Bamboo and engineered bamboo for a new generation of constructions

工程竹结构研究与实践-多高层与大跨建筑

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Research Professor, University of Southern California, USA

Adjunct Professor, University of Illinois at Urbana Champaign, USA

浙江大学讲席教授，长江学者，国家特聘专家，浙江大学-伊利诺伊大学联合学院（ZJUI）

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- Introduction and background 背景
- Trend of timber structures 木构趋势
- Engineered bamboo – Research 竹结构研究
- Engineered bamboo – Practice 竹结构工程
  - *Recent Projects* *近期实践*
- Conclusions and future plan 结语及计划

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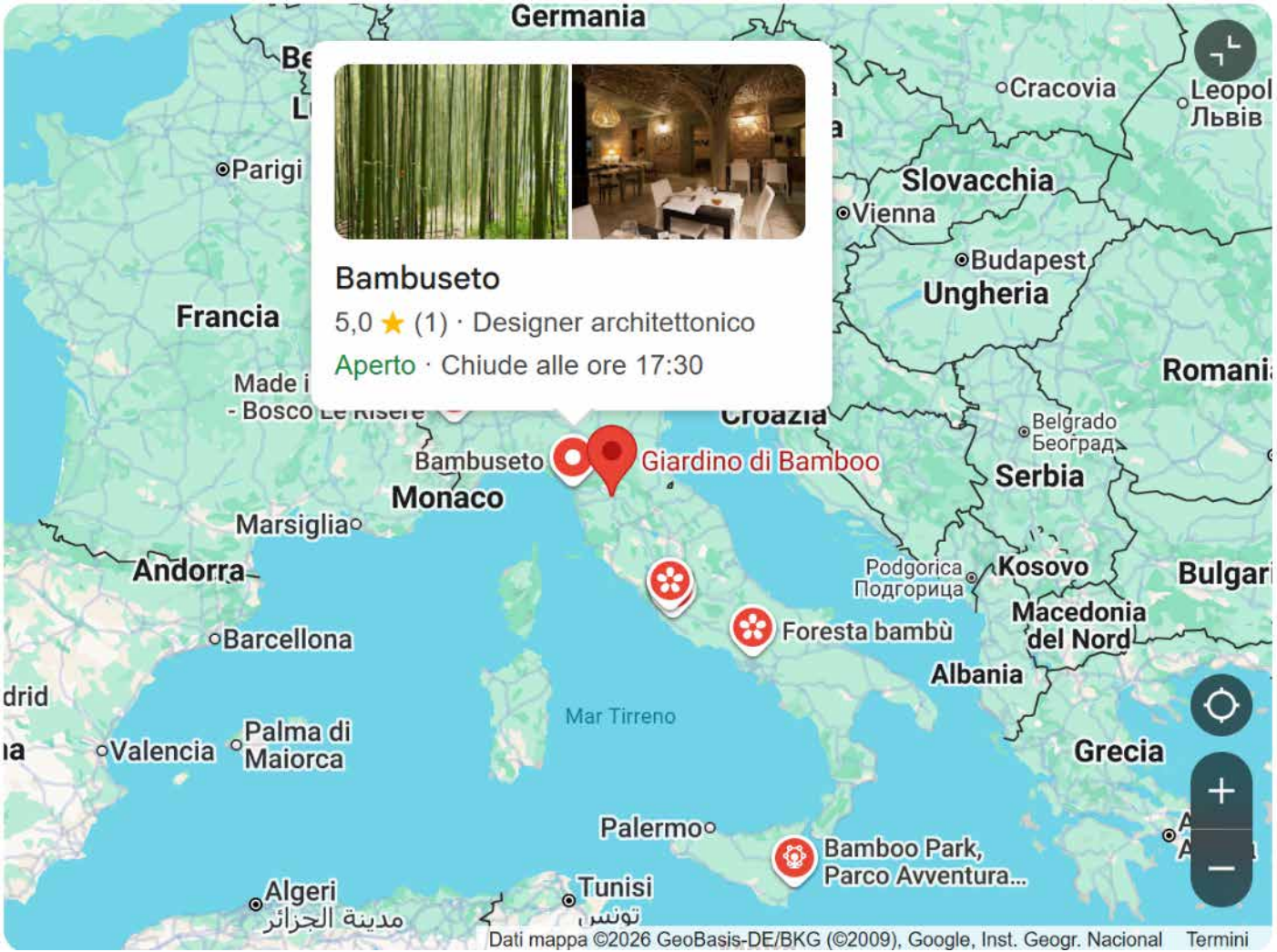
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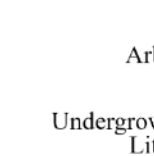
Bamboo

ZJUI









CO_2

O_2

Reduce carbon emissions

CO_2

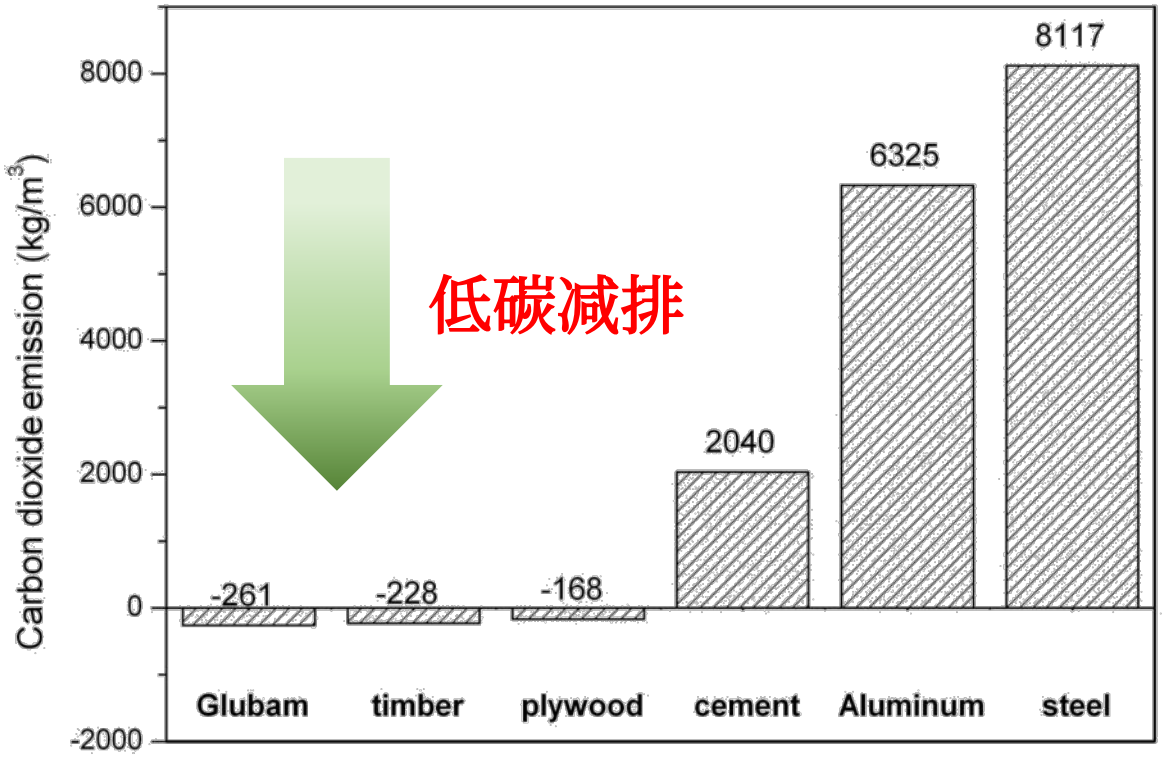
ury

CO2 emission 建材生产阶段的温室气

ZJUI

CO2 ton/m³

- Steel 8 tons
- Aluminum 6 tons
- Cement 2 tons
- Bamboo -0.3 tons



Xiao.Y, Yang.R.Z, and Shan.B, “Production, Environmental Impact and Mechanical Properties of Glubam,” Journal of Construction and Building Materials, Vol. 44(2013)765-773.

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Ex



意大利，米兰，2012 年竣工　德国，巴德艾比林，2011 年竣工　英国，伦敦，2009 年竣工

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市,2023.7

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Why bamboo？！





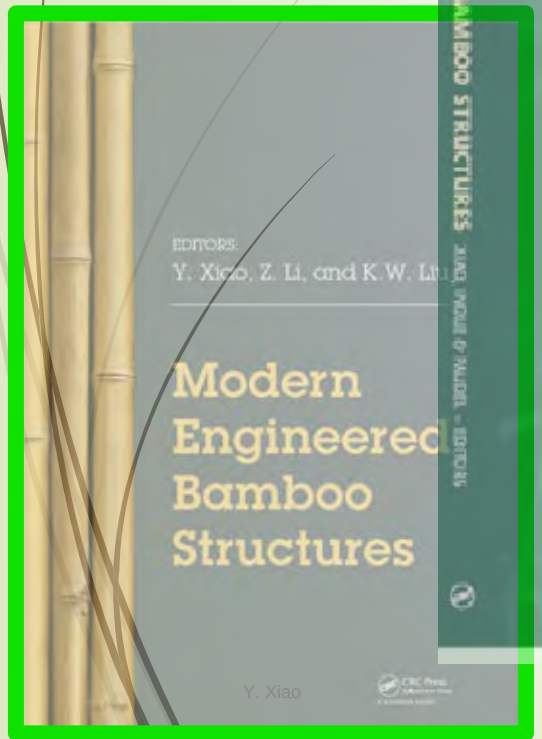
Selected previous demonstration projects, 2006~

Xiao's t
20 yea

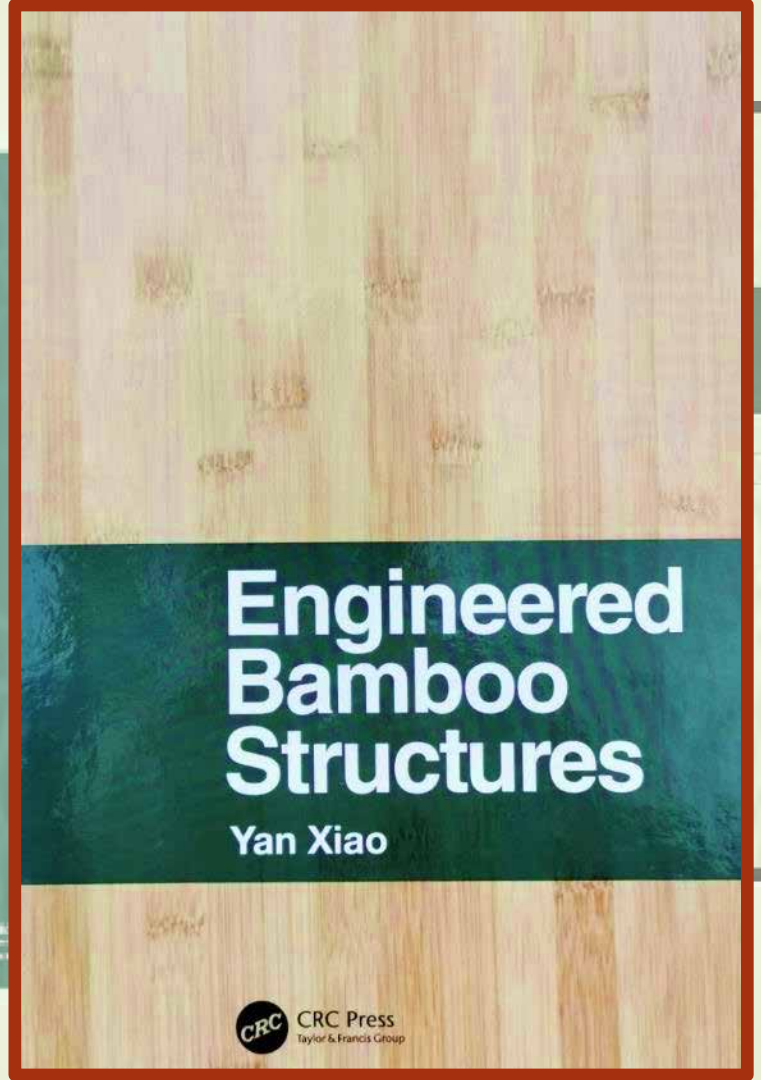


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New book


EDITORS:
Y. Xiao, Z. Li, and K.W. Liu
Modern Engineered Bamboo Structures
Y. Xiao


MODERN BAMBOO STRUCTURES

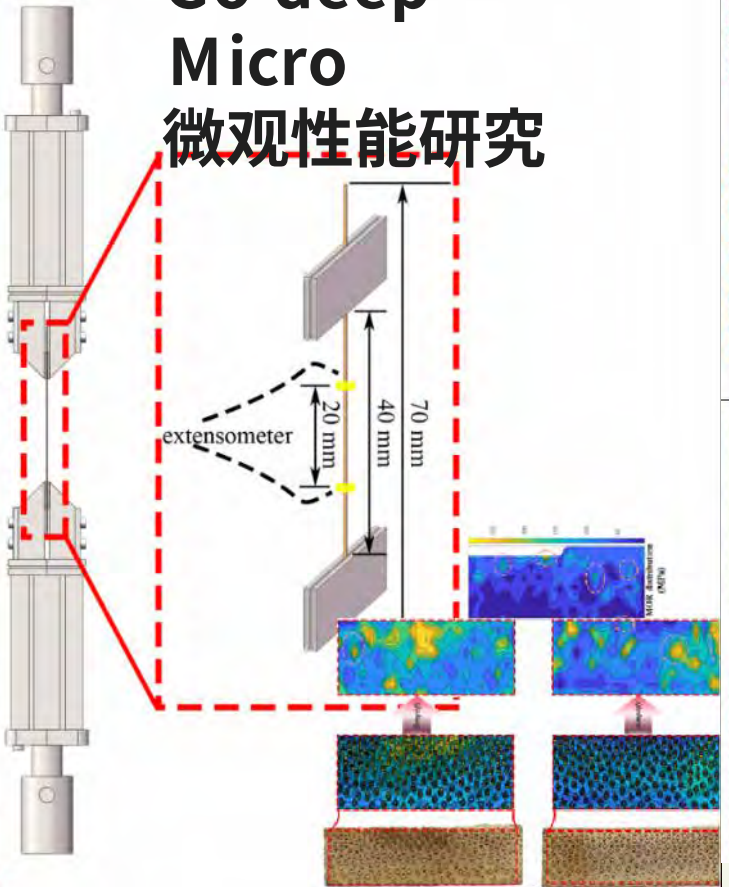

Engineered Bamboo Structures
Yan Xiao
CRC Press
Taylor & Francis Group

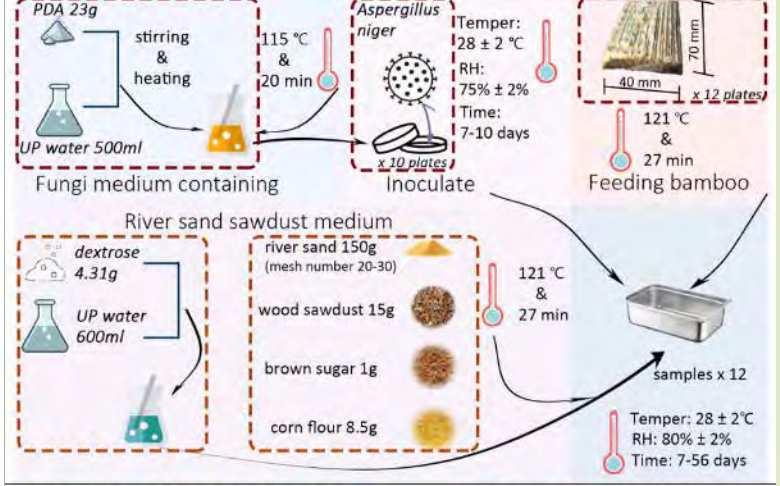

现代竹结构
GluBam Structures
肖岩 单波◎著

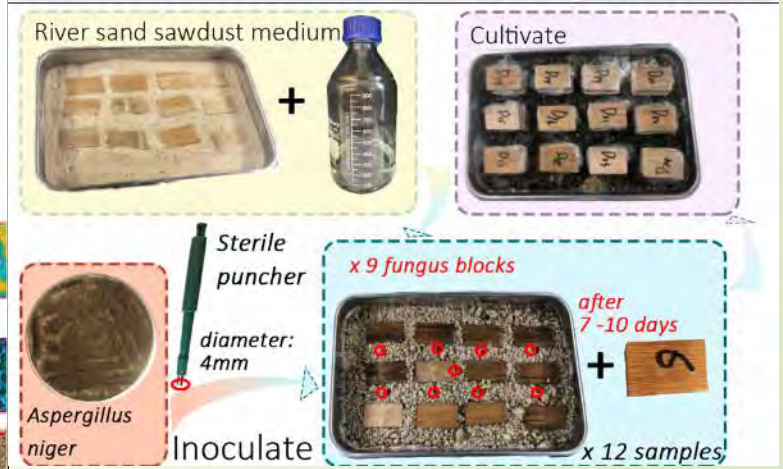
Recent work - **smaller!**



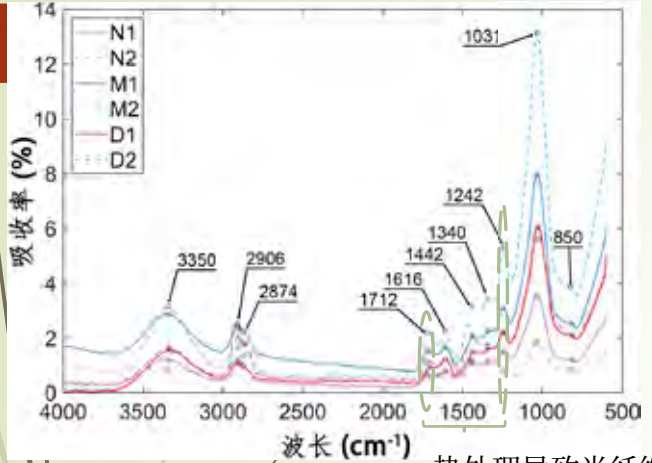
Go deep Micro 微观性能研究





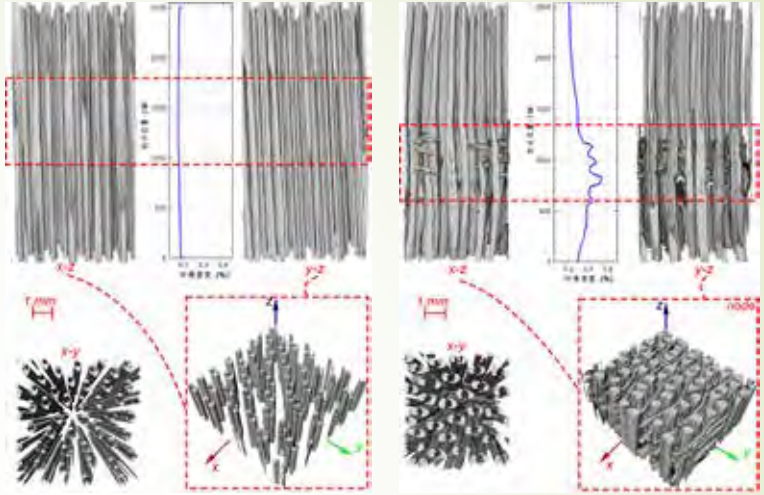


C.Q. Chen, S.J. Zhang, Y.B.H. Kong, T. Ji, W.W. Huang, Y.T. Hu, D.W. Zhang, Y. Xiao. Compressive strength degradation of engineered bamboo subjected to fungal attack. **npj Materials Degradation**. 2023;7:1-16.



热处理导致半纤维素变化

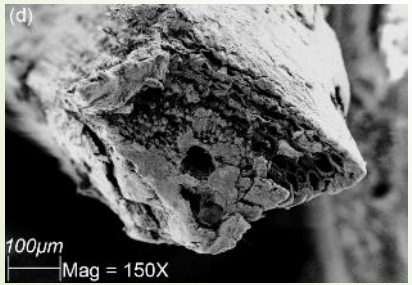
热处理后毛竹薄片的傅里叶变换红外光谱(FTIR)



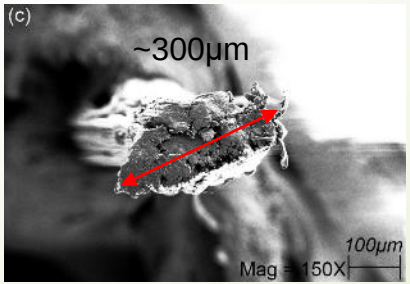
中度热处理后μ-CT三维成像显示的竹纤维束模型



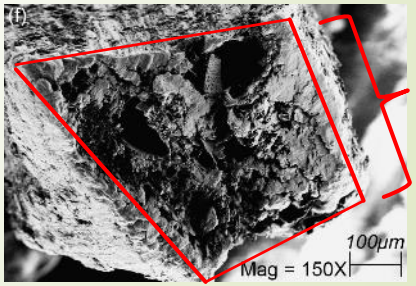
无热处理/化学提取



无热处理/机械提取



深度热处理/化学提取



深度热处理/机械提取

Modeling

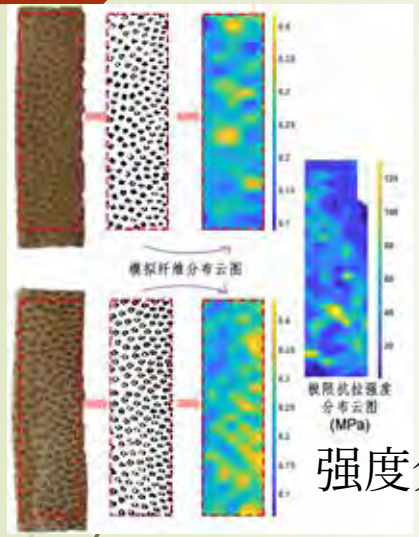
原图　黑白　灰度等高线 ⟶ 0-1数值

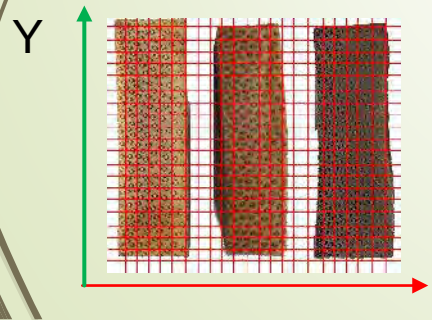
标准化

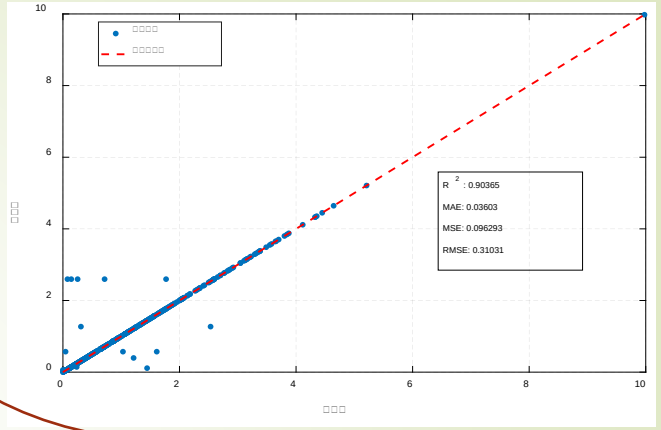
Random Forest
Regression
RFR-model

标准化

强度分布 ⟶ 14-110数值



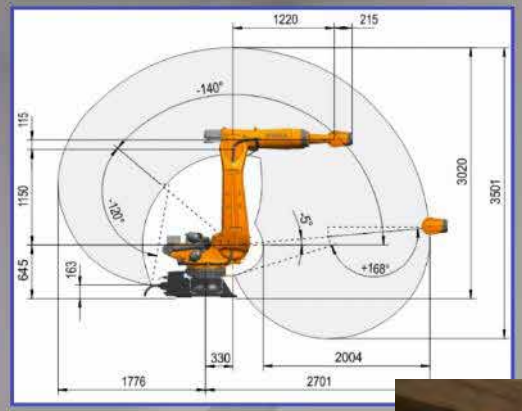






Recent work - **digital!**

Digital design and robotic fabrication
参数化设计与机械臂加工





- K. Ma, R.J. Wu, Y. Xiao, H.W. Wang. (2023). Spherical dome: design, digital twin manufacturing, and testing of a glubam structure. Architectural Engineering and Design Management. 1-18. 10.1080/17452007.2023.2276287.
- R.J. Wu, K. Ma, P.Y. Li, Y.B. Hou, P.X. Wang, B.B. Li, Y. Xiao (2024). Experimental and numerical studies on a glubam spherical dome. *Engineering Structures*, *303*, 117462.

Recent work - **cold!**

Background



(a)



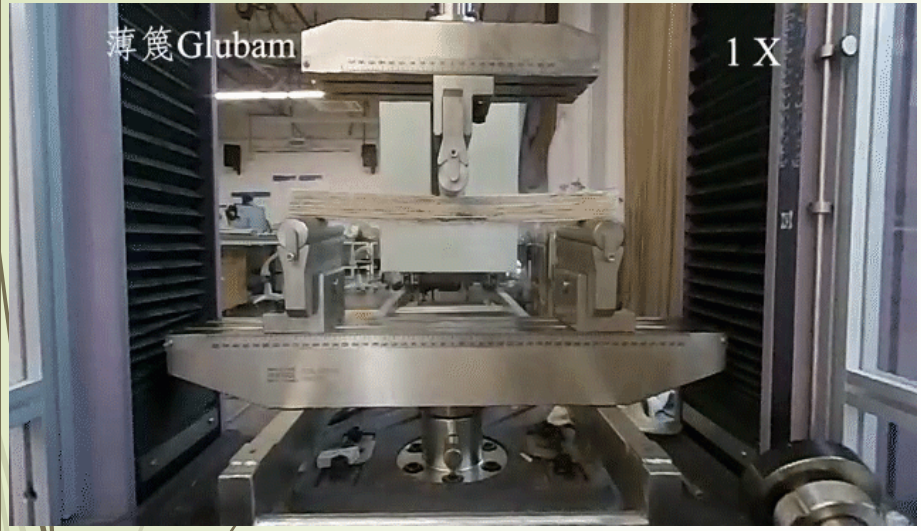
(b)

Record -53℃in Mohe, Heilongjiang, on January 22, 2023. Average below -5.1°C.

“ Y-house ” glubam solar house in Zhangjiakou, in collaboration with XJTLV. Recorded low temperature -35℃ .

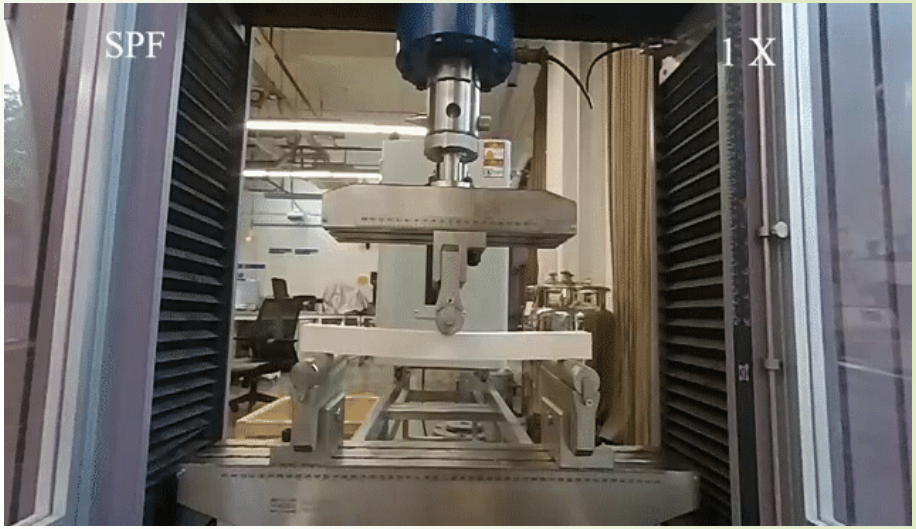
LNG shipping at -163℃.

Low temperature effects 低温力学性能试验



Air dry thin Glubam at -196℃

薄篾glubam气干材



Air dry SPF -196℃

SPF气干材



J.X. Chen, Z.E. Gao, C.Y. Peng, C.H. Shi, X.L. Ding, H. Hu, Y. Xiao,* (2024). Mechanical behavior of glubam engineered bamboo at low temperature.. **CBM** 414 (2024) 135045

Recent work - **hot!**

Post-fire damage residual strength







Ph.D. candidate
Deng Junyuan
邓钧远

Multi-purpose electrically heated fire test furnace

The inner wall of the furnace was made of ceramic fibre insulation material, and the outside was wrapped by a thick steel plate

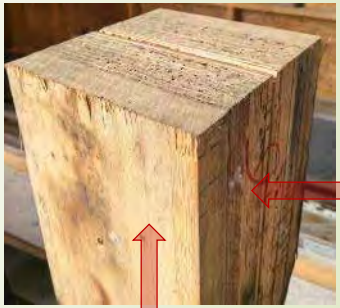
3. Charring rate

Materials	Specimens	Residual dimension (mm)	Fire duration (min)	Combustion zone Lf（mm）	Radial charring rate mm/min	Tangential charring rate mm/min
Thick and thin strips glubam	H-1200-30	114×132×1200	30	600	1.1	0.8
Thin strips glubam	B-1200-60	107×130×1200	60	600	1.21	0.83



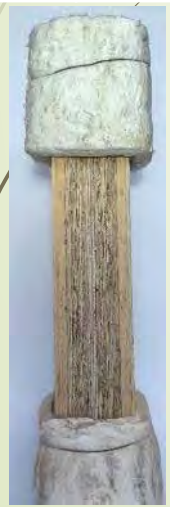
Tangential direction

Radial direction



Tangential direction

Radial direction



H-1200-30



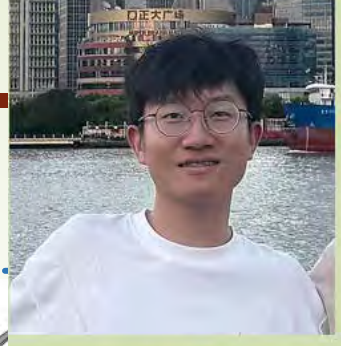
B-1200-60



After the fire

Recent work – **round!**

Back to round~





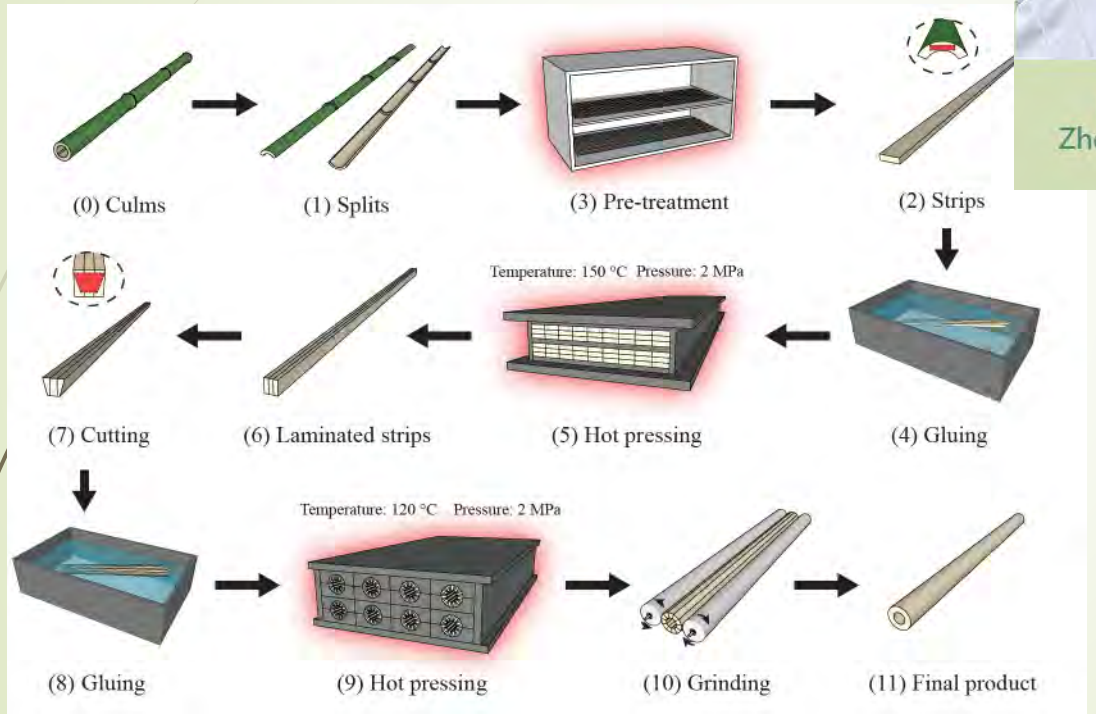
Hanlin Wei
Zhejiang University

Cristoforo Demartino
Università degli Studi
Roma Tre

Materials and Method

p **Laminated Bamboo Tube (LBT)**

Manufacturing Procedure



p **Adhesive:**
Phenol Formaldehyde

p **Curing time: At least one day**



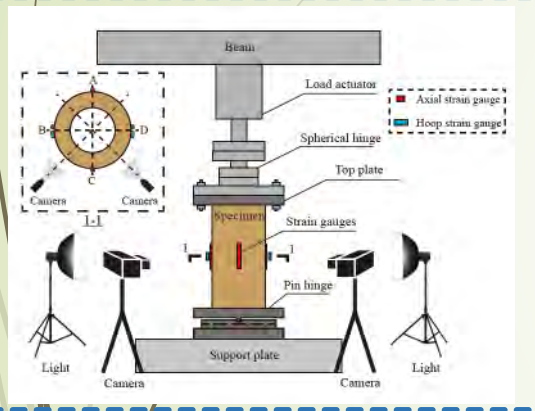
Final product

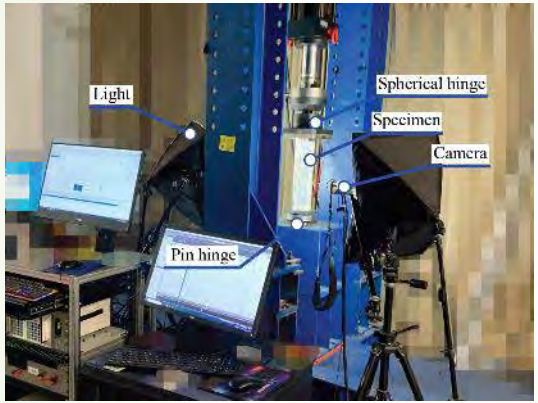
Axial Compression Test

Materials and Method

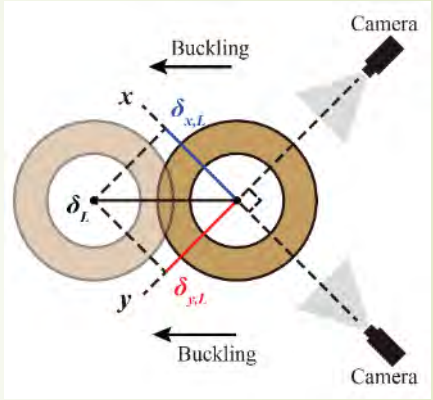
p **Test Setup**

Compression Test Setup





Lateral Displacement



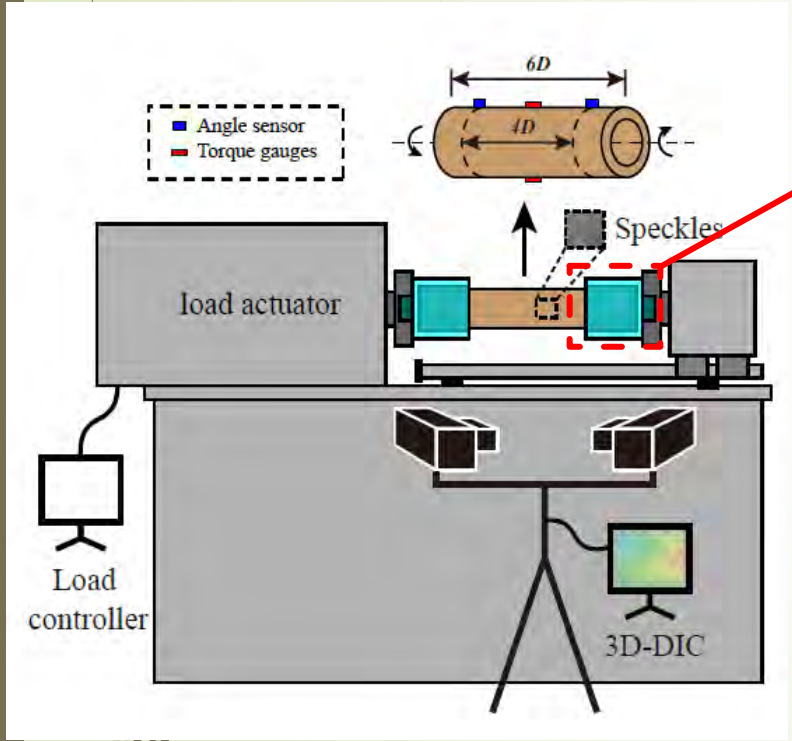
- 144 Specimens (Different Length, Thickness, Diameter)
- Double-hinged Boundary Conditions
- Axial and Hoop Strain (6 Strain Gauges)
- 2 Cameras for DIC Measuring
- Monotonic Loading to Failure

Repetitions	*L [mm]*	*D [mm]*	*T [mm]*	Total
3	100	80	8	144
	450	100	10	
	950	120	15	
	1500		20	

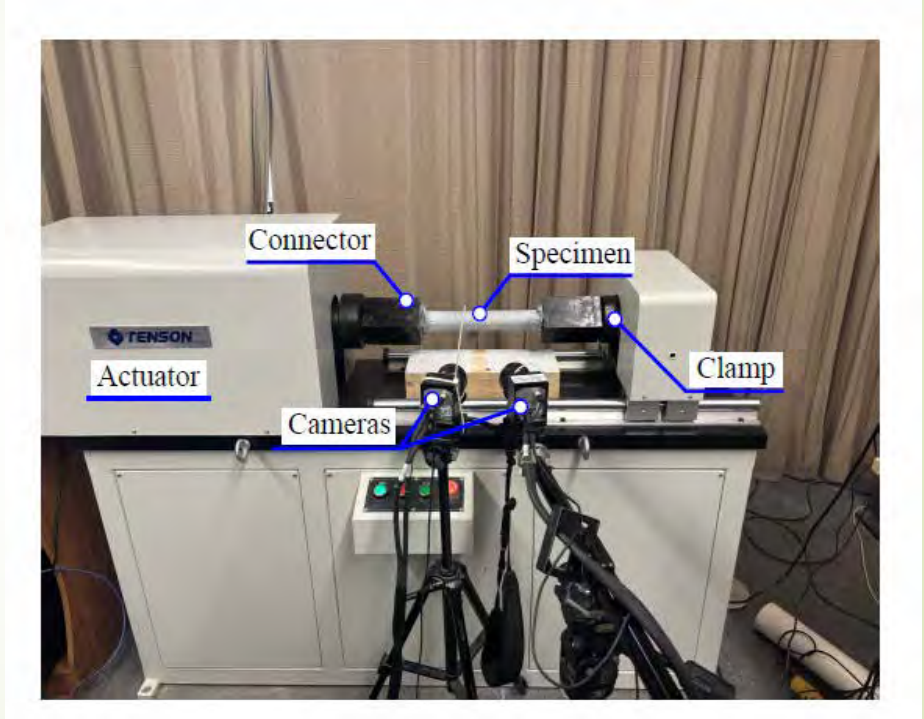
Specimens Matrix

Torsion Test

Test Setup



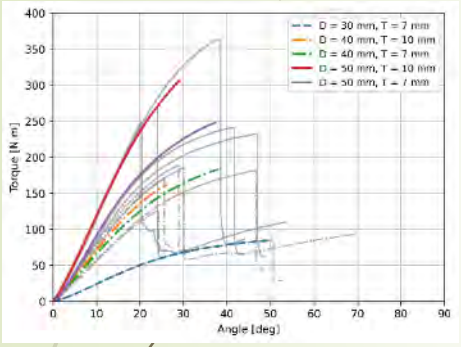




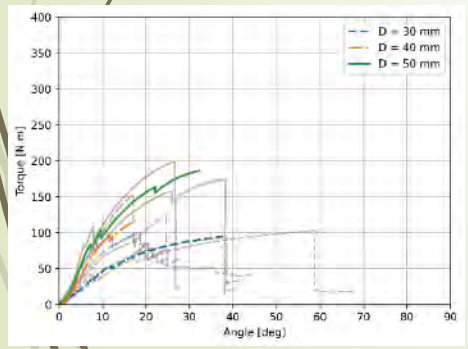
Torsion Test

Results

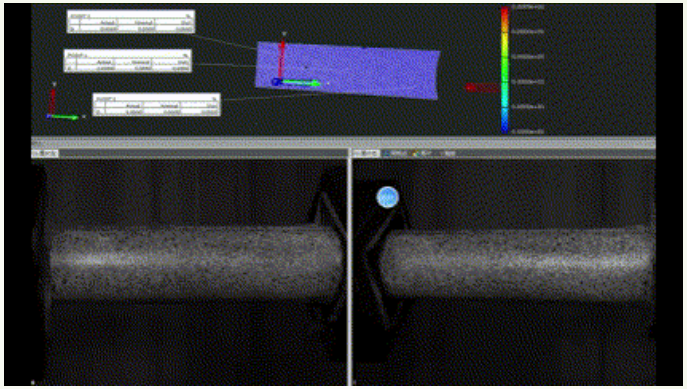
p **Torque-Angle (LBT)**

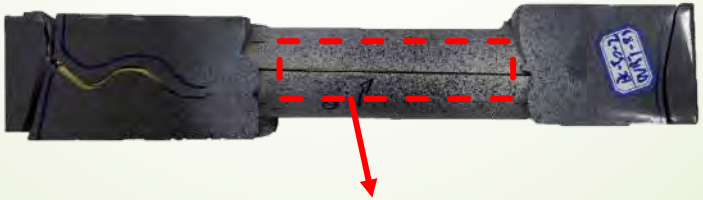


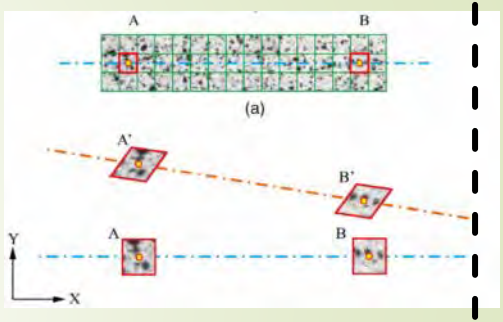
p **Torque-Angle (Culm)**



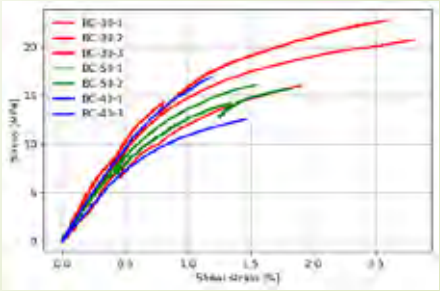
p **Failure Mode**







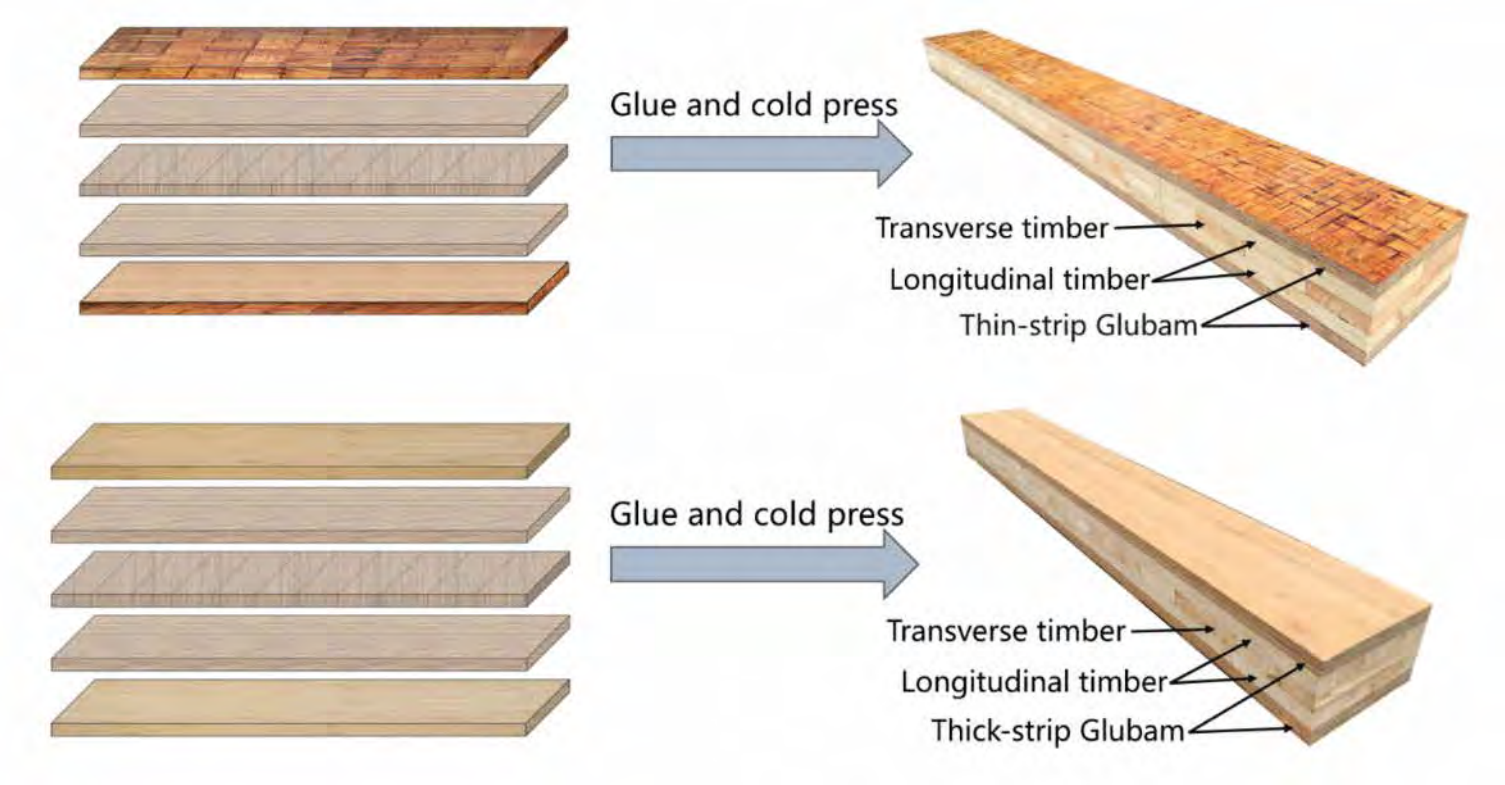
3D-DIC Method



Stress-strain

Recent work – **composite!**

CLBT-cross laminated bamboo and timber

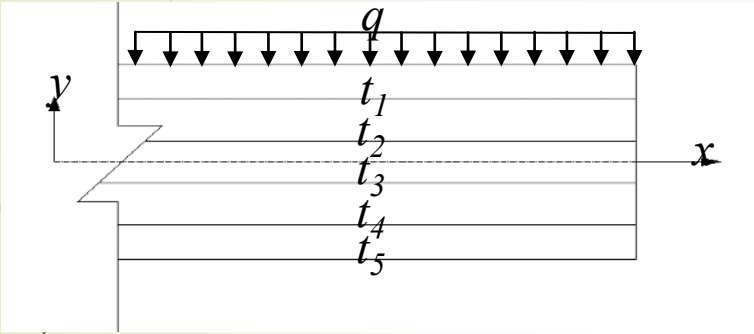


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Patented by Xiao, ZL 2017 2 0561674.8

Exact Elasticity solution of CLBT beams

The beam is assumed to be under plane stress condition



A 5-layer CLBT beam under flatwise bending

Equilibrium equations:

I = 1, 2, 3, 4 or 5 for different layers

Constitutive relationships:

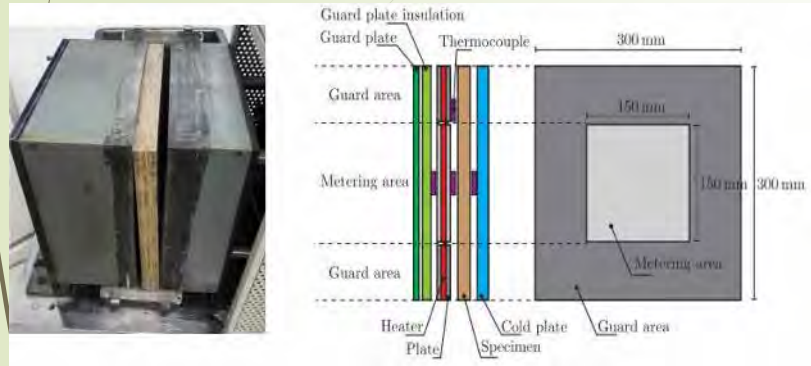
Compatibility condition:



Wen, Jie , and Y. Xiao . *Construction and Building Materials* 408(2023)

Thermal performance studies - materials

Guarded Hot Plate (GHP) test (ISO 8302, 1991)



$$\lambda = \frac{\Phi \cdot d}{A(T_1 - T_2)}$$

d: thickness of the specimen; Φ: heat flow equal to the average of the electric power in the metering area heating circuit under steady-state conditions; and A is the metering area; T_1 and T_2 temperatures of the hot plate, and the cold plate

Characteristics and thermal conductivity of different materials tested.

Specimens	Thickness (mm)	Density (kg/m³)	T2-T1 (°C)	λ (W/mK)	$\bar{\lambda}$ (W/mK)
CLT	31.543 (3.028)	405.633 (5.520)	10~20	0.1048 (9.12)	0.1016 (6.81)
			20~30	0.0937 (5.29)	
			30~40	0.0966 (4.41)	
			40~50	0.1113 (5.40)	
CLT-J	29.680 (6.352)	389.882 (0.366)	10~20	0.1028 (7.64)	0.0998 (5.75)
			20~30	0.0923 (6.64)	
			30~40	0.0966 (6.46)	
			40~50	0.1073 (6.32)	
CLBT	36.073 (1.15)	709.664 (3.772)	10~20	0.1302 (3.41)	0.1389 (10.62)
			20~30	0.1249 (3.92)	
			30~40	0.1373 (2.23)	
			40~50	0.1633 (13.61)	
Stucco	22.817 (0.568)	304.850 (0.450)	10~20	0.2700 (15.94)	0.3178 (14.19)
			20~30	0.2816 (15.49)	
			30~40	0.3375 (12.16)	
			40~50	0.3822 (15.43)	
XPS	34.400 (0.306)	30.122 (0.285)	10~20	0.0345 (4.32)	0.0370 (11.29)
			20~30	0.0315 (6.81)	
			30~40	0.0402 (2.96)	
			40~50	0.0418 (1.41)	

Note: data in parentheses are COV (%).

Thermal testing of CLBT wall panels

ISO 8990 (ISO 8990, 1994)

Specimen	Size (m)	Thickness (mm)
CLT wall panel	1.83×1.83	246
CLBT wall panel	1.83×1.83	232

Guarded hot box

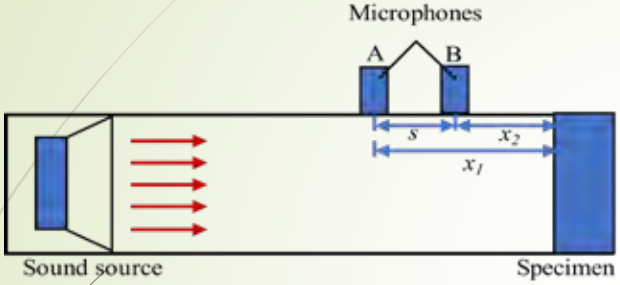




B. Shan; B.Z. Chen; J. Wen; Y. Xiao, (2022) Thermal Performance of Cross Laminated Timber (CLT) And Cross Laminated Bamboo And Timber (CLBT) Panels. Journal of Architecture Engineering and Design Management

Acoustic testing of CLBT materials

Two-microphone impedance tube





Incidence reflection factor

$$r = \frac{H_{12} - H_I}{H_R - H_{12}} e^{2jk_0x_1}$$

Incidence sound absorption coefficient

$$\alpha = 1 - |r|^2$$

$$H_I = \frac{p_{1I}}{p_{2I}} = e^{-jk_0(x_1 - x_2)}$$

$$H_R = \frac{p_{1R}}{p_{2R}} = e^{jk_0(x_1 - x_2)}$$

$$H_{12} = \frac{p_2}{p_1}$$

p_1 and p_2 are the
measured at micr

Kong, Wen, et al. (2023), Acoustic properties of glued laminated bamboo and spruce-pine-fir. Wood Material Science & Engineering

©肖岩研究组



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- Introduction and background 背景
- Trend of timber structures 木构趋势
- Engineered bamboo – Research 竹结构研究
- Engineered bamboo – Practice 竹结构工程
  - *Recent Projects* *近期实践*
- Conclusions and future plan 结语及计划

Glubam 胶合竹工程案例

ZJUI











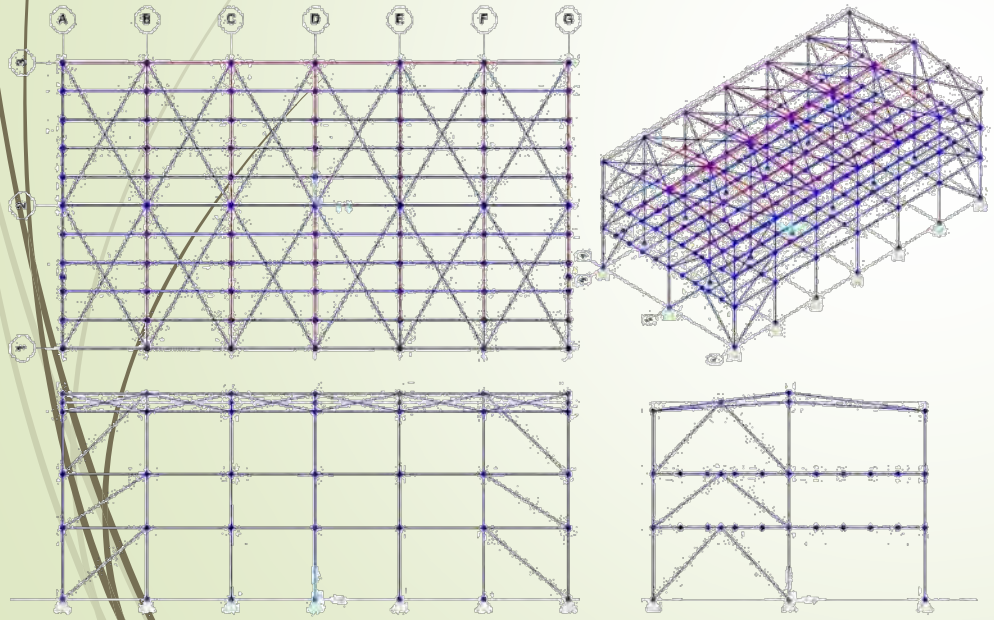
©肖岩工作室 Xiao's Lab

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  - *Recent project-1* ***近期****实践- 1*
- Conclusions and future plan 结语及计划

Taohuajiang 3-story office building design
湖南桃花江科技有限公司办公用房

Concept： Xiao Y.肖岩
Structure： Chen J.X.陈景轩
Pre-architecture：Ma K.马克

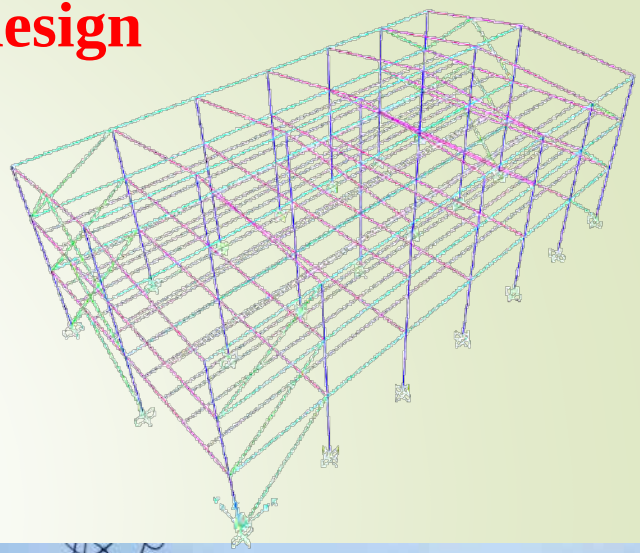




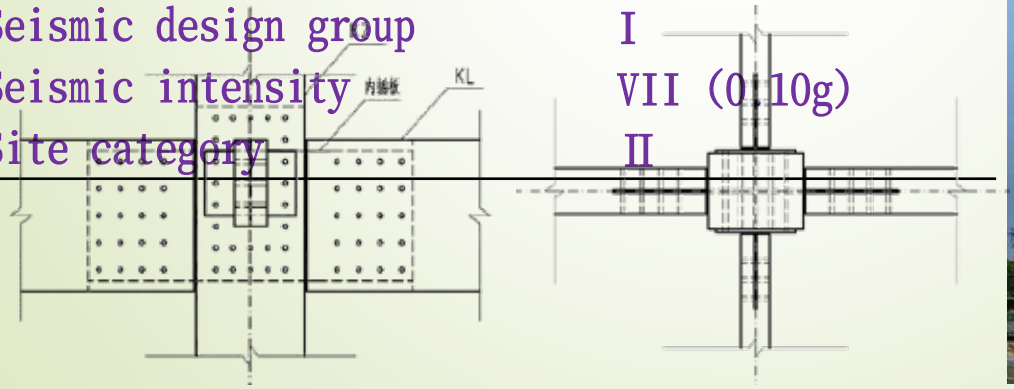


桃花江竹节构办公用房

Taohuajiang 3-story office building design
湖南桃花江科技有限公司办公用房



Design parameter 设计参数	
Safety level	II
Service life (ref)	50年
Dead load	1.85 kN/m^2
Live load	2 kN/m^2
Basic wind pressure	0.35 kN/m^2
Basic snow load	0.45 kN/m^2
Seismic design	III
Seismic design group	I
Seismic intensity	VII (0.10g)
Site category	II





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- Engineered bamboo – Practice 竹结构工程
  - *Recent project-2* ***近期****实践- 2*
- Conclusions and future plan 结语及计划

Overview

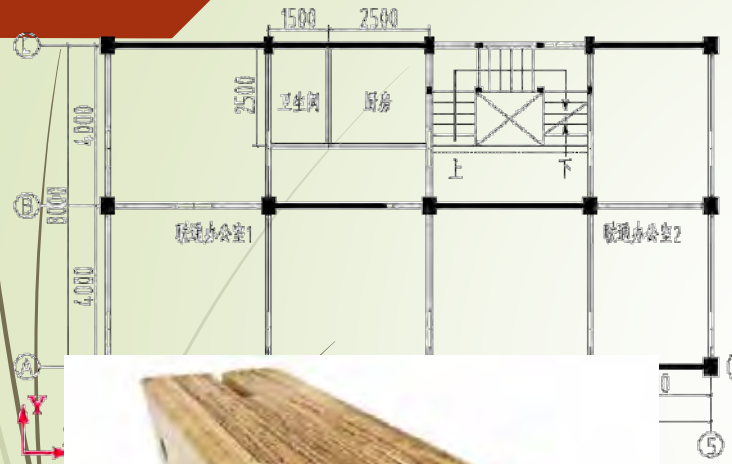
Building Purpose	**Research, education, and demonstration**
Building Overview	Height: **20.3 m**: Land Area: **129 m²**. Total floor: **790 m²**
Project Management	Ninghai County Investment Group Co. Ltd.
Project Operations U	
Research Funding	
International Collaboration	
Conceptual Design	
Structural Designer	
Architectural Consu	
Construction Drawing Drafting	R.J. Wu, Y.B. Hou, X.L. Li, Y.F. Bai
Fabrication and Construction	Ningbo Bamduos New Materials Technology Co.. Ltd.
Construction Materials	Hybrid GluBam®; Cross Laminated Bamboo and Timber CLBT®; Steel Connectors, Bolts, etc.

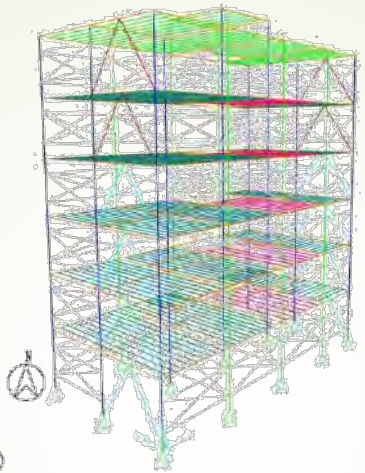






Design conditions







Thick strip glubam

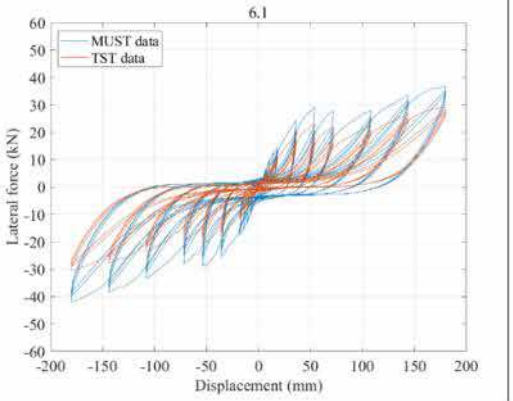
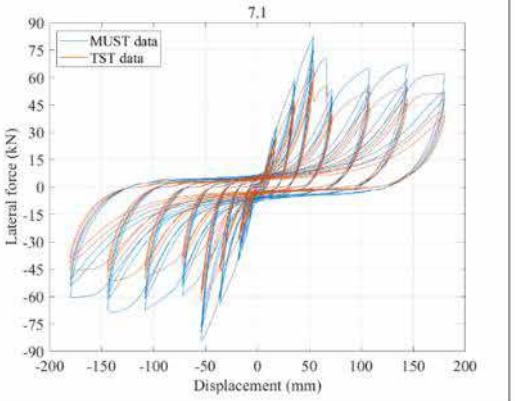
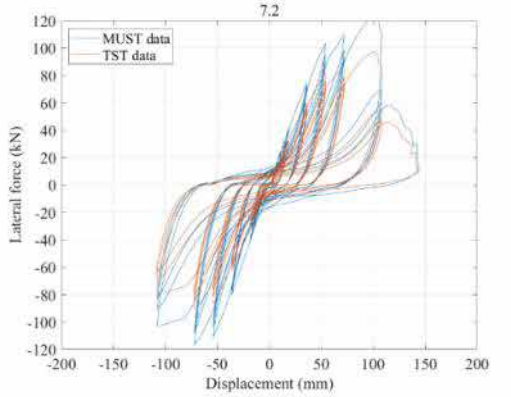
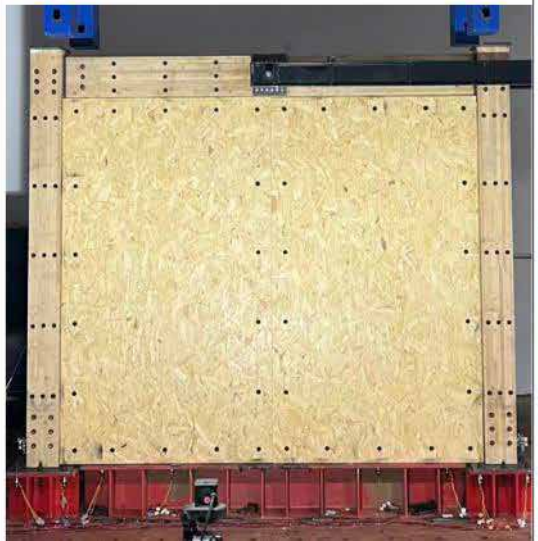
Thin strip glubam

Table 1. Design Parameters

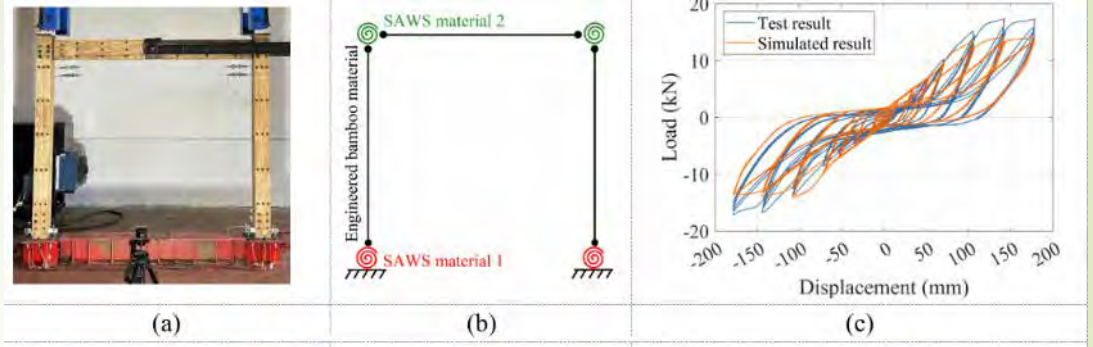
Design Index	Parameter
Safety Level	Level 3
Design Life (Reference)	50 years
Dead Load (Standard Value)	1 kN/m^2
Live Load (Standard Value)	2 kN/m^2
Basic Wind Pressure	0.50 kN/m^2
Basic Snow Load	0.30 kN/m^2
Seismic Protection Category	Category C
Seismic Design Group	Group 1
Seismic Intensity	8 degrees (0.30g)
Site Category	Category I1

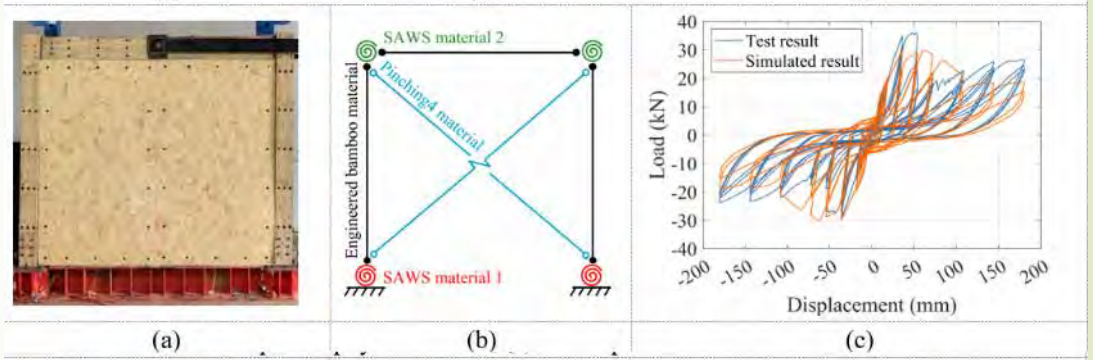
erial Properties

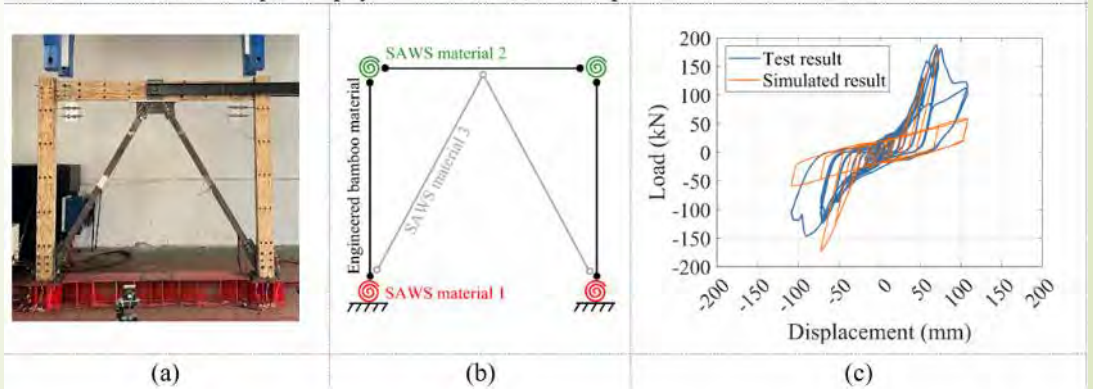
	Density kg/m^3	Modulus of Elasticity, MPa	Tensile strength, MPa	Compressive strength, MPa	Bending strength, MPa	Shear strength, MPa
rip	800	8000	32.4	20.4	38.4	2.4
n	800	8000	18.4	10.7	29.0	4.7

6：F3+WW1	7.1：F1+WW2（150/150）	7.2：F1+GBW2（150/150）
厚箪三孔框架，无轴力，轻型 OSB 剪力墙，钉间距 150/300	薄箪三孔框架，无轴力，夹板 OSB 剪力墙，钉间距 150/150	薄箪三孔框架，无轴力，夹板竹胶板剪力墙，钉间距 150/150
		
		

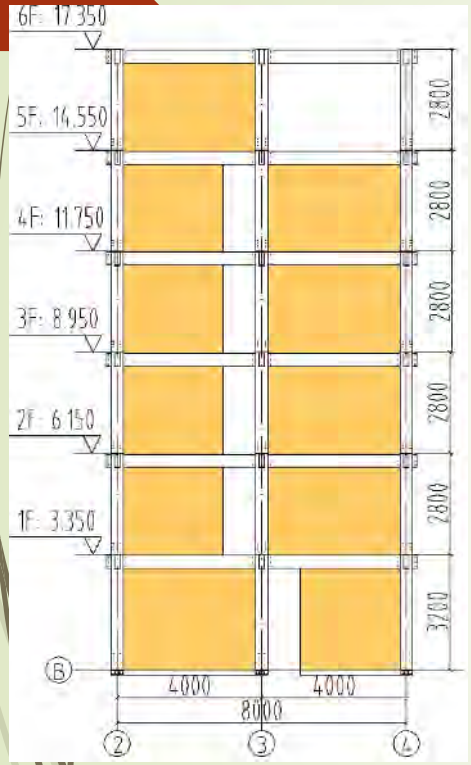
Results simulation

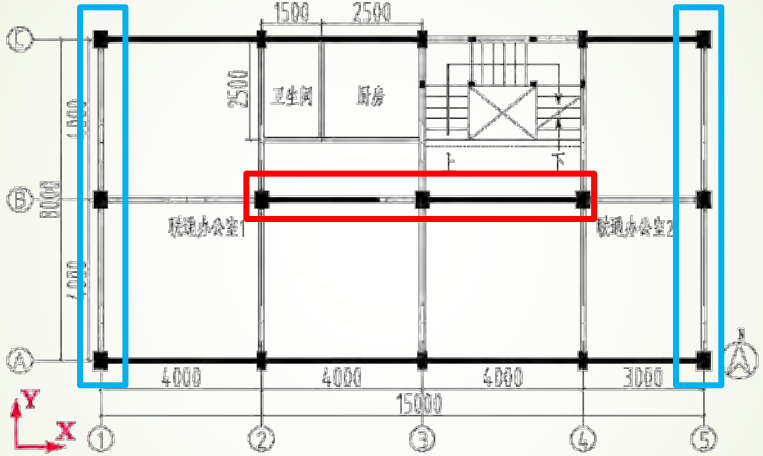


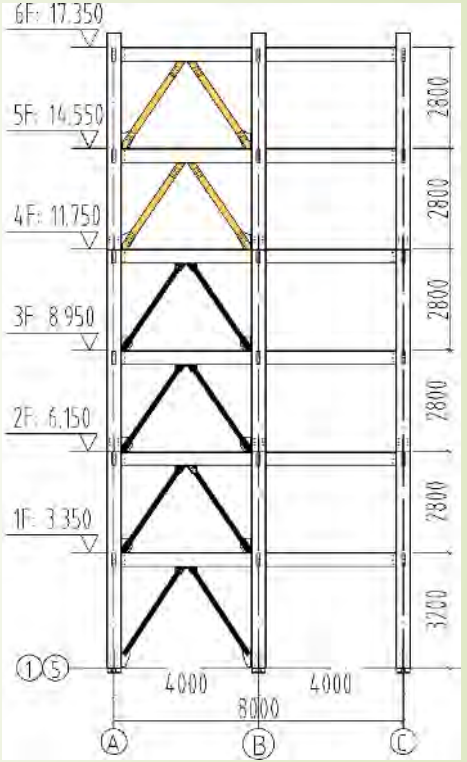




Lateral resistance system 抗侧力结构体系



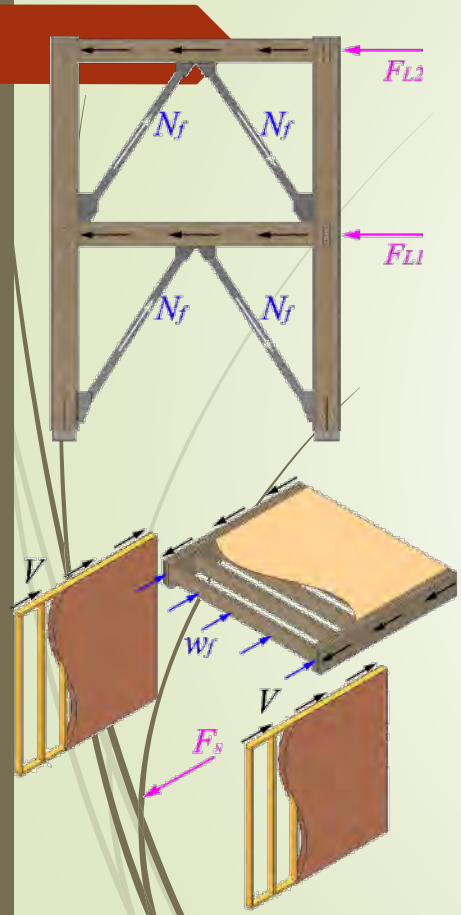


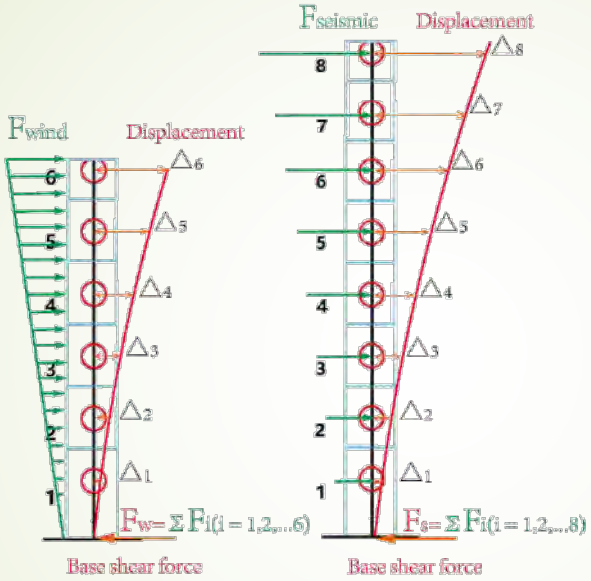


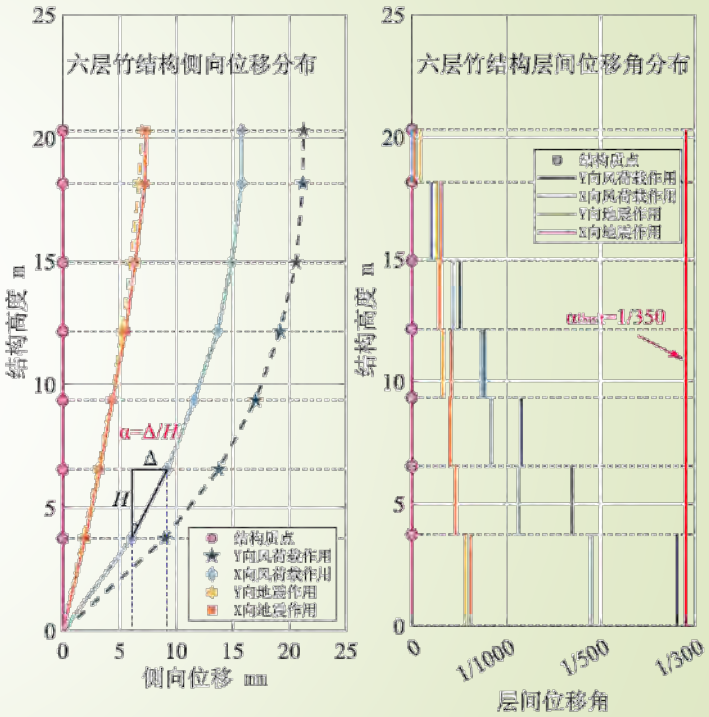
X: stud shear walls

Y: steel or bamboo braces

Lateral resistance system 抗侧力结构体系







Components manufacture



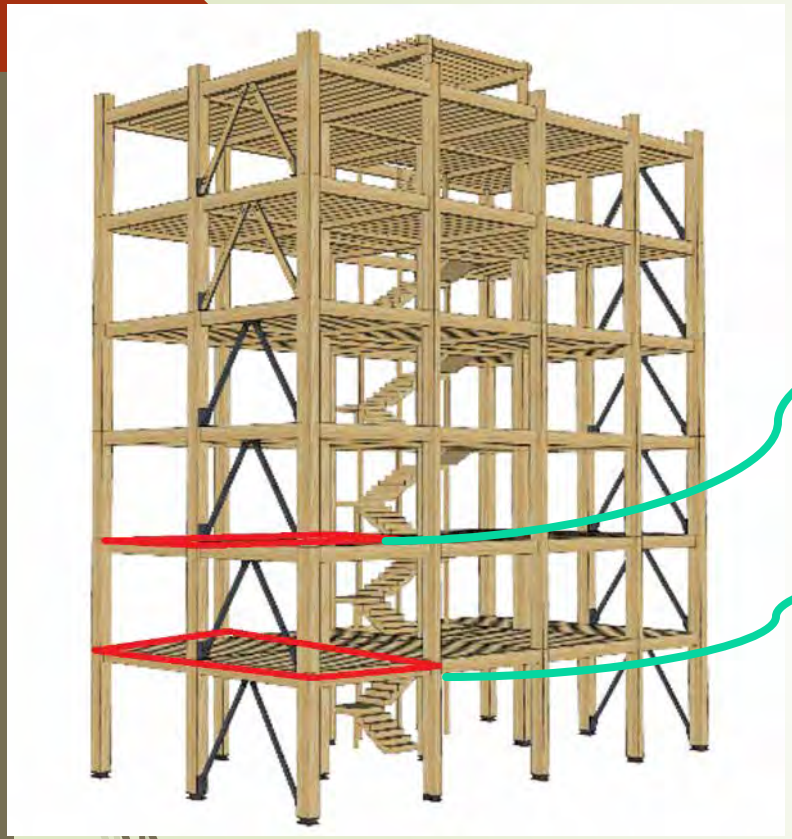








4 CLBT for partial floor





CLBT 楼板

Construction 施工建造





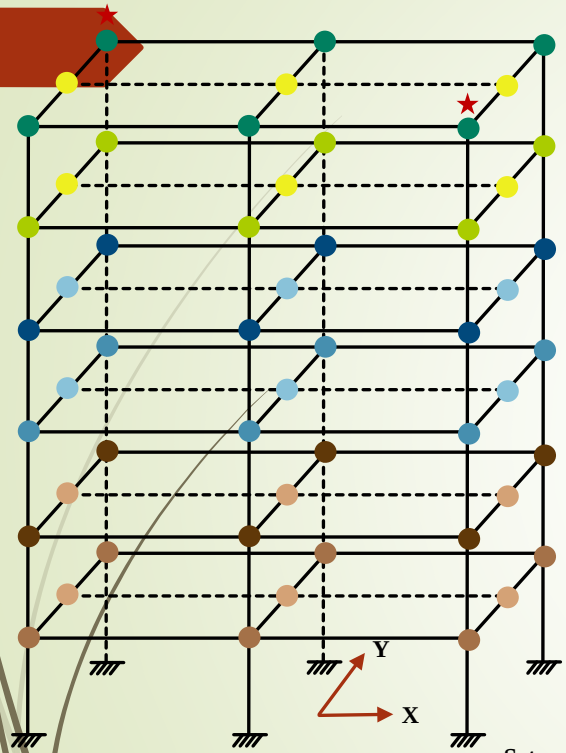








Vibration 结构动力测试



Set up figure

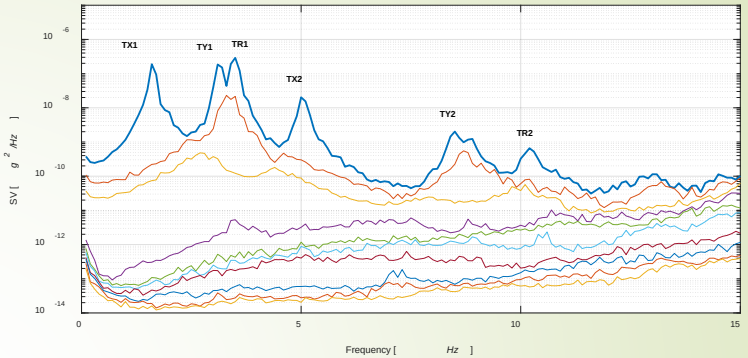
★ Reference point

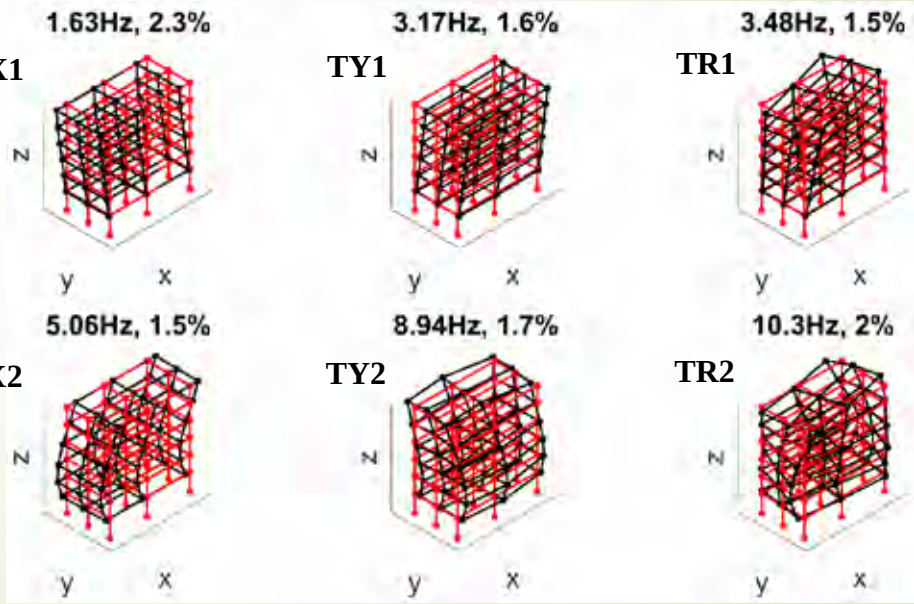
Setup 1 Setup 4 Setup 7

Setup 2 Setup 5 Setup 8

Setup 3 Setup 6 Setup 9

SV spectra

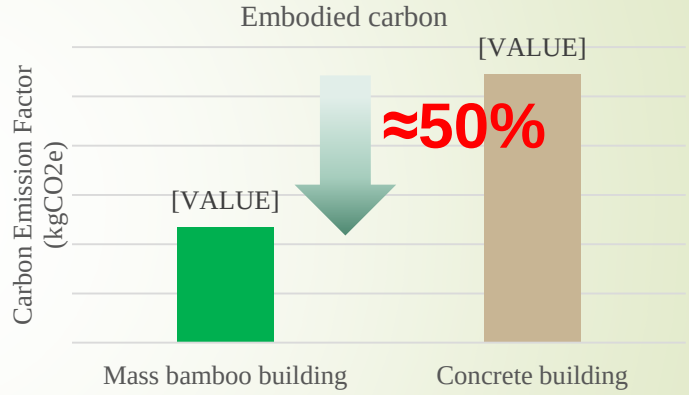


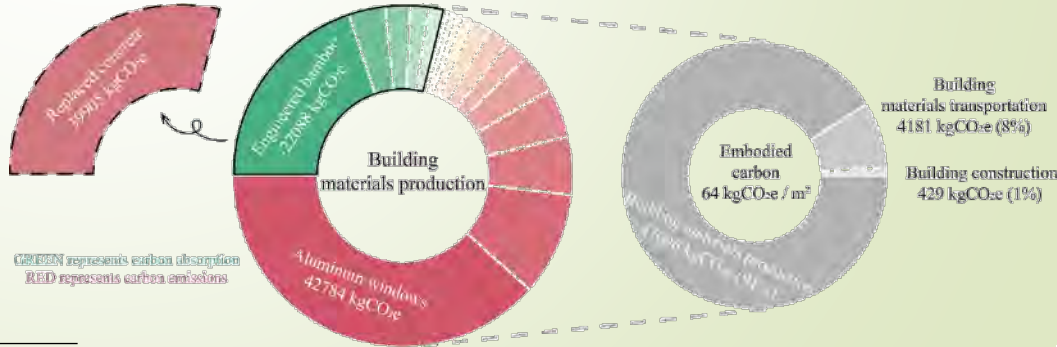


Embodied carbon calculation

Material type	Unit	Consumption	Carbon Emission Factor (unit / $kgCO_2e$)	Carbon emission ($kgCO_2e$)
Glubam	**m^3**	**84.63**	**-261.00**	**-22088.43**
SPF	m^3	17.00	-228.00	**-3876.00**
Oriented strand board (OSB)	m^3	16.10	-168.00	**-2704.80**
CLBT	m^3	8.14	-236.00	**-1921.04**
Wood based flame retardant board	m^3	9.40	-168.00	**-1579.20**
Waterproof roll	kg	420.00	0.54	226.80
HRB300 Steel	t	0.20	2340.00	468.00
Painting	kg	200.60	3.50	702.10
Plasterboard	t	4.51	163.00	735.13
Polyurethane insulation	t	0.24	5220.00	1231.92
Structural adhesive	kg	620.80	3.30	2048.64
Fiber cement board	t	3.07	735.00	2256.45
Wood door	m^2	39.60	60.00	2376.00
Preservative	kg	4000.80	1.05	4200.84
Rock wool board	t	2.62	1980.00	5187.60
Concrete	***m^3***	***20.75***	***295.00***	***6121.25***
Q235 Steel	t	5.33	2050.00	10926.50
Aluminum window	m^2	291.05	147.00	42784.35

Stage	Carbon emission ($kgCO_2e$)
Building materials production	47096.11
Building materials transportation	4180.92
Building construction	428.66
Total	51705.69





Award


AEI
ASCE
Architectural Engineering Institute of ASCE
2025 Professional Project Award
for the
Most Innovative Project
less than $100 million
presented to
Zhejiang University
for
Ninghai Bamboo Tower
Architectural Engineering Institute of ASCE
2025 Professional Project Award
Award of Excellence
Structural Systems Design
presented to
Zhejiang University
for
Ninghai Bamboo Tower
Architectural Engineering Institute of ASCE
2025 Professional Project Award
Award of Merit
Sustainability | Life Cycle
presented to
Zhejiang University
for
Ninghai Bamboo Tower
Nicholas A. Pitas, P.E.
Chair, AEI Professional Project Awards
AEI Professional Project Awards
Kansas City
HOME
ABOUT

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- Engineered bamboo – Practice 竹结构工程
  - *Recent project- 3* ***近期****实践- 3*
- Conclusions and future plan 结语及计划

宁波

宁海县

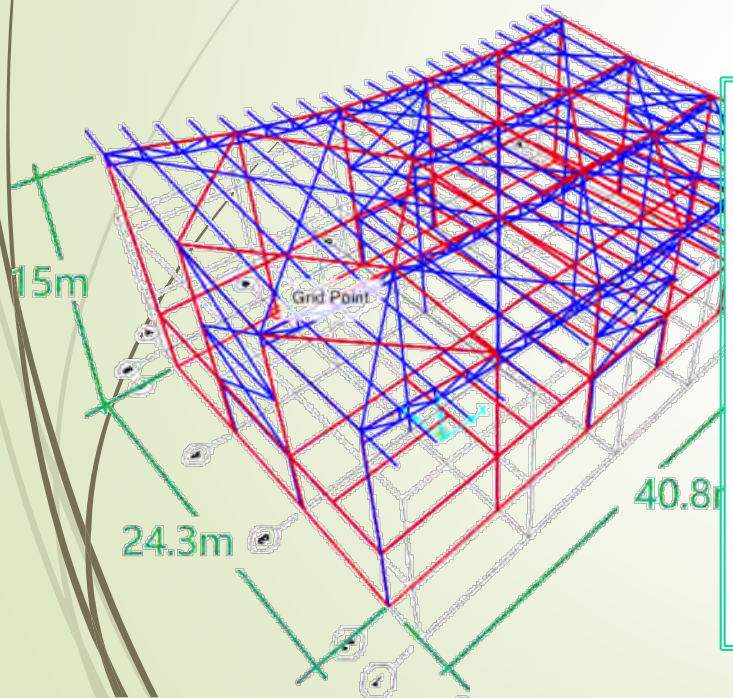


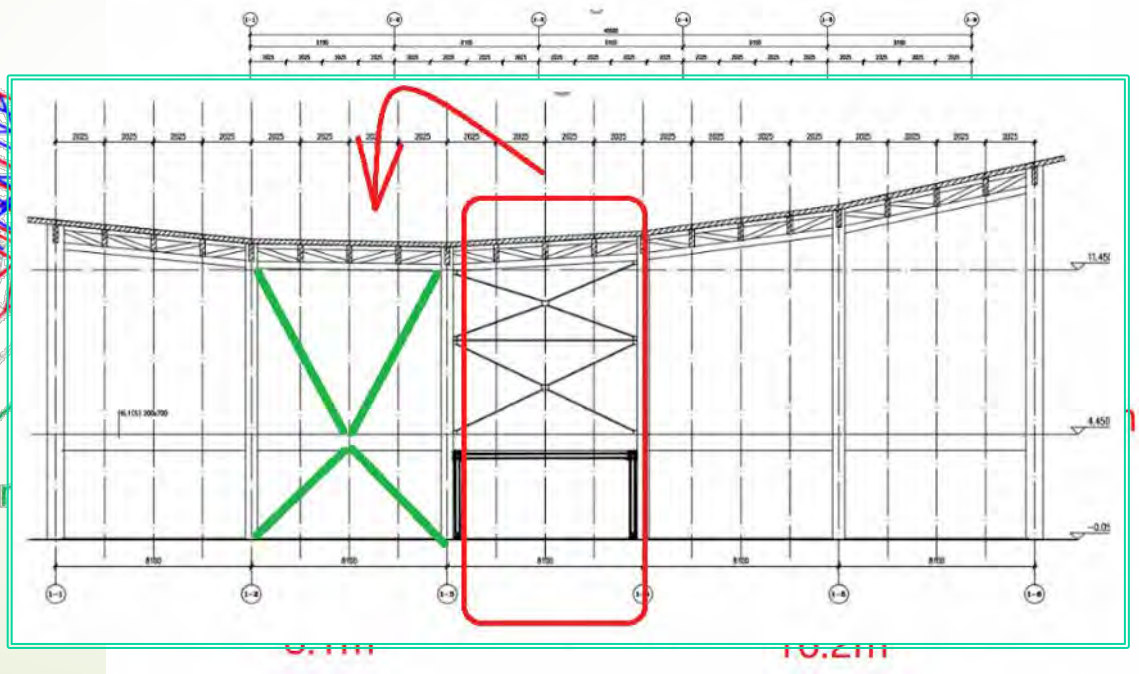
Ninghai Shuangshui Low Carbon Hall
宁波宁海双水未来社区低碳展厅





Architect: China Eastern Hydraulic Design 水利华东院
Structure：Xiao Y., Dai, S.L., etc. 肖岩，戴邵雷，等
Construction：Bamduos，Huayu， etc：班多、华宇





Main features of design

建筑用途	**未来社区九大**场景体验平台社区智慧管理可视化中
建筑概况	
项目主管	
项目设计	
工作年限	
结构形式	
结构方案	
结构设计	**戴邵雷，郭唯**畅，邓钧远，张翔飞
建筑设计	**浙江**华洲国际设计工程顾问有限公司
施 工 图	**戴邵雷，郭唯**畅，邓钧远，张翔飞**等**
加 工	**宁波班多新材料科技有限公司**
安 装	华宇建设有限公司

Key breakthroughs 创新点：

- First large scale engineered mass bamboo building
- Relatively large span, heavy public building load
- Bamboo plus solar panel etc. to achieve low CO2
- 27m long 940x300mm girder lifted
- CLPT floor slabs (754sqm)
- TLBT roof panels, etc. (1150sm), etc.







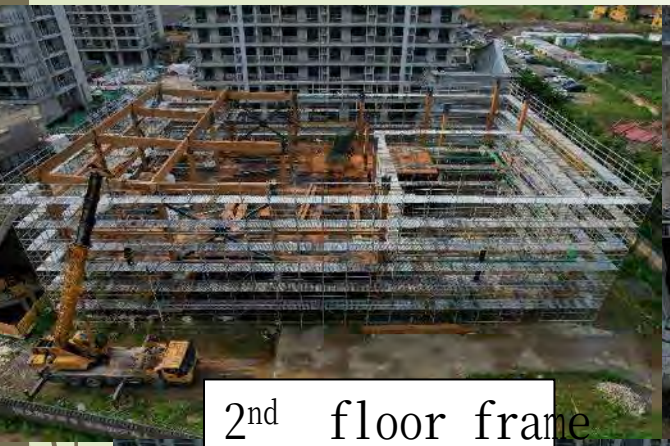
“flat” pressing 16m long girder



Lifting large glubam girders



9 施工 Construction process



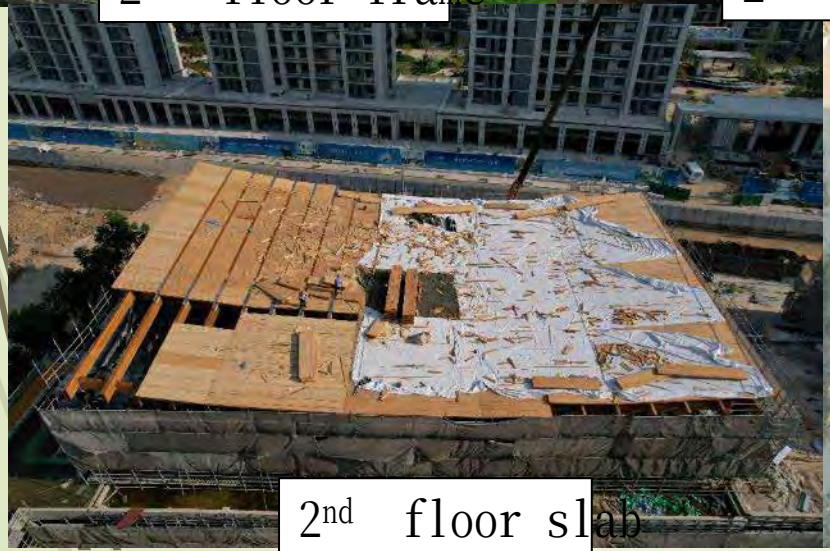
2nd floor frame



2nd floor frame



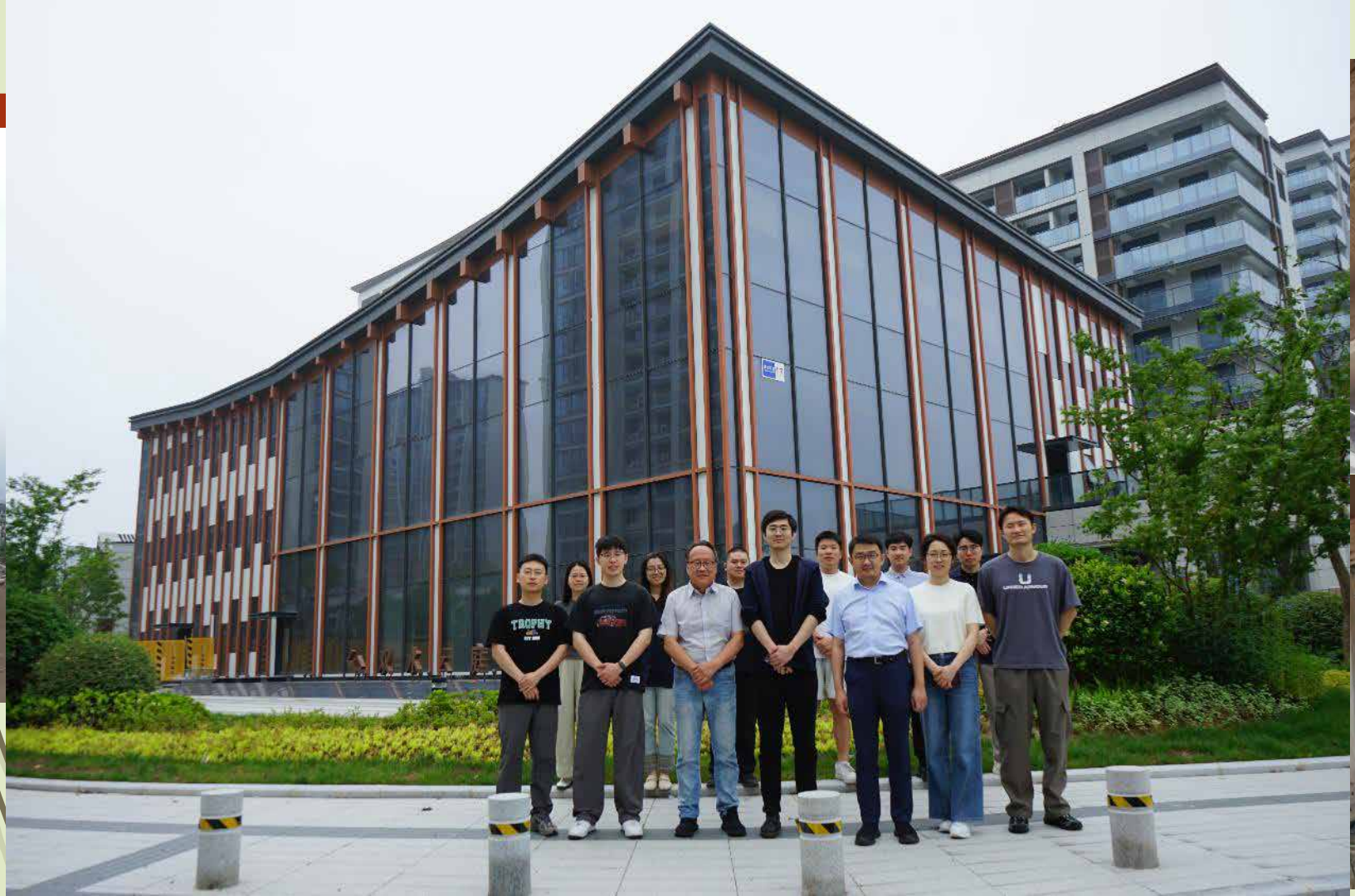
2nd floor lateral



2nd floor slab

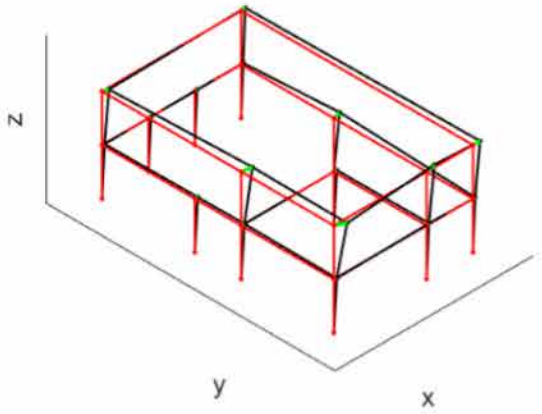


2nd floor slab

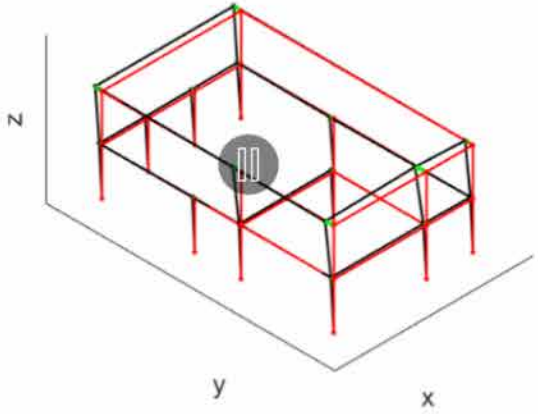

TROPHY

Vibration modes 动态监测

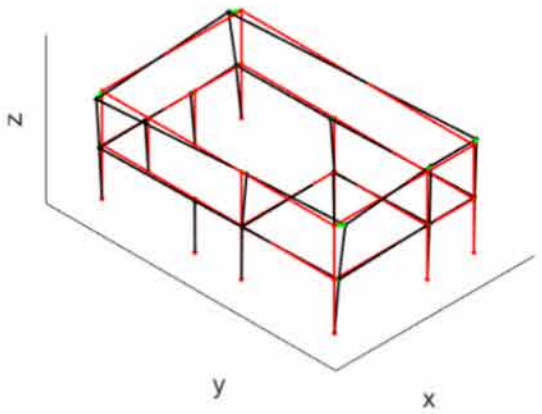
1.77(Hz)



2.03(Hz)

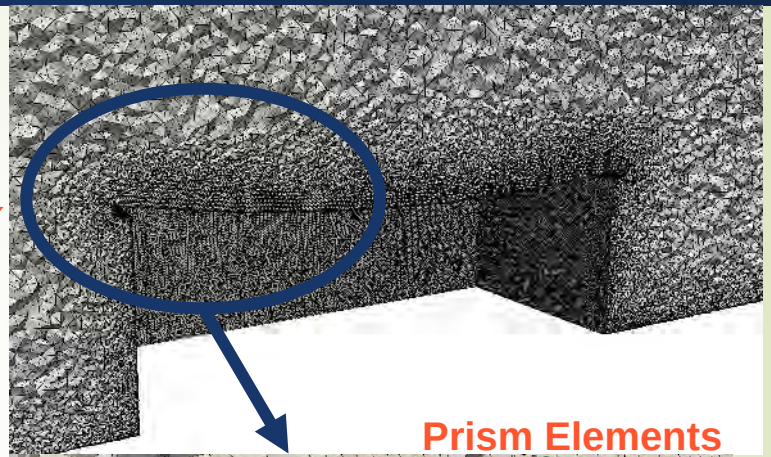


2.91(Hz)

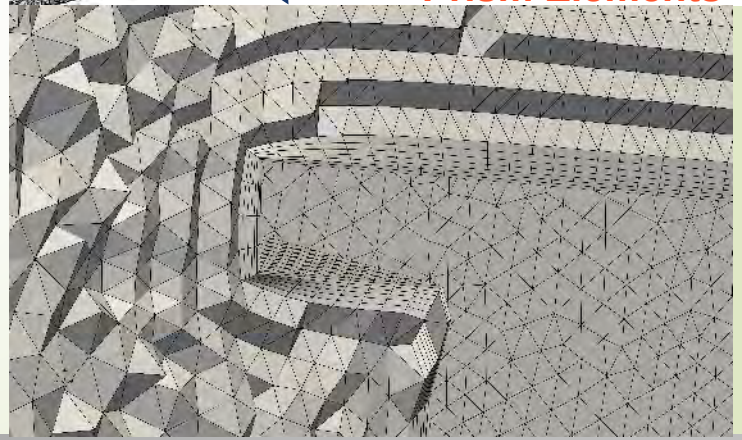


Boundary-fitted simulations, collaborated by Prof. Yan, Jinhui, UIUC – *CFD mesh details*





Prism Elements

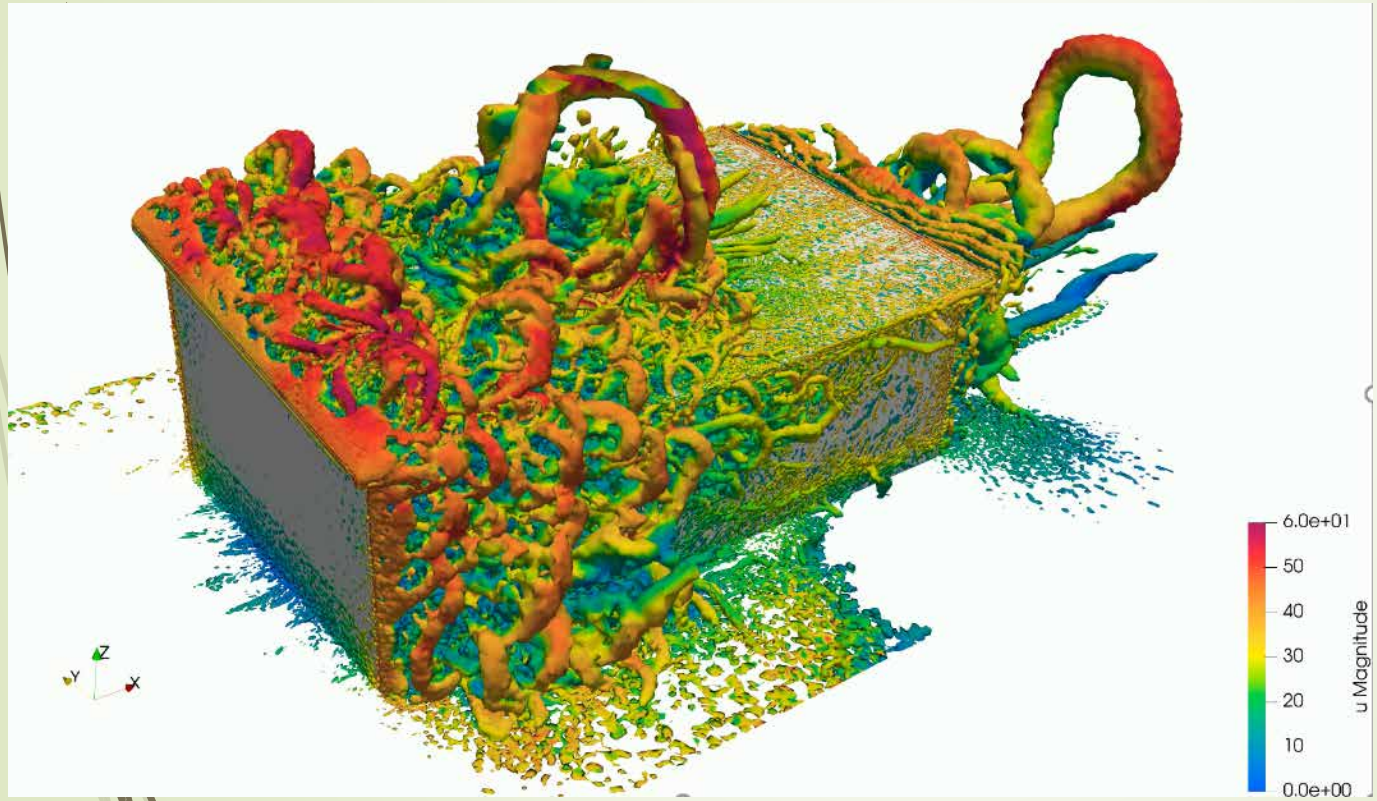


Mesh X-section visualized

Mesh Details

- Unstructured grid è approximately 25 million tetrahedral elements + prism elements on structure

Boundary-fitted simulations – *Vortices visualizations on the structure*



Visualization of wind vortices at 30 m/s windspeeds

Typhone 严阵以待



2026 ASCE AEI Awards



Structural System Design – Award of Excellence

Sustainability (Life Cycile) – Award of Merit

Special Award-Most Innovative Project (Less than $100 MM)

2026 PROFESSIONAL PROJECT AWARDS

ASCE ARCHITECTURAL INSTITUTE

Double-Water Low-Carbon Community Center

Winning multiple categories in the ASCE Architectural Engineering Institute (AEI) Professional Project Awards (PPA) is a distinct honor reserved for projects that demonstrate excellence across multiple engineering disciplines.

Project By

Ninghai Municipal Architecture Design Institute, Ltd. & Zhejiang University-Ninghai Center, China

Project Team: Y. Xiao; S.L. Dai; Y.S. Chu; J.Y. Deng; W.C. Guo; Y.B. Hou; G. Li, X.D. Lin; H.L. Hu

STRUCTURAL SYSTEMS DESIGN - AWARD OF EXCELLENCE
SUSTAINABILITY (LIFE CYCLE) - AWARD OF MERIT
SPECIAL AWARD - MOST INNOVATIVE PROJECT (LESS THAN $100 MM)

Nicholas A. Pitro
Chair, AEI Professional Project Awards

Derek Clements
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AEI President 2025-2026

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- Referencing design specifications for wooden structures and the team's in-depth research on laminated bamboo over the past 20 years, a breakthrough has been achieved with the world's first mass bamboo tall story building demonstration project.
- Engineering bamboo is shown great potential in multi story and large-span building structures.
- These demonstration projects will also serve as platforms for interdisciplinary research, such as wind effects, vibration and control, thermal, acoustic effects, etc.

Future Project

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Grazie! 謝謝！ Thank you !

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