Developments in Structural Design Standards with Bamboo

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Senior Lecturer / Chair of the INBAR Task Force for Bamboo Construction
Content

• Origin of codes/standards
• Code and standard development of bamboo: a brief history
• Current developments within ISO and INBAR Task Force
  – ISO 19624 Bamboo structures — Grading of bamboo culms — Basic principles and procedures
  – ISO 22157 Bamboo structures — Determination of physical and mechanical properties of bamboo culms — Test methods
  – ISO 22156 Bamboo — Structural Design
  – ISO/NP 23478 — Bamboo structures — Glued laminated bamboo — Test methods for determination of physical and mechanical properties
• Final thoughts and invitation
Origin of codes/standards

- Codes? Standards?
- Codes and standards for bamboo (Gatóo et al. 2014)

<table>
<thead>
<tr>
<th>Country</th>
<th>Code</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colombia</td>
<td>Reglamento Colombiano de Construcción Sismorresistente – chapter G12 Estructuras de Guadalua (Guadua structures) (ICONTEC, 2010)</td>
<td>NTC 5407: Uniones de Estructuras con Guadua angustifolia Kunth (Structural unions with Guadua angustifolia Kunth) (ICONTEC, 2006)</td>
</tr>
<tr>
<td>Ecuador</td>
<td>Norma Ecuatoriana de la Construcción – chapter 17 Utilización de la Guadua Angustifolia Kunth en la Construcción (Use of Guadua angustifolia Kunth in construction) (INEN, 2011)</td>
<td>NTC 5525: Métodos de Ensayo para Determinar las Propiedades Físicas y Mecánicas de la Guadua angustifolia Kunth (Methods and tests to determine the physical and mechanical properties of Guadua angustifolia Kunth) (ICONTEC, 2007)</td>
</tr>
</tbody>
</table>

Table 1. Existing structural bamboo standards and codes
Origin of codes/standards

Timeline:

• 1824 – invention of Portland Cement
• 1830 – invention of the I-beam
• 1856 – development of the Bessemer process (steel)
• 1857 – first rolled steel rails
• 1880s – First iron and steel-frame high-rise buildings
• 1890s – first Reinforced Concrete (RC) frame buildings
• c1925 – welding of steel
Origin of codes/standards

• 1892 - Francois Hennebique patented a form of RC
• High quality control on site
• Sold licences for system
• 1899 - >3,000 projects used the system
• 1909 - ≈ 20,000 projects & 62 offices worldwide
• Many other contractors had their own system
• Eventually RC codes/standards emerged
• These broke the monopoly
• It allowed authorities to check designs for safety
Origin of codes/standards

- Standards provide a consensus about best practice
- Codes/Standards collected three types of information:
  - “Properties of materials, including the quality of their manufacture;
  - the various loads that building structures should be designed to carry;
  - codes of design practice that provided suitable methods for designing the various structural elements of buildings – columns, beams, floors and shear walls – and the connections between them.” (Addis, 2007)

- Committees of code writers typically consist of representatives of:
  - Product manufacturers,
  - Structural designers,
  - Researchers
Development of codes and standards is a slow and lengthy process, it requires a compromise between the parties and needs to be underpinned by extensive experimental research, which is expensive.
## Code and standard development of bamboo: a brief history

<table>
<thead>
<tr>
<th>Design code/standard</th>
<th>Year</th>
<th>Country</th>
<th>Species included</th>
<th>Mechanical properties</th>
<th>Derivation of design values</th>
<th>Beams</th>
<th>Columns</th>
<th>Connections / joints</th>
<th>Shear walls</th>
<th>Grading</th>
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<tr>
<td>AC 162</td>
<td>2000</td>
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<td>x</td>
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<tr>
<td>NBC</td>
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<td>x</td>
<td>x</td>
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<td>E.100</td>
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<td>✓</td>
<td>✓</td>
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<td>✓ (simple)</td>
<td>x (Details)</td>
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<tr>
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<td>Ecuador</td>
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<td>✓</td>
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<td>x (Details)</td>
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<tr>
<td></td>
<td>2017</td>
<td>México</td>
<td>3</td>
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</table>
Engineered ‘Bahareque’

On to a bamboo frame apply bamboo strips or mesh

Apply a cement mortar render onto mesh or strips

Engineered ‘bahareque’ school
Engineered ‘bahareque’ school
Bahareque in the Philippines

Engineered ‘bahareque’ has been adopted in Colombia, Peru, Ecuador, Mexico, Costa Rica and The Philippines.
Current developments within ISO and INBAR Task Force
ISO Technical Committee 165 Working Group 12

• In September 2013, at the annual meeting of TC 165 ‘Timber Structures’ the development of bamboo standards was reactivated.
• Working Group 12 – ‘Structural Use of Bamboo’ of ISO TC 165 was created.
• Members across: Colombia, Ecuador, Ethiopia, Indonesia, Malaysia, China, UK, Germany, Australia and USA.
31ST ANNUAL MEETING OF ISO TC165 TIMBER STRUCTURES
4-8 September, 2017 in Vienna
INBAR Task Force

• In 2015, INBAR launched the Bamboo Construction Task Force.
• The Task Force “coordinates the activities of international research institutes and commercial companies interested in the structural uses of bamboo”
• It does so by linking individuals who are experts in the field.
• The intention is to pool and coordinate the isolated and disparate efforts occurring throughout the world.

Delegates at ‘Bamboo in the Urban Environment’ Symposium at Pittsburgh, USA, 2016
INBAR Task Force

- Amongst the objectives of the Task Force are:
  - "Help drive and refine the development of new international standards on the structural uses of bamboo and review and update existing international standards…"

Delegates at ‘Bamboo in the Urban Environment’ Symposium at Bogor, Indonesia, 2017
## INBAR Task Force members

<table>
<thead>
<tr>
<th>Task Force Coordinator:</th>
<th>Coordinator of Global Bamboo Construction Programme at INBAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liu Kewei</td>
<td>Coordinator of Global Bamboo Construction Programme at INBAR</td>
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</table>

### Task Force Chair:

<table>
<thead>
<tr>
<th>Task Force Chair:</th>
<th>Coventry University</th>
<th>UK</th>
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<tbody>
<tr>
<td>David Trujillo</td>
<td>Arup</td>
<td>UK</td>
</tr>
<tr>
<td>Andrew Lawrence</td>
<td>Moso</td>
<td>The Netherlands</td>
</tr>
<tr>
<td>Arjan Van Der Vegte</td>
<td>Institut Teknologi Bangdun</td>
<td>Indonesia</td>
</tr>
<tr>
<td>Andry Widyowijatnoko</td>
<td>University of Bath</td>
<td>UK</td>
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<tr>
<td>Bhavna Sharma</td>
<td>Addis Abada University</td>
<td>Ethiopia</td>
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<tr>
<td>Denamo Addissie</td>
<td>ETH Zurich</td>
<td>Switzerland</td>
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<tr>
<td>Edwin Zee Escamilla</td>
<td>University of British Columbia</td>
<td>Canada</td>
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<tr>
<td>Greg Smith</td>
<td>Nanjing Forestry University</td>
<td>China</td>
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<tr>
<td>Hector Archila Santos</td>
<td>Amphibia BASE</td>
<td>UK</td>
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<tr>
<td>Juan Francisco Correal Daza</td>
<td>Universidad de los Andes</td>
<td>Colombia</td>
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<tr>
<td>Kent Harries</td>
<td>University of Pittsburgh</td>
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<td>Luis Felipe López</td>
<td>Base Bahay</td>
<td>The Philippines</td>
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<tr>
<td>Martin Tam</td>
<td>Able Mart Limited</td>
<td>Hong Kong</td>
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<tr>
<td>Mateo Gutiérrez Gonzalez</td>
<td>Université of Queensland</td>
<td>Australia</td>
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<tr>
<td>Mauricio Cardenas Laverde</td>
<td>Politécnico de Milano</td>
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<td>Michael Ramage</td>
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<td>Nripal Adhikary</td>
<td>ABARI</td>
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<td>Rodolfo Lorenzo</td>
<td>UCL</td>
<td>UK</td>
</tr>
<tr>
<td>Romildo D. Toledo Filho</td>
<td>Universidad Federal do Rio de Janeiro</td>
<td>Brazil</td>
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<tr>
<td>Sebastian Kaminski</td>
<td>Arup</td>
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<tr>
<td>Verónica María Correa Giraldo</td>
<td>Kaltia / Bambuterra</td>
<td>México</td>
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<tr>
<td>Xu Qingfeng</td>
<td>Shanghai Research Institute of Building Sciences</td>
<td>China</td>
</tr>
<tr>
<td>Yann Barnet</td>
<td>Universidad de San Martin</td>
<td>Peru</td>
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</tbody>
</table>
INBAR Task Force publications
INBAR Task Force collaborations

Nonconventional and Vernacular Construction Materials
Characterisation, Properties and Applications
Edited by Kent A. Harries and Bhavna Sharma

Structural use of bamboo. Part 4: Element design equations

Bamboo reinforced concrete: a critical review

https://doi.org/10.1617/s11527-018-1228-6

ORIGINAL ARTICLE

Received: 20 January 2018 / Accepted: 16 July 2018
Grading is:

“(…) the process of sorting every piece of bamboo in a sample into grades according to defined selection criteria. The criteria identify dimensional, visual, geometric, mechanical and/or physical properties that reflect the bamboo’s mechanical strength or structural capacity and may affect the utility of the product.”
Contents

Key
$D_b$  diameter at the base of the piece
$D_t$  diameter at the top of the piece
$L$   length of the piece
$\delta_b$  wall thickness at the base of the piece
$\delta_t$  wall thickness at the top of the piece

Figure 3 — Longitudinal section of bamboo culm showing external and internal taper

Figure 1 — Manifestation of fissure on surface of culm and cross-section through fissure
Figure 4 — Elevation of a bamboo culm showing bow

Key

\( b_{\text{max}} \) maximum perpendicular distance from the centre of the culm section to the chord drawn from the centres of either end of the piece

\( L_{\text{ref}} \) reference length of the piece

Check compliance with grading rules for:
- Condition properties
- Taper, bow and ovality

Does it comply with all?

Reject specimen i.e. non-structural grade

Accept material: deemed of structural quality.

Grade by diameter. Check other geometric properties.

Does it comply with all grade requirements?

Assign to different grade, if possible, or reject

Assign to grade

Figure A.1 — Grading of bamboo culms by external diameter
Ways to improve grading: Linear mass
(image not in standard)

\[ y = 3.173x - 1.5639 \]
\[ R^2 = 0.866 \]
Ways to improve grading: flexural stiffness
(image not in standard)

$y = 7 \times 10^{-11}x + 0.9585$

$R^2 = 0.8655$
Low-cost measurement of flexural stiffness (EI)
ISO 22157 Bamboo structures — Determination of physical and mechanical properties of bamboo culms — Test methods

• Replaces ISO 22157-1:2004
• Removes ISO 22157-2:2004
• Removes shrinkage test
• Incorporates two tests
• Clarifies other tests
ISO 22157 Bamboo structures — Determination of physical and mechanical properties of bamboo culms — Test methods

Two new tests:
- Tension perpendicular to fibres
- Bending perpendicular to fibres
ISO 22156 Bamboo – Structural Design

• Update to ISO 22156:2004
• Due 2022
• Objectives:
  – To be the most comprehensive and modern structural design standard for bamboo in the world,
  – Push bamboo engineering forward and try to close the gap between bamboo and the other materials,
  – To draw from experience and expertise from across the globe,
  – Serve as the template for all other bamboo codes.
ISO 22156 Bamboo – Structural Design

Features:
• Methods of design:
  – Allowable Stress Design
  – Load and Resistance Factor Design (Limit State)
• Approaches:
  – On the basis of stresses (as a material)
  – On the basis of capacities (as a product)
• Allows:
  – Experience from previous generations
  – Design by testing

Bamboo specific considerations:
• Susceptibility to splitting
• Durability & preservation
• Redundancy of members
• Maintenance, Inspectability and Replacement
ISO 22156 Bamboo – Structural Design

Includes:
• Design of
  – Beams
  – Columns (Ylinen)
  – Tension member
• Principles for the design of:
  – Connections
  – Trusses
  – Shear walls
• Provides methods to derive design values
• Does not contain mechanical properties

• Provides guidance about how to model,
• Includes Seismic Force Reduction Factor for Bamboo Structures
  – Most R = 1.25
  – Bahareque R = 2
• For connections gives:
  – Design philosophy
  – Requires thought for yield loads, elastic stiffness and ductility.
  – Robustness against splitting
ISO 22156 Bamboo – Structural Design

Links to other ISO standards:
• ISO 12122 for characteristic values,
• ISO 19624 for grading,
• ISO 22157 for testing,
• ISO 21581 for testing of shear walls,
• ISO 16670 for connection testing,
• ISO TR 21141 for analysis of connection tests,

It proposes a way to design certain types of dowel connections.
• Since 2015 the TF has deliberated about standards for Engineered Bamboo Products (EBPs), as these could potentially enter the structural market.
• First step is knowing how to test them.
• The first product to be studied is ‘glued laminated bamboo’
Other standardization work

• In 2015, ISO TC 296 Bamboo and Rattan was created
• Structural aspects remain under TC 165, because of the importance that the committee understands structural safety.

<table>
<thead>
<tr>
<th>Standard and/or project under the direct responsibility of ISO/TC 296 Secretariat (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO/CD 21625 [Under development]</td>
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<tr>
<td>Terminology of bamboo products</td>
</tr>
<tr>
<td>ISO/WD 21626 [Under development]</td>
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<tr>
<td>Bamboo charcoal</td>
</tr>
<tr>
<td>ISO/WD 21629 [Under development]</td>
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<tr>
<td>Bamboo floorings</td>
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<tr>
<td>ISO/WD 23066 [Under development]</td>
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<tr>
<td>Terminology of Rattan Materials and Products</td>
</tr>
<tr>
<td>ISO/AWI 23067 [Under development]</td>
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<tr>
<td>Grading System for Rattan: Guidelines and Classification</td>
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</tbody>
</table>
Final thoughts

- Development of standards/codes is a process that requires a lot of experimental backing, as well as expertise.
- There are very few structural engineers in the world who have experience and knowledge about bamboo.
- There are no large funders. So we need to be efficient.
- We need to pool expertise and resources, as well as coordinate experimentation.
An invitation

• Please use the standards we have developed, develop them further, criticise them,
• Please join our work in developing the other two standards.
• Many thanks.
• Any questions?