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Bamboo as alternate structural material

By

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The views expressed are those of the author and do not necessarily reflect the views of UNCTAD.

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Bamboo as alternate structural material

Luisa Molari

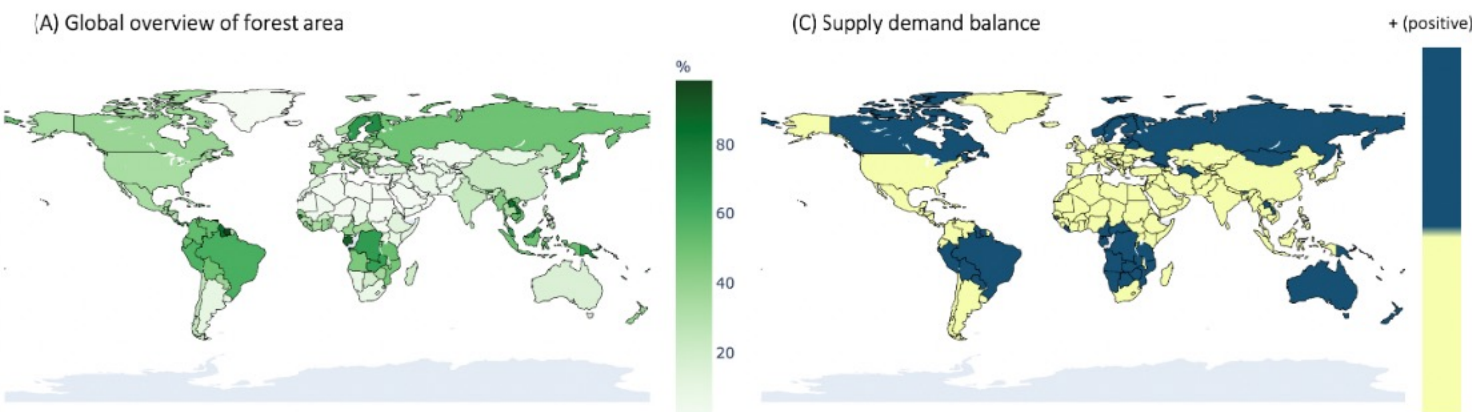
DICAM – Department of Civil, Chemical, Environmental and Material Engineering

The building and construction sector is responsible of almost 40% of CO_2 emissions in Europe

Construction materials made with biomass can invert this

Bio-based construction materials have been largely overlooked with the exception of ***timber****.*

Can timber be used to turn the global building stock into a carbon sink?



[Pomponi et al. (2020), 10.17632/rtfmgzp357.1]

Bamboo has the potential to meet the increasing demands of the building stock

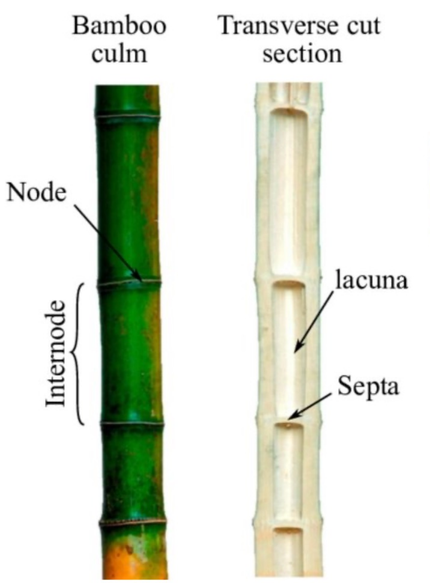
Vogel, Gardner. EEOB IowaStateUniversity

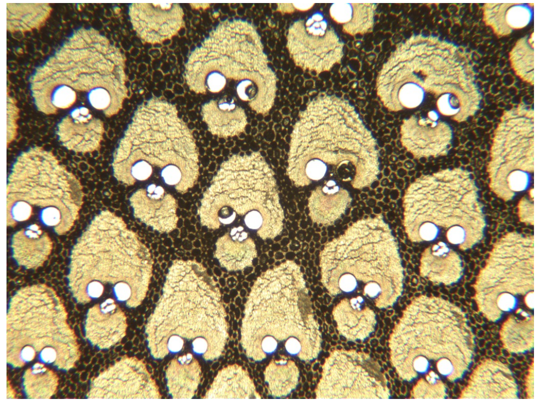
What are the differences between wood and bamboo?

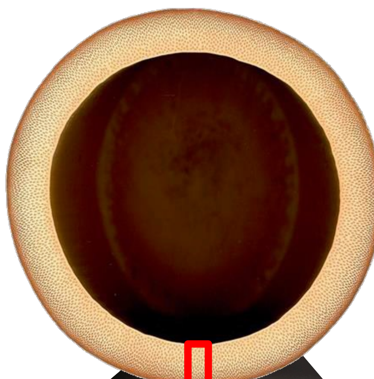
	Wood	Bamboo
Family	wood	grass
Time to grow	30-50 years	3-5 years
Regeneration	By plantation	Grow itself back
Fibers	2 directions	1 direction
Stem	Solid cylinder	Hollow cylinder

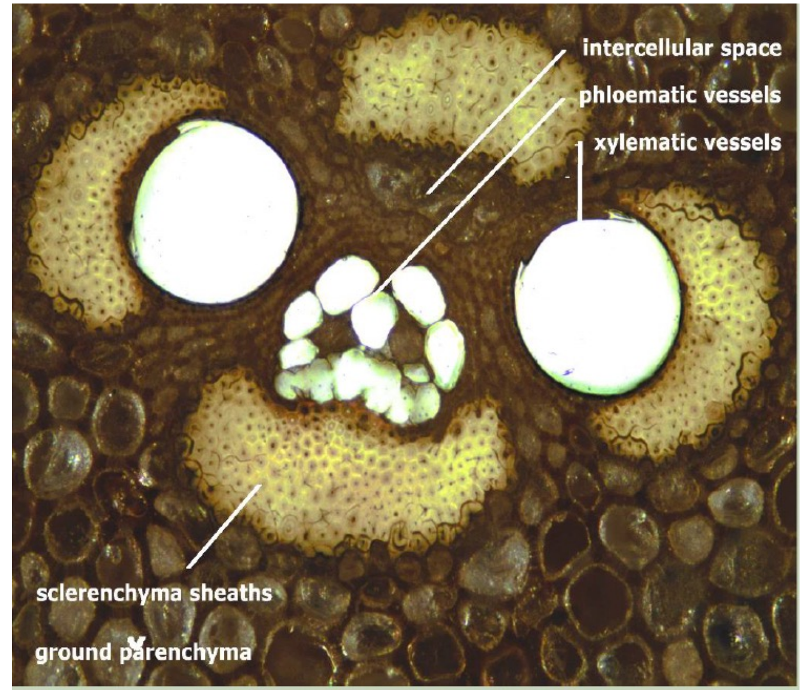
What are the challanges posed by geometry and microscopic features?

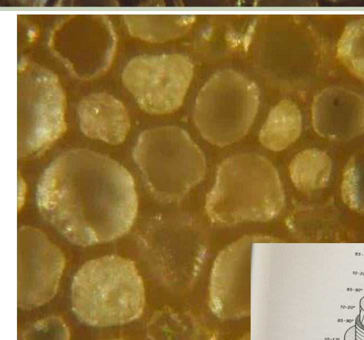
- Hollow cylinder
- Diaphragms
- Tapered along the axis

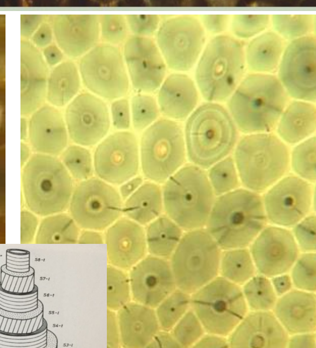


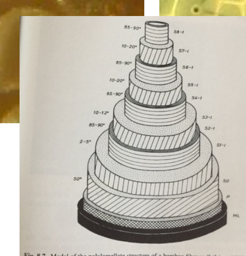












Microimaging-informed continuum ..
Gangwar, Schillinger

What are the challanges posed by bamboo microscopic features?

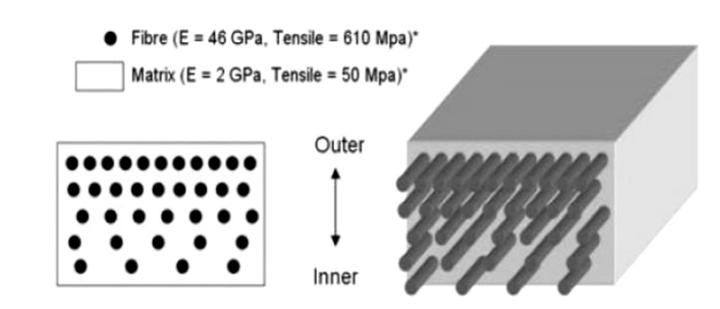
Bamboo is a composite material:

1) Vessels 10%
2) Parenchyma 50%
3) Sclerenchyma 40%

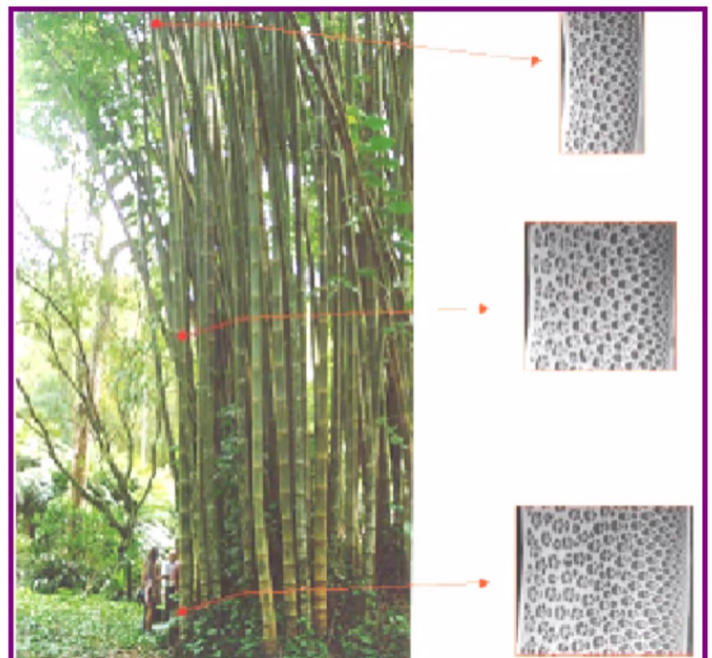
PROPERTIES	MATRIX	FIBRE
Tensile strength (MPa)	50	610
Young modulud (GPa)	2	46
Density (Kg/cm^3)	0,67	1,16

Functionally graded in radial but also in the longitudinal direction

Deeply **orthotropic** behaviour



Amada et al. (1997)



Ghawami et al. (2003)

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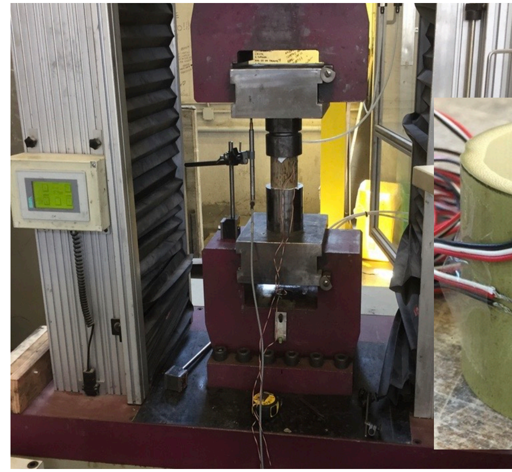
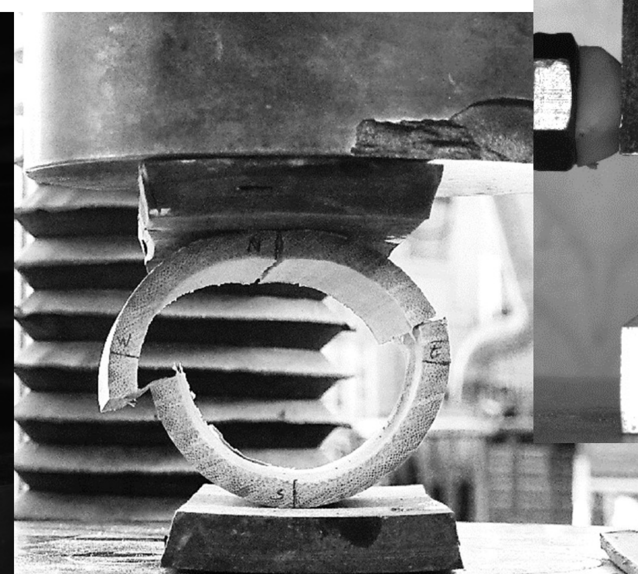
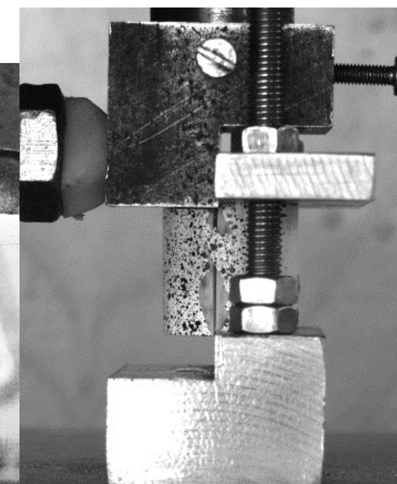
What about mechanical performance?

Test in two directions
Parallel to the fibers

and orthogonal
to the fibers







What about mechanical performance?

Compression strength parallel to the fibers

	$f_{c,0}$ [Mpa]		$E_{c,0}$[GPa]		w [%]	
	Mean	std	mean	std	mean	std
BAM	80,43	6,75	20,34	5,02	9,60	0,79
EDU	68,69	8,06	14,04	3,64	10,84	0,30
IRI	80,12	5,00	21,89	3,99	10,38	0,39
VIO	59,50	7,26	16,27	5,71	10,15	1,50
VIV	64,35	2,80	17,37	2,61	10,11	0,23
VIR	71,4	5,70	18,11	7,87	12,03	-

Guadua	f c,0	E c,0
	56-68 MPa	17,8- 20,0 GPa

Tension strength parallel to the fibers

	$f_{t,0}$ [Mpa]		$E_{t,0}$[GPa]		w [%]	
	mean	std	mean	std	mean	std
BAM	220,28	41,91	21,80	2,60	9,59	0,78
EDU	193,51	42,73	15,19	2,92	9,09	0,30
IRI	229,38	34,92	18,22	3,12	9,11	0,39
VIO	148,91	31,40	18,17	4,63	9,04	0,23
VIV	188,84	37,62	14,90	4,75	8,94	1,5
VIR	214,99	33,86	16,95	2,35	10,37	0,52

Molari, Mentrasti, Fabiani *Structures*. 24: 59-72. 2020.

Guadua	f t,0	E t,0
	108-163 MPa	17,6 20.2 GPa

Phyllostachys Bambusoides, Edulis, Iridescens, Violacescens, Vivax, Viridiglaucecsens

Tension strength orthogonal to the fibers

	Tensile strength (MPa)	
Species	Inner	Outer
BAM	17,6 (0,30)	30,5 (0,23)
EDU	39,9 (0,16)	14,5 (0,16)
IRI	16,9 (0,27)	23,2 (0,12)
VIO	24,1 (0,72)	22,6 (0,27)
GA	9,9 (0,24)	16,5 (0,24)

Molari, Garcia. *Journal of Building Engineering*, 33, 101557, 2021.

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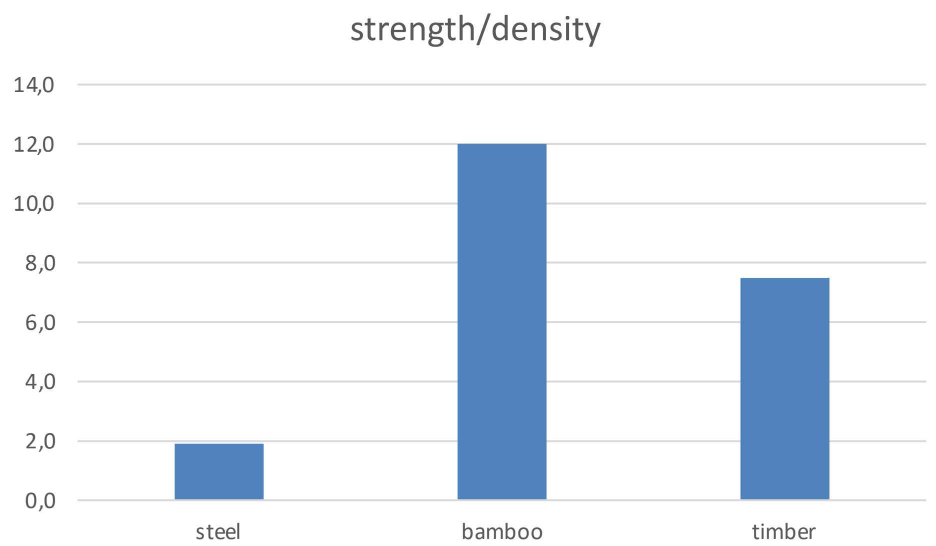
Comparison with other materials

Merit indices

Specific strength



Energy in [MJ] for the production of 1 m^3 per unit strength [MPa]

Material	MJ/m^3 Mpa
Steel	1500
Wood	80
Bamboo	30

[K. Ghavami]

Structural applications

Culms

Split

Planed

Engineered

Flakes and fiber

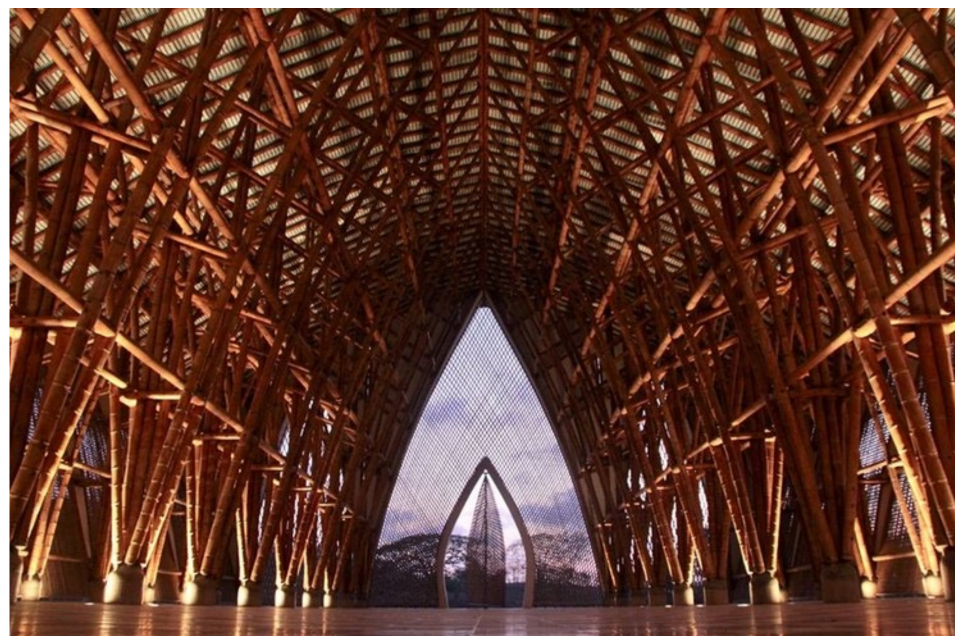
Culms

Culms

Architect Yasmeen Lari and the Heritage Foundation of Pakistan. The shelters.

https://edition.cnn.com/style/article/pakistan-floods-bamboo-shelters-climate-intl-hnk/index.html?fbclid=IwAR2cA5SrK6YLrkE5BY6iC3jN4M33M5z9npdYt8ZV1FrGi0sF-ETviu5L7CA

Arch. Mauricio Cardenas
https://www.studiocardenas.it



Arch. Simon Velez
https://www.studiocardenas.it

Culms

Culms

Bundles of culms

Arch. Mauricio Cardenas INBAR PAVILLON
https://www.studiocardenas.it

Canyaviva Italia
https://www.facebook.com/canyavivaitalia/

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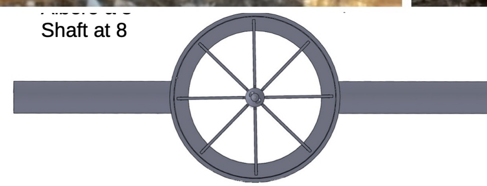
Planed

Split



https://www.madeinbamboo.com/

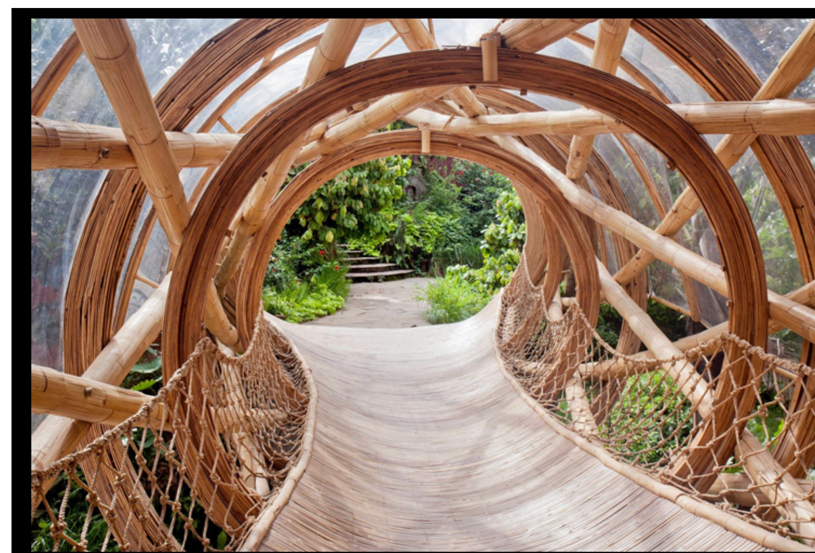


Photo by Tim Street Porter

https://inhabitat.com/interview-ibuku-founder-elora-hardy-on-creating-amazing-sustainable-buildings-with-bamboo/sharma-springs-ibuku-2/

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Engineered

Split

Planed

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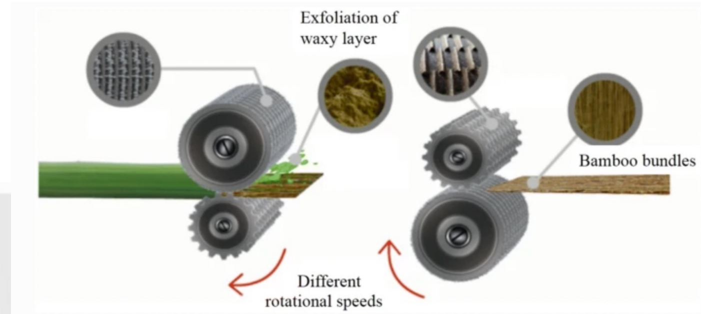
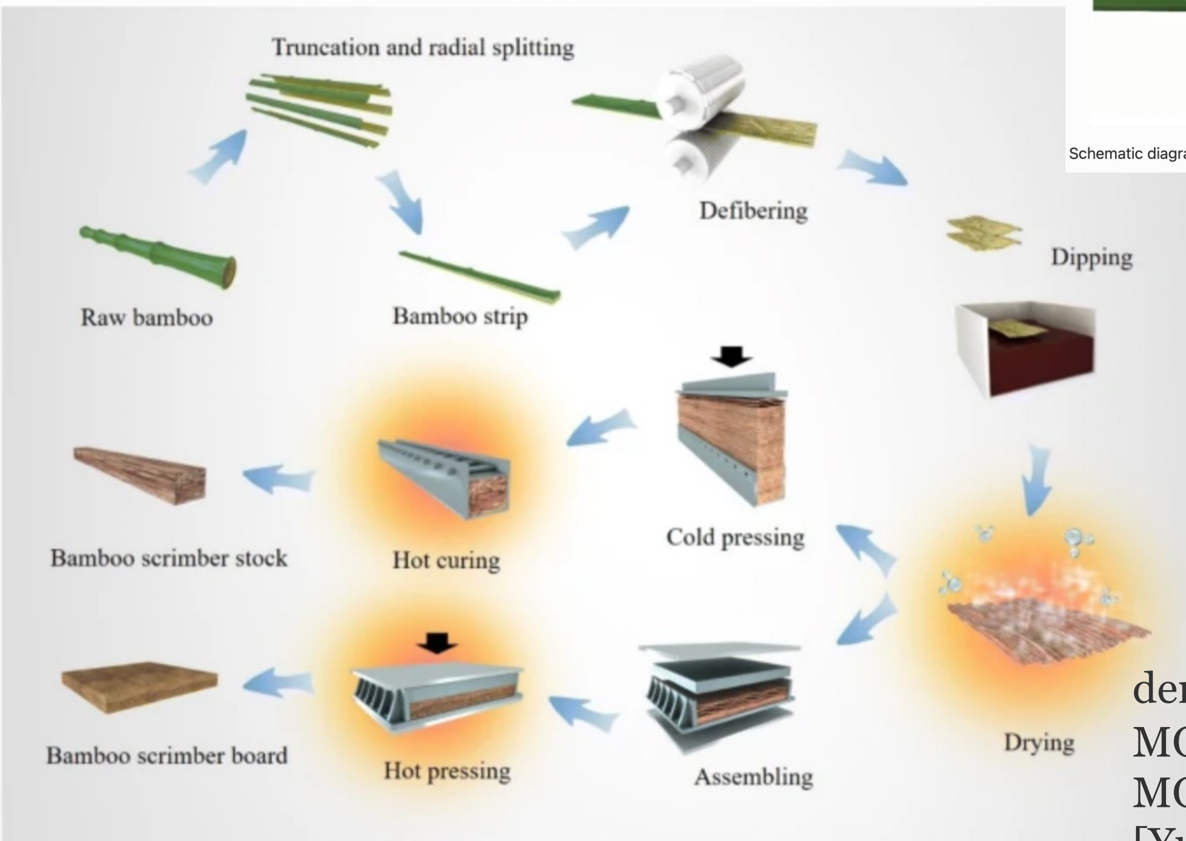
Scrimber bamboo



Schematic diagram of the novel fluffer machine developed by Chinese Academy of Forestry



Process flow diagram of bamboo scrimber

Dipping is the key process, impregnation of phenolic resin (in vacuum or at normal pressure) designed according to the requirements of bamboo scrimber's performance and use.

density from 1.02 to 1.3 g/cm^3,
MOR from 271 to 398 MPa
MOE from 26.4 to 32.3 GPa
[Yu Y, et al. 2018].
The water absorption decreased from 43.0 to 5.01% [Xie J, et al. 2016].

Development of bamboo scrimber: a literature review
•Yuxiang Huang, Yaohui Ji & Wenji Yu
Journal of Wood Science **volume 65**, Article number: 25 (2019)

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Laminated bamboo

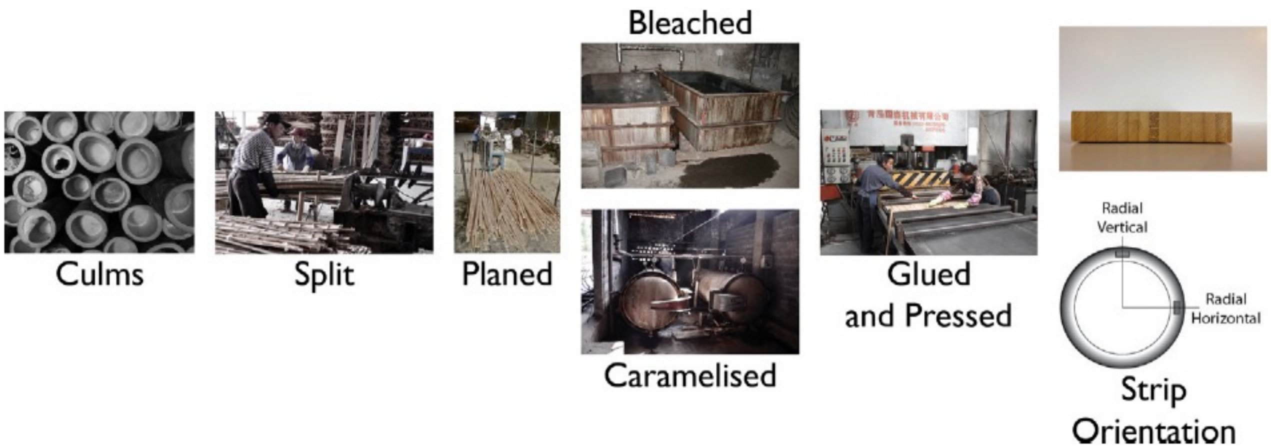

Fig. 2. Laminated bamboo general manufacturing process in China.

Table 2
Material properties for structural bamboo and comparable bleached bamboo and timber products.

		Density	Compression		Tension		Shear	Flexural		E_bI
		ρ kg/m^3	$f_{c\parallel}$ MPa	$f_{c\perp}$ MPa	$f_{t\parallel}$ MPa	$f_{t\perp}$ MPa	$\tau_\parallel$ MPa	f_b MPa	E_b GPa	kN-m^2
Bleached bamboo[a]	$\bar{x}$	644	55	a	124	3	14	76–79	10.2–10.5	79–89
	COV	a	0.09	0.15	0.15	0.14	0.09	0.09–0.07	0.08–0.06	
Semi-caramelised[a]	$\bar{x}$	673	60	22	116	3	17	79	10.4	81
	COV	0.01	0.04	0.07	0.20	0.11	0.03	0.12	0.08	
Caramelised bamboo[b]	$\bar{x}$	686	77	22	90	2	16	77–83	10.8–12.9	82–103
	COV	0.05	0.05	0.07	0.26	0.13	0.05	0.06–0.08	0.05–0.06	
Raw bamboo *Phyllostachys pubescens*[c,d]	$\bar{x}$	666	53	–	153	–	16	135	9	
Sitka spruce[e,f]	$\bar{x}$	383	36	–	59	–	9	67	8	
Douglas-fir LVL[g,h]	$\bar{x}$	520	57	–	49	–	11	68	13	

[a] Present study.
[b] Sharma et al. (2015) [24].
[c] Ghavami and Marinho [25].
[d] de Vos [26].
[e] Lavers [27].
[f] Kretschmann [28].
[g] Kretschmann et al. [29].
[h] Clouston et al. [30].

Effect of processing methods on the mechanical properties of engineered Bamboo, Bhavna Sharma, Ana Gatóo, Michael H. Ramage Construction and Building Materials 83 (2015) 95–101

What is limiting the use of bamboo? What can be done?

Culms

Issues: durability and strength, variability in dimension, connections, cultural feelings, lack of standards

Advantages: rapidity in construction, sustainability

International Standards:

ISO 19624 Bamboo structures — Grading of bamboo culms Basic principles and procedures

ISO 22156 Bamboo – Structural Design (milestone)

Engineered

Issues: sustainability (adhesives), industrialization of the process, standardization

Advantages: durability, strength, standardization, dimensions

International Standards:

Published:

ISO 23478:2022 Bamboo structures — Engineered bamboo products — Test methods for determination of physical and mechanical properties

Under developments:

ISO/DIS 6128 Laminated products made of bamboo strips for indoor furniture purposes (Draft International Standard)

ISO/WD 7567 Bamboo Structures — Glued laminated bamboo --Product specification (working draft)

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Bamboo flake and fibers

Bamboo Based Biocomposites
Material, Design and Applications
S. Siti Suhaily, et al.

Biocomposite: Mytril with Hemp and bamboo (without chemical additives 100% bio product)

MY.FIBERS
innovation & green technologies

https://www.myfibers.it/

Conclusions

Bamboo is a sustainable material with good mechanical properties which can play a crucial role in the green transition of the construction sector

Row bamboo material can have great applications but the engineered bamboo can greatly spread the applications

Standards need to be enlarged to cover all the aspects of the constructions.
There is the path already designed by timber.

There are new completely green perspectives also in panels made by bamboo fibers.

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