

Bamboo in Contemporary Architecture: A Composite Climate in India

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Abstract: *The rapid pace of growth requires the creation of appropriate space through infrastructure development. However, it's crucial to prioritize environmental considerations and additional construction's necessity. Bamboo, a versatile and sustainable material, holds immense architectural potential, especially in regions like Central India and Uttar Pradesh (UP) where it is abundantly available. To maximize the use of locally available bamboo in India's composite climate, investigate its properties, address usage challenges, and assess its potential as a sustainable material. Bamboo can be used structurally and non-structurally. Dendrocalmus strictus, Bambusa Bamboos, and Bambusa Balcoa are the locally available species that can be grown in local regions. Can be used for making temporary toilets near rivers, and sitting spaces that can be changed after 15 years. Can be used in making facades as well as interior walls.*

Keywords: Bamboo, Composite, Dendrocalmus, Bambusa

1. Introduction

In the age of environmental consciousness and sustainable development, architecture stands at the forefront of innovative solutions to mitigate the impact of climate change. Amidst this pursuit, bamboo emerges as a beacon of hope, offering a versatile, eco-friendly alternative to traditional building materials. Nowhere is the potential of bamboo more evident than in India, a land of diverse climates and cultures where the fusion of tradition and modernity creates a unique architectural landscape. Bamboo's inherent qualities, including strength, flexibility, and rapid growth, offer immense potential for adaptable architectural solutions in response to evolving environmental, and social contexts. (Lapina, A.P.) However, numerous challenges hinder its widespread adoption despite its advantages, ranging from structural limitations and material sourcing issues to regulatory constraints.

Resources and Species in Composite Climate Regions of India

Growth of Bamboo in Composite Climate Regions of India

The highest number of shoots recorded was 20 in Bambusa bamboo during its second year of planting, while Dendrocalamus strictus exhibited a peak of 28 shoots during its third year of growth. Performance of various clones (Species) after growth on the number of shoots formed (er clumps) and girth (in cm) in Eastern U.P. conditions at NDUAT, Faizabad. (Kumar & Kumar, 2018)

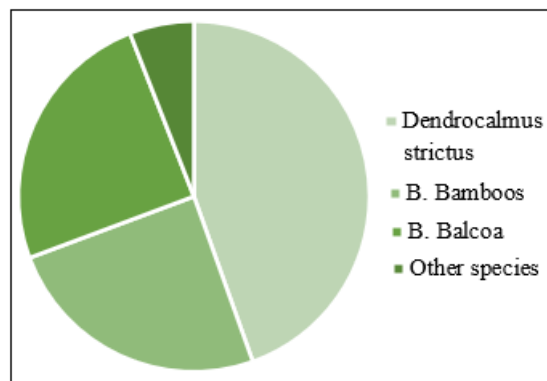


Table: Availability of Species

Bamboo Species	States availability	Percentage
Dendrocalmus strictus	U.P., M.P., Jharkhand, Bihar, Andhra Pradesh, throughout the country	53%
Bambusa bamboos	Central India, hilly areas of North India	45%
Dendrocalmus somdevai	Uttar Pradesh, Himachal Pradesh	14%

Table: Properties of bamboo species

Properties	Dendrocalmus Strictus	Bamboosa Bambus	Bamboosa Balcoa	References
Culm diameter	15-18 cm	15-17 cm	8-16 cm	https://www.guaduabamboo.com/
Culm internode length	15-30 cm	15-46 cm	Around 15 cm	https://www.guaduabamboo.com/
Wall Thickness	1.5 cm	2.5 cm	1.6	https://www.guaduabamboo.com/
Height	20-30 cm	27-30 m	8-15 cm	https://www.guaduabamboo.com/
Average compressive strength	78.03 M Pa	62 M Pa	39.4- 50.6 N/mm ²	(Sooriyalakshmi & Helena, n.d.)
Average Tensile Strength	95.78 M Pa	110 M Pa		(Sooriyalakshmi & Helena, n.d.)

Importance of Bamboo Preservation

Chemical preservatives should be used to protect bamboo products from degradation. The following are well-used methods that provide good protection even in adverse conditions.

The selection of the appropriate treatment method depends on various factors:

State of the bamboo - green or dry; form of the bamboo- round bamboo or split; End applications; ground contact; exposed to atmosphere or undercover; structural or non-structural; Scale-quantity to be treated and available time; Potential causes of decay - biotic (fungus or insects) and abiotic (cracks or weathering). By employing suitable treatments, it's feasible to extend the lifespan and durability of bamboo to 50 years or beyond. These treatments enhance durability and are cost-effective and sustainable in the long term. Guadua Bamboo. (n.d.). *Experts in the world's strongest bamboo*

Cracks and splits -These issues arise from stresses induced by abrupt drying and direct sunlight exposure. While cracks themselves don't weaken the culm, they provide entry points for decay organisms. Splitting occurs primarily from nailing without pre-boring, especially noticeable in thin-walled bamboo. To prevent end splitting, coating the ends with wax emulsion or coal tar is recommended.

Weathering- The exposure of bamboo to weathering is a consequence of various atmospheric factors, including temperature variations and changes in humidity levels. Repeated cycles of drying and wetting cause small surface cracks to expand. Solar radiation contributes to the breakdown of cellulose. Additionally, wind and dust particles have an abrasive effect on the surface of the culm, contributing to its weathered appearance.

Natural Drying and Curing Methods Post-treatment, drying, and curing are crucial to ensure the bamboo's structural integrity and durability. Proper drying methods reduce the moisture content in bamboo and enhance its strength and stability.

Sealing the Ends of Poles

The ends of bamboo poles are particularly prone to cracking due to rapid moisture loss. Sealing these ends can significantly reduce this risk. Various materials, such as beeswax, paint, or commercial sealants, can create an effective barrier against moisture loss, minimizing the likelihood of cracking.

Drilling Air Holes

To prevent pressure build-up inside the bamboo culms, especially during temperature fluctuations, small air holes can be drilled into the bamboo. This technique is beneficial during storage or transportation when bamboo might be exposed to varying temperatures. The holes should be small enough not to affect the structural integrity of the bamboo.

Selection of Bamboo Age and Species for Construction

The choice of bamboo age and species is critical for construction purposes. Generally, 3–5-year-old bamboo is ideal, as it has lower starch and sugar contents, reducing the

risk of insect infestation. Different bamboo species have varying characteristics, making some more suitable for specific applications than others. Selecting the right species based on strength, flexibility, and diameter ensures the best outcome for construction projects.



Figure: Bamboo culms being treated with borax powder



Figure: Vertical stacking after 7 days of soaking in boric acid or borax solution



Figure: Being left to dry in the sun solution
Images source: Guadua Bamboo. (n.d.). Experts in the world's strongest bamboo

Parameters

Area of Application:

Bamboo can be used both as structural as well as non-structural elements. Analyzing the area where bamboo can be used in composite climate regions depends on its durability and strength. Structural elements- Foundations, walls, beams and columns

Non- Structural- Non-load bearing walls, floors, doors and windows, façades. Can be used in combination with other materials

Bamboo Type:

Depending on the area of application the bamboo species based on the diameter, durability, and strengths can be selected.

Construction and joinery:

Forms of bamboo- round or splits. Using ties or anchor bolts.

Sizes and dimensions:

Maximum heights achieved and diameters required for the specified use.

Treatments:

Understanding treatments that might increase the durability of bamboo.

Location: Faridabad, India; Architects: Neha Rane, Avnish Tiwari; Area: 420m²; Year: 2023;

Installations and structures

Case Studies

Northeast Bamboo Pavilion, Faridabad, India

The pavilion was designed as an exhibition area aimed at highlighting the cultural offerings of the eight North Eastern states of India during the 2023 Suraj Kund Craft Fair. This fair, held annually, serves as a platform for artisans to promote Indian handicrafts and showcase their skills.

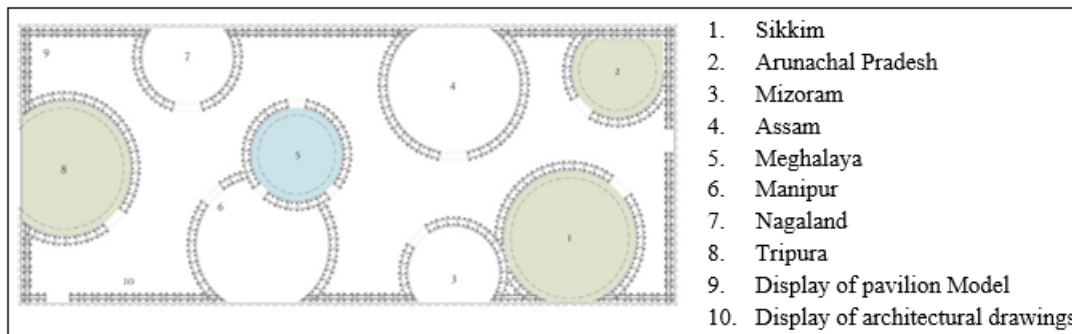


Figure: Plan of North-east Pavilion

Source: ArchDaily. (n.d.). ArchDaily. Retrieved June 4, 2024, from <https://www.archdaily.com>

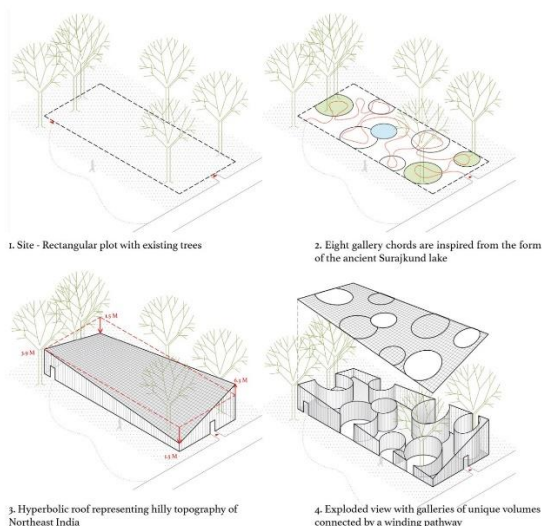


Figure: Isometric and exploded view

Source: ArchDaily. (n.d.). ArchDaily. Retrieved June 4, 2024, from <https://www.archdaily.com>

The structure consists of 8 exhibitions as shown in figure 6. Each courtyard represents the works of all northeast states. The spaces are circular in plan and made with curved walls. Hyperbolic roof at different heights with bamboo shingles. 90 workers, built in 60 days. Bamboo- fast growing species and cheaply available

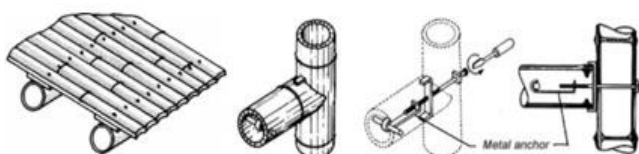


Figure: Joinery details

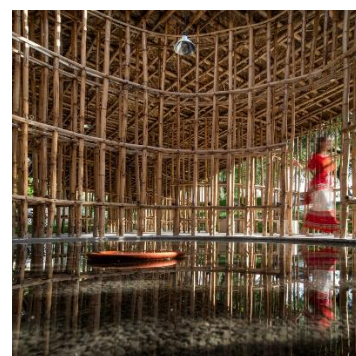


Figure: Curved bamboo splits



Figure: 3 cm splits



Figure: Roof

Climate: Composite Climate, Single Floor Structure

The entire structure is made up of bamboo. Bamboo connected from steel anchors and bolts- Can stand wind loads. The curves sectors consist of a single bamboo- Flexibility of 15. Only bamboo structures cannot withstand heavy loads. Metal anchors are best suited to make the structure strong since ties are not feasible. Proper water treatment to prevent swelling and cracking of bamboo. Bamboo culm diameter- 15 cm. Height of bamboo- 20 m (approx.)

MARHINHO DA SERRA, VIETNAM

Location: Hoan Kiem District, Vietnam; Architects: Vazio S/A; Area: 110m²; Year: 2022



Figure: Bamboo in façade

Source: ArchDaily. (n.d.). ArchDaily. Retrieved June 4, 2024, from <https://www.archdaily.com>

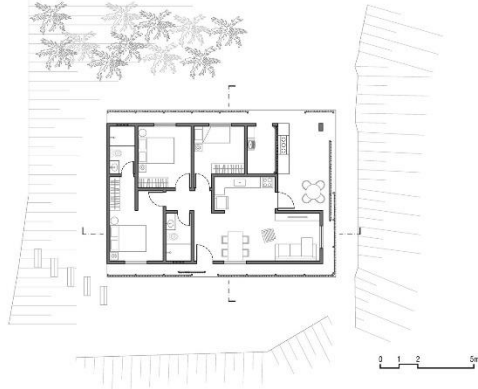


Figure: Plan

The standout feature of the house are the bamboo louvers encircling the entire structure, except the south-facing facade, which is left open as it doesn't receive direct sunlight. The room windows, positioned to the west or east, are shielded by bamboo screens, utilizing the region's plentiful natural resource. On-site, bamboo underwent pretreatment through immersion in a solution containing borax and boric acid, a widely favored preservation technique for its efficacy and lower toxicity compared to alternative wood preservatives. This treatment yields insecticidal, fungicidal, and fire-resistant properties.

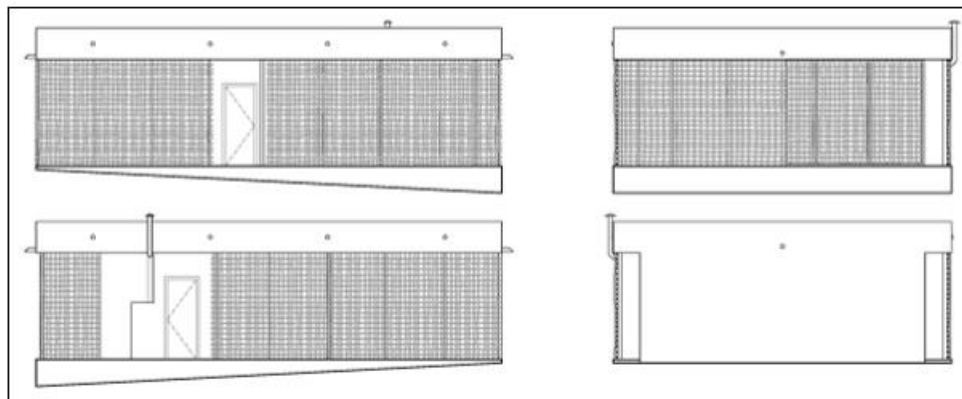


Figure: Elevations

Climate: Temperate Climate.

Single Floor Structure

Used in façade as bamboo louvers and doors and windows protected by bamboo weave. Bamboo connected from steel bolts. Treated with borax and boric acid which acts as insecticide, fungicide and fire retardant.

Bamboo culm diameter- 5.6 cm; Height of bamboo- 3 m (approx.)

The Endemic House, South America

Location: Ecuador, South America; Architects: ESEcolectivo Architects; Area: 120m²; Year: 2021

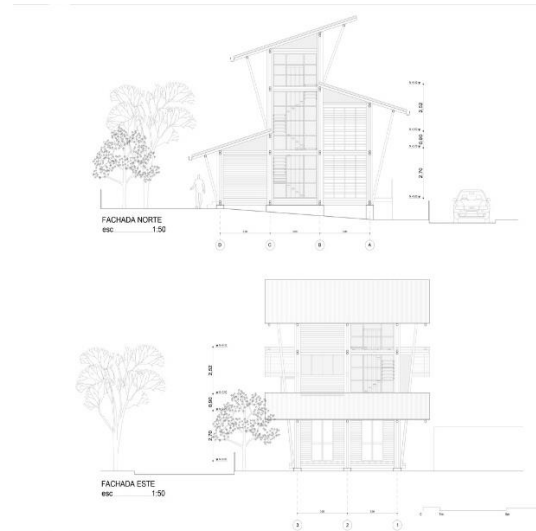


Figure: Elevations



Figure: Used in columns, beams and walls



Figure: View of room



Figure: Detail and Joinery



Figure: Glass frames and windows
Figure 6.12: Detail and Joinery

Climate: Composite Climate; G+1 Structure
Used as structural as well as non-structural. Beams, columns, foundation, roofs, walls, fencing, railing. Bamboo connected from steel bolts and metal anchor. Treated with borax and boric acid which acts as insecticide, fungicide and fire retardant.

Bamboo culm diameter- 15 cm; Height of bamboo- 9.3 m (approx.)

CRECHE, DEI, AGRA, India

Design Team- CGBMT, Manasaram Architects; Location- DEI (Deemed University), Agra; Built-up area- 670 sq. m./ 6540 sq. ft.; Completion year- 2018



Figure: View of the institute

The structure predominantly utilizes bamboo and comprises four interconnected pentagonal classrooms, connected by a central entrance alley. The principal architect led a team consisting of local artisans, students, faculty members, and the Dayalbagh Work department during the execution phase



Figure: Plan

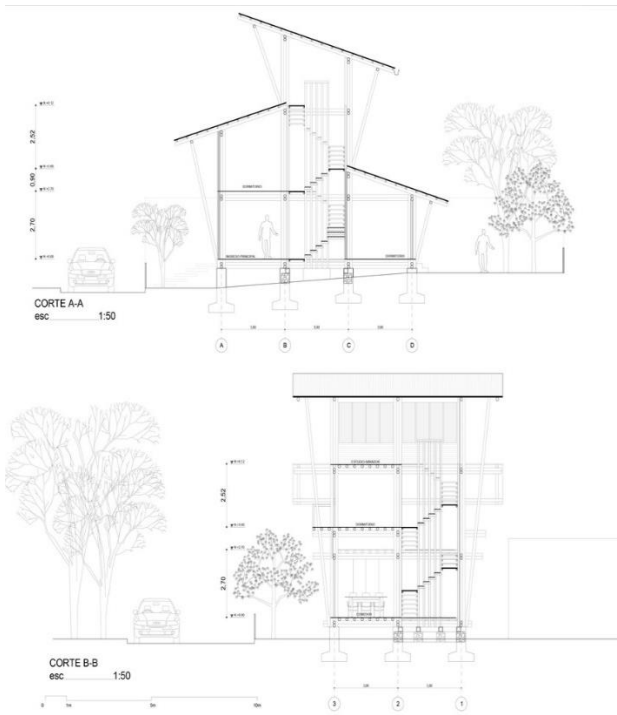


Figure: Sections

Source: ArchDaily. (n.d.). ArchDaily. Retrieved June 4, 2024, from <https://www.archdaily.com>



Figure: Elevations



Figure: Roof and bamboo joinery



Figure: Bamboo splits used



Figure: Daub walls construction

Source: Manjunath, A. N. (n.d.). *Symphony of the Bamboos*. www.cgbmt.net



Figure: Woven bamboo screens

Source: ArchDaily. (n.d.). ArchDaily. Retrieved June 4, 2024, from <https://www.archdaily.com>

Climate: Composite Climate; Single Storey Structure

Used as structural as well as non-structural. Beams, columns, foundation, roofs, walls, fencing, railing. Bamboo connected from steel bolts and metal anchor. Use of bamboo Splits and lidis. Bamboo culm diameter- 6-8 cm; Height of bamboo- 4 m (approx.)

Climate: Composite Climate

Single Storey Structure

Used as non-structural. Facades and doors and windows. Bamboo Splits connected to MS Steel frames using steel bolts.

Bamboo Split width - 4 cm; Height of bamboo- 6 m (approx.)

Artist Residency Farm8, New Delhi, India

Design Team- Studio Array; Location- Arjanghar, New Delhi; Built-up area- 600 sq. m.; Year of completion- 2023

Comparative Analysis



Figure: Bamboo in façade

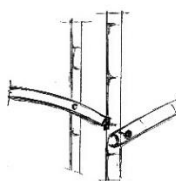

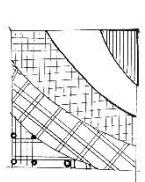
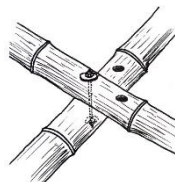
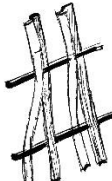


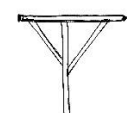

S. No.	Parameters	North-east bamboo pavilion	Marinho Da Serra, Vietnam	Artist Residency Farm8, New Delhi, India	The Endemic House, South America	CRECHE, DEI, Agra, India
1	Climate	Composite	Temperate	Composite	Composite	Composite
2	Area of Application	Both Structural and non-structural. The entire structure is made up of bamboo. Curved walls, Roofs.	Used as a non-structural element. Used in facades and doors and windows.	Used as non-structural Facades and doors and windows	Used as structural as well as non-structural. Beams, columns, foundation, roofs, walls, fencing, railing	Used as structural as well as non-structural. Beams, columns, foundation, roofs, walls, fencing, railing
3	Construction technique And joinery	 <p>Curved walls made by joining bamboo splits to vertical bamboo through bolts.</p>  <p>Bamboo shingles</p>  <p>Layers in roof</p>	 <p>Bamboo assembly by architect Simon Velez</p>	 <p>Screening done by bamboo splits woven through MS steel sections.</p>	 <p>Foundation construction</p>	  
4	Dimensions	15 cm diameter 20 m height	5.6 cm diameter 9 m height	Bamboo Split width - 4 cm Height of bamboo- 6 m (approx.)	Bamboo culm diameter- 6-8 cm Height of bamboo- 4 m (approx.)	Bamboo culm diameter- 15 cm Height of bamboo- 9.3 m (approx.)
5	Bamboo Type	Dendrocalmus strictus, Bambusa bamboos, Bambusa Balcoa	Dendrocalmus asper	Dendrocalmus strictus	Guadua angustifolia, Dendrocalmus asper	Dendrocalmus strictus, Bambusa bamboos, Bambusa Balcoa
6	Treatments	Proper water treatment to prevent swelling and cracking of bamboo				Treated with borax and boric acid which acts as insecticide, fungicide, and fire retardant.

Table: Comparative Analysis of case studies through parameters

SWOT Analysis

<p>STRENGTHS</p> <p>Availability (Locally available)</p> <p>Flexibility</p> <p>Sustainable material</p> <p>Cost-effective</p> <p>Good tensile, compressive strengths</p>	<p>WEAKNESSES</p> <p>Hollow</p> <p>Irregularities in shape</p> <p>Prone to attacks by insects</p> <p>Shrinkage due to temperature fluctuations</p> <p>Structures cannot be constructed above 2 floors</p> <p>Permanent structures cannot be made in composite climate</p>
<p>OPPORTUNITIES</p> <p>Durability can be increased by proper treatments</p> <p>Used in temporary structures in composite climate</p>	<p>THREATS</p> <p>Durability</p> <p>Spanning issues</p> <p>Maintenance</p> <p>Since only 2 storey structures can only be made, future infrastructure development issues</p>

2. Conclusion

Bamboo construction in the composite climate of India can be utilized for temporary structures. For temporary single-floor structures, bamboo can be used structurally and non-structurally. *Dendrocalamus strictus*, *Bambusa Bambos*, and *Bambusa Balcoa* are the locally available species that can be grown in local regions. Can be used in making daub walls for internal partition walls. Used even in temporary shelters and low-cost housing. Treatments and proper use can increase its durability whereas natural durability is 1-2 years. Can be used for making temporary toilets near rivers, and sitting spaces that can be changed after 15 years. Can be used in making facades as well as interior walls.

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