Exploring bamboo as a building/design/construction/engineering material

Hosted by A4A
20th-21st Oct 2007

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Rainforest Biome, Eden Project

Bamboo Biology and Species
What is Bamboo?
What is Bamboo?

- It is a giant grass – part of the **Gramineae family**.
- 1100 species in the world, 451 in the Americas.
- Large group of woody bamboos
  - 141 species in Brazil
  - 72 in Colombia
- 11 million Ha of Latin America
What is *Guadua* bamboo?

- Guadua genus contains 30 species
- Species of greatest structural applicability in Colombia: *Guadua angustifolia* Kunth
Guadua angustifolia Kunth
Where does Guadua bamboo grow?

- Native to Colombia, Ecuador, and Venezuela
- Introduced to Costa Rica, Mexico, Puerto Rico, Brazil...
Anatomy of Bamboo

- Nodes and internodes
- No cambium
- No bark
- Hard skin
- No radial fibres at internodes
- It is hollow
Anatomy of Bamboo

- Vascular bundles contain phloem, xylem and fibres.
Anatomy of Bamboo

- Vascular bundles at nodes
- Vascular bundles at internodes
Life Cycle of Bamboo

- 20 – 25m in 6 months
- 3-5 years to mature
- Roots “branch-off” to produce a network of stems or culms and roots.
- When a stem or culm is felled, the clump still survives.
- Very sustainable.

Continue to Mechanical Properties
Mechanical properties
(for Guadua angustifolia Kunth)

- Compression
  Parallel to grain
- $f_{c,0,k} = 28 \text{N/mm}^2$
- C16 softwood
- $f_{c,0,k} = 17 \text{N/mm}^2$
Mechanical properties (for Guadua angustifolia Kunth)

- Tension Parallel to grain
  - $f_{t,0,k} = 90\text{N/mm}^2$
  - C16 softwood
  - $f_{t,0,k} = 10\text{N/mm}^2$
Mechanical properties
(for Guadua angustifolia Kunth)

- Bending
  - $f_{m,k} = 46\text{N/mm}^2$
  - C16 softwood
  - $f_{m,k} = 16\text{N/mm}^2$
Mechanical properties
(for Guadua angustifolia Kunth)

- Shear
- $f_{v,k} = 4-5\text{N/mm}^2$
- C16 softwood
- $f_{v,k} = 1.8\text{N/mm}^2$
Mechanical properties
(for Guadua angustifolia Kunth)

- Compression perpendicular to grain
- $f_{c,90,k} = \ ?$
Mechanical properties
(for Guadua angustifolia Kunth)

- Tension Perpendicular to grain
- $f_{t,90,k} = 0.1 \text{N/mm}^2$
- C16 softwood
- $f_{t,90,k} = 0.3 \text{N/mm}^2$
Moduli of elasticity

- Modulus of elasticity in compression
  \[ E_{c,0,\text{mean}} = 15000 \text{ N/mm}^2 \]
- Modulus of elasticity in bending
  \[ E_{m,\text{mean}} = 11800 \text{ N/mm}^2 \]
- C16 softwood
  \[ E_{\text{mean}} = 8800 \text{ N/mm}^2 \]

To history of bamboo use
History of Bamboo use in Colombia
History of use of Bamboo in Colombia

Archaeological evidence shows Pre-Columbian use in housing.
Temporary bridges are another traditional use.
History of use of Bamboo in Colombia

- In the 19th Century
  Colonization of the Coffee-growing region
- Spanish architecture
- Rammed earth
- Earthquakes
- Wattle and daub combined with timber/bamboo frame
- “Bahareque”

To Present use of bamboo
Present use of Bamboo in Colombia

- Shanty towns
- Low budget housing
- Modern architecture for the wealthy
The 1999 Coffee-growing Region earthquake

- Damage to RC structures
The 1999 Coffee-growing Region earthquake

How did bamboo structures perform?

Figure 2. A house at the “Experimental Centre for Bamboo Construction”. Other new bamboo structures also performed well during this earthquake.
Bamboo housing projects after the earthquake

- Houses donated by: German, Spanish, Italian and Swiss development agencies...
- …and Colombian NGOs working with government funds
Bamboo School

- Donated by UNICEF and several Worker’s Trade Unions
- Designed by ...
- ...Architect Simón Vélez
Development of the bamboo code

In 1999 the Colombian Earthquake Engineering Association (AIS) undertook a study of "bahareque" structures financed by the Fund for the Reconstruction of the Coffee-growing Region (FOREC).

The World's First (?) Bamboo Code

- Earthquake-resistant mortar-rendered bahareque construction handbook.

Modern Architecture
Modern Bamboo Architecture

- Many Colombian architects have worked with bamboo...
- Óscar Hidalgo
- Simón Vélez
The work of Simón Vélez

- The grouted connection
- This simple connection allowed Simón...
The work of Simón Vélez

- ... to build this.
- This technique was mastered...
...and this enabled Simon to build this.
This is possibly the world’s largest bamboo structure.
The Bamboo Pavilion

ZERI commissioned Simon to design and build a bamboo structure for Expo Hanover.
The Bamboo Pavilion
The Temporary Church

The temporary cathedral of Pereira
The Temporary Church

This structure was demolished when the main cathedral was reopened.
The Jenny Garzón Bridge

- 45.6m span footbridge over one of Bogotá’s most important avenues.
To Structural guidelines
Guidelines for Structural use of bamboo

- Drawn from direct and indirect experience
Qualities

- **Sustainability**: Carbon sequestration and quick growth
- **Strength**: in bending, tension and compression (parallel to grain)
- **Flexible**: can be beneficial in seismic design
- **Shape**: round and hollow means it is structurally efficient
- **Weight**: it is light, i.e. high strength to weight ratio
- **Anatomy**: it has nodes and parallel fibres
- **Appearance**: Shiny skin
Disadvantages

- Shape: round and hollow - connections are difficult
- Strength: low shear, tension and compression (perpendicular to grain)
- Parallel fibres: splitting and shearing
- Flexible: horizontal members deflect and vibrate
- Durability: if exposed to the elements it has poor durability
- Fire resistance: if exposed will burn, charring rate unknown
General guidelines

Walls: as a concealed stud

Space frames: good in compression and tension

Columns: works well but indoors. Fire?

Trussed rafters: look out for connections

Rafter: works well in modern roofs

Floor joists: vibrations and support crushing

Beams: deflections and support crushing

Seismic design: ...
Seismic design

- High strength to weight ratio √
- Flexible ≈
- Not ductile X
- but ductile connections can be introduced √
- Traditional techniques have shown good results √
- Flexibility ≠ ductility
Connection Design

- A few definitions first
Mechanical Fasteners

- Mechanical fasteners
  - Nails
  - Screws
  - Bolts
  - Dowels
  - Pegs
- Splitting failure
- Shear failure
- Bearing failure
Carpentry or Traditional Joints

- “Fish mouth”
- Handsome
- Labour intensive

- “Flute tip”
Connection Design

- Complete joint detail
- Fasteners
- Carpentry joints
- Gusset plates
- Cement grout
- Geometry
The grouted connection

- A typical shear connection
- 12.7mm fastener
- $F_u = 10-13\text{kN}$
The grouted connection

- A grouted connection
- 12.7mm fastener
- \( F_u = 35 \text{kN} \)
The grouted connection

- The improved grouted connection
- 12.7mm fastener
- + 6.35mm rebar pins
- $Fu = 60kN$
The grouted connection

- The whole internode must be full
- A node must be present between the fastener and the loaded edge
- This connection increases the weight of the structure
- Reduces crushing failure
- Reduces tension perp to grain failure
- Bamboo must be dry to avoid excessive shrinkage
- Use cement grout sparsely

To the future of bamboo
The future of bamboo in construction...
The “Bambusa” housing project

- First housing project to the code
- 80 houses
- Donated by US-AID for tenants that lost their homes
- Structure cost US$2200 approx each
- 40% larger than traditional build (but tiny all the same 35m²)
Life Cycle assessment for a “Bambusa” house


Comparing 1 p assembly “Finished guadua house RJM” with 1 p assembly “Finished masonry house RJM”. Method: Eco-indicator 99 (H) V2.1 excl. Land Use & Radn. / Europe EL 99 H/A / characterization
Life Cycle assessment for a "Bambusa" house


Comparing 1 p assembly "Guadua house walls, floors & stairs RJM" with 1 p assembly "Masonry Walls total incl slab, stars & trusses"; Method: Eco-indicator 99 (H) V 2.1 excl. Land Use & Fadin. / Europe E1 39
What the future holds

- Developing countries relief and development programmes
  - Housing
  - Schools
  - Bridges
  - Medium rise buildings

- Support from developed countries is needed for
  - Further research
  - Further code development
  - Promotion of the material and construction systems

- Can occupy a role in modern construction as a sustainable "hard wood"
  - Laminates
  - Sheathing
  - Joists
  - Anywhere where timber can go

- Space frames
  - Temporary structures
  - Permanent structures
Contacts

- **Worldwide**
  - The International Network for Bamboo and Rattan (INBAR)
- **In the UK**
  - Buro Happold
  - TRADA Technology
- **In Colombia**
  - Colombian Earthquake Engineering Association (AIS)
  - Colombian Bamboo Society (Sociedad Colombiana del Bambú)
Further reading

Some titles available in amazon.co.uk

- Grow your own house
- Tropical bamboo
- Mechanical properties of Bamboo
- New Bamboo Design and Architecture
- Building with Bamboo: A handbook
Acknowledgments

- Villegas Editores
- Colombian Bamboo Society - Ximena Londoño
- AIS – Luis Felipe López and Samuel Darío Prieto
- Universidad Nacional - Caori Takeuchi
Many thanks

Any questions?
Bamboo joints
MSc. Arch. Gema Diaz-Matthias
Traditional joints

• Use of lashings (natural fibres or others) and/or pegged joinery
• Specific cuts are important
• Hand made
• Economical (in third world countries)
• Not very lasting
• Don't allow the application of greater forces
Traditional cuts
• With one ear
• With two ears
• With beveled edge
• Flute tip
• Fish mouth
Fish mouth
Fish mouth w/ear
Flute tip
w/ear
Mizoram (India)
Improved traditional joints

- Threaded rods, bolts and mortar is introduced
- They bear higher allowable forces
- They last longer
- The structure is not so light anymore
- Mortar and bamboo act in different ways
Improved fish mouth
Flute tip w/support
Shear reinforcement

Shear joint with a longitudinal screw

Mortar in between nodes

Bonding nuts
Longitudinal joints
Foundations joints
Other variants
Designing joinery

Orificios para Inyectar Mortero

UNIONES "BOCA DE PESCADO"
Núcleo con cemento
Restaurante "Al-Mudábil"

High-tech joints

- An external element is used to join more than 2 bamboo culms
- Keep bamboo light
- Bear as much force as possible
- Easy to assemble and to dismantle
- Makes bamboo appropriate for modern designs
Thank you!!!
A4A Collaboration
Thailand Bridge
Shoots Event

Buro Happold Infrastructure
Kien Hoang
20th Oct 2007
Buro Happold

Kien Hoang
MEng(Cantab) MIstructE CEng
Senior Bridge Engineer
About myself
About myself
The Project
Background: location
Background: context
Background: client
Background: site
Background: site constraints
Background: precedent
Background: precedent
Proposal: **brief**

- **Total length:** >80m (to suit)
- **Loading:** pedestrian + small scooter
- **Construction:** local semi-skilled labour
- **Programme:** completion by July 08
- **Budget:** $10,000 approx
Proposal: overview

Challenges:

• Site constraints
• Resources
• Construction
• Engineering
• ‘Sustainability’

*two spans or not two spans...*
Proposal: **substructure**

- (a) **Log Crib Abutment** - suitable for fairly flat stable bank. If necessary excavate base for crib. Seat legs on a stone bed.
- (b) **Log Pier** - suitable for medium slope bank.

- Use 10mm diameter spikes and 2mm galvanised wire to anchor footbridge to posts.
- Anchor posts at each corner, at least 80mm in size and 0.8m in ground.
- Posts at least 100mm and 1m into ground.
- Pile at least 250mm diameter and at least 1.5m into ground. 2 pairs at 1.1m spacing for 1.4m wide bridge. 3 pairs at 1.0m spacing for 2.1m wide bridge.

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Proposal: substructure
Proposal: **superstructure - form**
Proposal:  superstructure - form
Issues: site specific “environmental” drivers

- flood loading
- scour
- river course
Issues: engineering

- global design
- detail connections
Issues: engineering
Issues: engineering
Issues: construction & erection

Figure 7.9: Sinking of Piles into Ground
Issues: *construction & erection*
**Issues:**

**construction & erection**

- Erect temporary piers with cross beams to support runners (logs/beams) on which stringer can be pulled across gap.

- Runner beam log

- Piers need to be securely bound and braced.

- Pull manually with a winch.

- Rope in case needed to steady forward movement of load.

- Traveller (Pulley with lifting device)

- Distance between legs roughly equal to half the height of frame.

- Guy

- Pull by hand or preferably with a winch.

- Cable anchor - include a tensioning device, if available, to tension the cable.

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Issues: site survey & setout
Further investigations

- Shoots event
- calculations
- weekend in Wales
Programme

Nov/Dec ’07: site setup, substructure construction
bamboo harvest & treatment

Jan/Feb ’08 superstructure construction

Summer ’08 fingers crossed!
Shoots
Individual exercise

Options 1: Baseline
(Everyone to make)

Options 2: Advanced
(only a few)
Use same material
from option 1!!!
Prototype 1: truss with rod connections
Prototype 2: truss with gusseted connections
Prototype 3: Vierendeel truss
Examples
Examples
Enjoy!

(but please take care)