LM, Hong G, Song W, Zhang S. Polypyrrole-modified bamboo fiber/polylactic acid with enhanced mechanical, the antistatic properties and thermal stability. Industrial Crops and Products. 2021;**162**: 113227

[28] Chen F, Deng J, Cheng H, et al. Impact properties of bamboo bundle laminated veneer lumber by preprocessing densification technology. Journal of Wood Science. 2014;**60**(6):421-427

[29] Zhang D, Wang G, Ren W. Effect of different veneer-joint forms and allocations on mechanical properties of bamboo-bundle laminated veneer lumber. BioResources. 2014;**9**(2): 2689-2695

[30] Deng J, Chen F, Li H, Wang G, Shi SQ. The effect of PF/PVAC weight ratio and ambient temperature on moisture absorption performance of bamboobundle laminated veneer lumber. Polymer Composites. 2016; **37**(3):955-962

[31] Chen F, Jiang Z, Wang G, Li H, Simth LM, Shi SQ. The bending properties of bamboo bundle laminated

veneer lumber (BLVL) double beams. Construction and Building Materials. 2016;**119**:145-151

[32] Javadian A, Smith IFC, Hebel DE. Application of sustainable bamboo-based composite reinforcement in structural-concrete beams: Design and evaluation. Materials. 2020; **13**(3):696

[33] Zhou H, Sun F, Li H, Zhang W, Cheng H, Chen L, et al. Development and application of modular Bamboo-Composite Wall construction. BioResources. 2019;**14**(3): 7169-7181

[34] Li G, Wu Q, Zhang AJ, Deeks J. Su, ultimate bending capacity evaluation of laminated bamboo lumber beams. Construction and Building Materials. 2018;**160**:365-375

[35] Sharma B, van der Vegte A. Engineered bamboo for structural applications. In: Nonconventional and Vernacular Construction Materials. Woodhead Publishing; 2020. pp. 597-623

[36] Pozo Morales A, Güemes A, Fernandez-Lopez A, Carcelen Valero V, De La Rosa Llano S. Bamboo–polylactic acid (PLA) composite material for structural applications. Materials. 2017; **10**(11):1286

[37] Suhaily SS et al. Bamboo Based Biocomposites Material, Design and Applications. 2013

[38] Smith & Fong. PlybooSport Bamboo Sport Flooring [Online]. San Francisco: Smith & Fong Company; 2010. Available at http://www.plyboo.com/

[39] Nghia VT. Vo Trong Nghia Architects [Online]. Vietnam. 2010. Available at http://www.votrongng hia.com

[40] Williams A. Infinity Bamboo Bench [Online]. New York. 2010. Available at http://www.designaw.me

[41] Huang T. TomHuangStudio.Com [online]. 2007. Available at http://www.tomhuangstudio.com.

[42] Chen MA. Hangzhou Bamboo Stool [Online]. China. 2013. Available at http://chen-min.com

[43] Makinejad MD, Salit MS, Ahmad D, Ali A, Abdan K. A review of natural fibre composites in the automotive industry. Research on Natural Fibre Reinforced Polymer Composites. 2009;**16**: 247-262